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Three-dimensional displacement of the center of gravity during the sprint start

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ABSTRACT

The purpose of this study was to identify the three-dimensional position of the body CG during the sprint start. Additionally, it was also the aim to investigate the influence of age and some selected anthropometric parameters as skeletal muscle mass (SMM), corrected thigh girth (CTG), corrected calf girth (CCG) on the position of the CG. Sixty Flemish (30 boys and 30 girls) young elite sprint athletes (from 11 to 18 years old with a mean age of 14.7 ± 1.8 years and 14.8±1.5 years for boys and girls respectively) volunteered. Classical student T-tests and ANOVA's with Scheffé post hoc test were used for the detection of significant differences between subpopulations. The result indicated that the horizontal distance of the centre of body mass (CG) from the starting line, as expected, was found to be shorter for young sprinters as compared to adults. However, the height of the CG, unexpectedly this time, was comparable with adult sprinters. Moreover, athletes with higher age and skeletal body mass showed a higher CG position which was also closer to the starting line at the set position. Moreover, the boys and girls did not present any significant difference in the position of their CG during sprint start, except for the oldest boys displaying a significantly higher position of the CG in the set position.

Kewords: Sprint Start, Young Elite Sprinters, Center of Gravity, Anthropometry

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INTRODUCTION

The sprint start has been a topic of investigation for many researchers, since it is considered to be one of the most important phases that directly affect sprint performance [1, 2, 3]. Moreover, an efficient start is being an important part in winning sprint races. It is well understood that a good sprint start can be attributed to the ability to develop large horizontal forces at a high rate, not only in the blocks but also in the subsequent strides [2].

The objective of the sprint start is enabling the sprinter to produce maximal force and power. In this way, the following objectives can be considered: Firstly, the sprinter must establish an optimal body position for applying sufficient force on the blocks and leaving the blocks as quickly as possible. This implies that the CG at the set position must be as high and as close to the starting line as possible and that the athlete must optimize the angular position of the knee, hip and ankle joints in both the front and rear leg enabling the sprinter to come out of the blocks at the greatest possible velocity [4, 5]. The center of gravity (CG) is a useful concept for the analysis of human movement because it is the point at which the mass or weight of the body may be considered to be concentrated.

In this way, the global motion of a rigid body can be conceived as the sum of the translational motion of the body center of gravity and the rotational movement of the same rigid body around this center of gravity [6]. Therefore, the positioning of the center of gravity in most sports and thus also for the start position in sprinting, is quite important to achieve a good performance, as an optimal position of the center of gravity within the body reflects the optimal position of the limbs on the starting blocks [7].

The purpose of this study was to identify the three-dimensional position of the body CG during the sprint start. Additionally, it was also the aim to investigate the influence of age and some selected anthropometric parameters as skeletal muscle mass (SMM), corrected thigh girth (CTG), corrected calf girth (CCG) on the position of the CG.

METHODOLOGY AND EXPERIMENTAL PROCEDURES

Sixty Flemish (30 boys and 30 girls) young elite sprint athletes (from 11 to 18 years old with a mean age of 14.7 ± 1.8 years and 14.8±1.5 years for boys and girls respectively) volunteered. They were all members of the Flemish Athletic Federation and were all involved in competition on a regular base. . In this study besides age, other important variables such as skeletal muscle mass, body weight, height, calf circumference, and thigh circumference were chosen in order to analyze the influence of these anthropometrical parameters on sprint performance.

Circumferences measurements were made in the plane orthogonal to the long axis of the body segment being measured. A flexible standard measuring tape was used to evaluate the circumferences of the thigh and medial calf at the nearest 1mm.

All values of the circumference's measurements are converted to corrected values by using the following formula:

Skin-corrected circumferences = circumference value – skinfold value [8].

For example for creating the corrected thigh circumference or girth (CTG), the value of the skinfold of the thigh was subtract from the value of the thigh circumferenc.

The anthropometric techniques in this study follow the definitions and descriptions from ISAK (International Standard for Anthropometric Assessment) book [8].

The three-dimensional kinematics of the sprint start and subsequent two running steps were collected with a Vicon® 620 motion analysis system equipped with 12 M1 infrared cameras running at 250 Hz and running the Vicon Data Station software.

Calibration was done with a 50cm wand swung through the calibration volume comprising the start position and the 2 subsequent running steps. Three-dimensional (3D) motion capture allows kinematic analysis by measuring segmental movement from anatomical and additional tracking markers. The reflecting markers used were 14 mm spheres attached with double sided tape to different locations of the body. For tracking full body motion, 44 markers were attached to the feet, legs, thigh, hip, hands, shoulders and head of the subjects [9]. Dynamic markers included the tracking markers (on thigh and shank) and the anatomical markers (on forefoot, calcaneus, hip, wrist, elbow, shoulder, and neck). In this way, four tracking markers were rigidly attached to a thermoplastic shell that was placed on the thigh and shank for both legs to track their motion.

Processing of the data

As mentioned above, the three dimensional positions of the body markers were recorded with a Vicon® 612M system, using infra red camera's and a light reflecting markers. The anatomical location of these markers, are in essence unknown to the measurement system. Therefore, a labeling procedure is performed within the Vicon® software Workstation. It is also within this software application that data cleaning (snipping, spline interpolation, etc…) was performed. Further on, the data quality was sufficiently good that no further filtering techniques were necessary. After the data were labeled and further processed in Workstation, they were exported in ASCI format. Hereafter, custom made applications in Matlab® were used to further analyze the data and prepare them for the calculation of the joint angles.

Finding the CG of a simple rigid object is a rather simple task. Assuming that the shape of a segment does not change and that there is no internal mass shift within this segment, the relative location of the CG does not change and remains fixed within that segment. But the human body is a system of moving segments linked to each other at the joints. In other words, the mass distribution changes continuously as the body posture changes. As a result, the relative CG location of the whole body changes continuously. In this study the segmental method was used for finding the CG during the start of the sprinters [10]. Consequently, forty four reflective markers were placed on the feet, legs, pelvis, trunk, head and arms and the CG calculated according to Dempster (1955) [11].

In order to calculate the center of mass, knowledge of the position of all segment ends and begin points is a prerequisite. As previously described, segment end and begin points were calculated using the anatomical markers in the static trial and the tracking frames. However, in case of the upper limb segment the necessary information to define the proximal begin point of the segment was not present. The only available proximal marker on this segment is the lateral trochanter marker. No medial marker was available and therefore the upper leg begin point was calculated indirectly using both left and right trochanter markers in combination with anthropometrical data [12]. However, one more issue needs to be addressed as no markers were attached on both hands and the head. Leaving these three segments not defined.

In order to solve this problem, two assumptions were made:
(1) The influence of the hand segments on the position of the center of mass is negligible because of their relatively small mass with respect to the whole body mass. Therefore, the hand segments could be disregarded in the calculations.
(2) In sprinting the head segment has the same orientation as the upper body during the start and first two consecutive steps.

Combination of this latter assumption and the use of appropriate anthropometrical data [12] allowed for a fair estimation of the position of the CM of the head. However, these same assumption will pose limits on the accuracy of the CG estimation and, therefore, they have to be considered as a limitation of the study.

Finally, the position of the center gravity (CG) was calculated in the three spatial directions (vertical or Z-direction, anterior-posterior or Y –direction and medio-lateral or X direction) during sprint start.

For analyzing the position of the CG in the set position, the anterior-posterior Y coordinate was adjusted relative to the start line. Moreover, to offset the effect of the preference leg on the rear block and express CG medio-lateral displacement in an equal way for both populations (thus independent from either a left or a right leg is being used as the rear leg), the medio-lateral X coordinate of the CG was recalculated relative to its value in the set position. Further, lateral CG displacements were considered negative when the CG was deviating to the front leg side (left side for most sprinters) and positive when deviating to the rear leg side (right side for most sprinters). Hence, in this study, the medio-lateral displacement of the CG was expressed in an identical way, whatever leg was used for the rear block.

Statistical analysis
All statistics were preceded by Kolmogorov-Smirnov normality test. As all subpopulations used proved to be normal, classical student T-tests and ANOVA′s with Scheffé post hoc test were used for the detection of significant differences between subpopulations, mostly tertiles according to the different anthropometrical variables. All statistics were carried out using the SPSS 16.0 statistical software package with an overall significance level set at $p < 0.05$

RESULTS AND DISCUSSION

The average values of the position of the body centre of gravity during the set position were shown in Table 1.

Table 1: The 3D position of the body CG during the set position

Frontal (cm)	Vertical (cm)	Transversal (cm)
-14.76±4.56	57.12±3.96	53.53±4.0

The studies mentioned previously in the literature section, referred to an adult populations. However, in the present study the position of the center of gravity during the sprint start relates to young athletes. Because of the differences between young and adults as for anthropometrical, anatomical and physical parameters, a comparison with the literature is difficult. Nevertheless, Rowland, (2005) reported that adults are bigger than adolescents and older children are larger than younger children [13]. Within the size differences, the small child and young adult are not entirely geometrically similar. The legs of young adolescent are short for their body height relative to older person. Therefore it would not be appropriate to compare the adolescent sprinters with adults. However, because of the absence of research comparing adolescent and young athletes, especially with regard to the sprint start, caution should be observed when trying to relate the results of this study about youngsters with literature about adults.

During the set position, the horizontal distance of the CG relative to the starting line was 14.8±4.5 cm, which as expected is shorter than the same data for adults ranging from 16.0 to 31.0 cm. Mero et al. (1983) found values of 18.0, 18.9 and 29.0 cm for the elite, good and average sprinters respectively [14].

Baumann (1976) reported an average of 16 cm to 27 cm behind the starting line at the set position for top and average sprinters respectively. He hereby reported that horizontal distance of the CG increased with decreasing performance level [15]. However, these values were obtained from adults sprinters displaying different body size and body dimension [13]. In this study the young sprinters put their CG closer to the starting line (14.8±4.5 cm) as compared to the elite adult sprinters 18.0±3.04 cm from Mero et al. (1983). This may be due to the shorter body length (162±8.3 cm) of the young sprinters in this study as compared to the same elite sprinters (179±5.3cm).

Moreover, the average height of the CG was 57.1±3.9 cm, which unexpectedly is comparable with the data (ranging from 54.38 to 66.1 cm) for taller sprinters [14, 15]. The same results were reported by other studies, Mero et al. 1983, mentioning an average of 57.0 cm for eight athletes running the 100m at 10.08 sec [14]. Moreover, Baumann (1976) reported an average of 66 cm and 60 cm for top sprinters and less skilled sprinters respectively. He mentioned that the elite sprinters hold their CG in a significantly higher position than other sprinters [15]. According to these results, comparable height values of the CG for young sprinters suggested that they may be pushing their back higher up than adults in the set position. This may be due to youngsters using the bunched start where sprinters push up more their body CG.

Analyses of the influence of anthropometrical parameters on the position of the center of gravity during the set position

Age

Dividing subjects according to age showed significant differences between tertiles. In the frontal axis, significant differences were found between the first and second tertiles. The youngest athletes (first tertile) kept their center of gravity farthest from the starting line. Moreover, according to the vertical axis significant differences were found between the first and second tertiles as well as between the first and third tertiles. The younger sprinters showed a lower position of the CG (53.0 ± 3.9 cm) as compared to the second (57.9±4.1cm) and third (58.3±4.6 cm) tertiles.

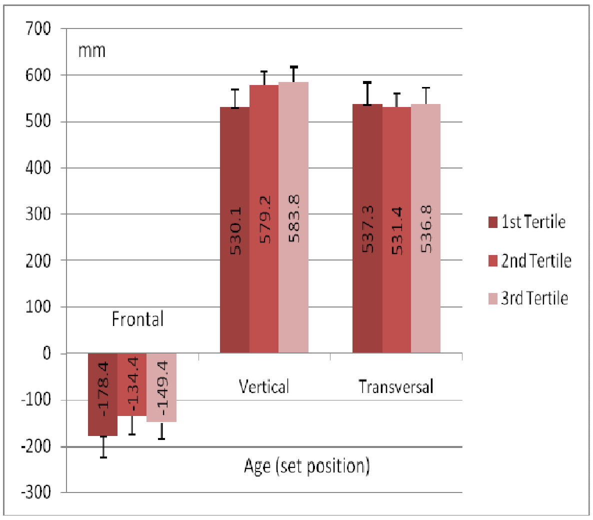

Figure 1: The 3D position of the body CG in the set according to age tertiles

On the other hand, according to the transversal axis no significant differences were found between tertiles. It means that age did not influence the medio-lateral displacement of the sprinters during the set position.

Muscle mass and body size is expected to grow from childhood to the adult stadium [13, 16]. Therefore it is expected that with increasing age, the position of the CG will change because of differences in body dimensions and size.

Moreover, it is well documented [2, 14, 16] that the optimal position of the CG (as high and close to the starting line as possible), creates maximum instability at the set position bringing the sprinters CG very close to the forward edge of the base of support (starting line) and therefore causing minimal delay for leaving the blocks [2]. The results of this study showed that older athletes displayed a higher CG position which was also closer to the start line at the set position. It is clear that while age increases the body length will increase too and this can account for the higher CG of the older sprinters.

As for the frontal axis, the older sprinters (third tertile) did not present their CG closer to the starting line (Figure 1). Instead, the second tertile positioned their CG closer to the starting line than the others. It means that other factors can be responsible for changes in CG position in the forward-backward direction for young sprinters. Although, no study has reported the behaviour of the CG in the medio-lateral direction, in this study, results show no age difference in medio-lateral displacement of the CG during the set position was found between older and younger sprinters. The results of this study indicate that age affects the anterior-posterior and vertical position of the CG more than the medio-lateral direction. Therefore without considering other factors, especially anthropometrical variables, it remains difficult to make a final conclusion as for the influence of age on the positioning of the CG for young sprinters during set position.

Skeletal muscle mass

According to the skeletal muscle mass (SMM) significant differences were found between the first and second as well as the first and third tertile for the frontal and vertical axes.

In this way, the sprinters with smaller amount of SMM put their CG in significantly farther and lower positions as compared to the sprinters with higher amount of SMM.

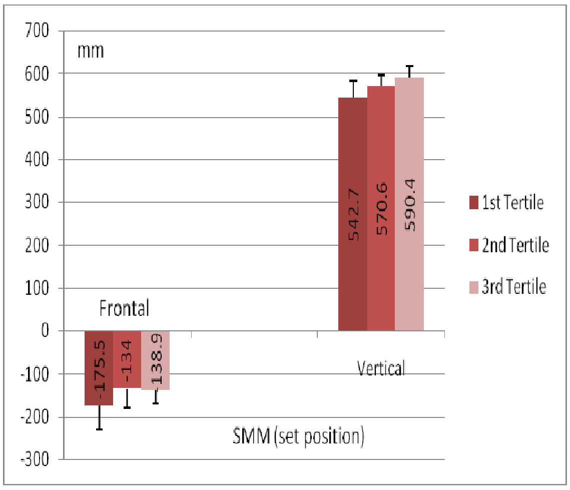

Figure 2: The position of the body CG in the set position in the frontal and vertical axes according to SMM tertiles.

As revealed in Figure 2, with increasing muscle mass the height of the CG increased also. The more skilled sprinters (third and second tertile) with higher amount of SMM showed significantly larger height of the CG as compared to the less skilled sprinters (first tertile). Moreover, the sprinters with smaller amount of the SMM also presented a position of the CG farther from the starting line. In contrast to the frontal and vertical axes, the transversal axis, presented no significant difference between tertiles in the medio-lateral direction. It means that the SMM did not affect the medio-lateral location of the CG during set position.

Although, because of the absence of the studies on the position of the CG especially during sprint start and as already mentioned above, it remains difficult to discuss these results with regard to related literature, these results indicate that the skeletal muscle mass significantly affected the upward-downward and forward-backward location of the CG during set position. As already discussed some studies showed that muscle mass will increase from childhood to the adulthood [13, 16]. Therefore it is expected that the sprinters with higher SMM present a more optimal set position (higher and closer to the starting line). Moreover, besides increasing age and SMM, the improvement of start techniques, experience and training when growing should also be considered. According to the position of the sprinters during the starting phase, it seems that the sprinters in the third tertile have more capability for optimizing their start position.

Calf and thigh girths
According to the calf and thigh girth, significant differences were found between first and second as well as the first and third tertiles in the vertical direction. The first tertile showed a significantly lower height than the second and third tertiles in both calf and girth parameters. No significant difference was found between second and third tertiles.

The results indicate that the sprinters with a higher circumference of the thigh and calf had a higher height of the CG than other sprinters. On the other hand, no significant difference was found in between tertiles according to the anterior-posterior and medio-lateral positions of the CG during the set position. Although, some studies indicate the importance of the muscle volume on sprint running performance [1, 17], no study has reported results on this topic. Therefore, the results of this study may overestimate the role of lower extremity muscle girth on the position of the CG during sprint start running.

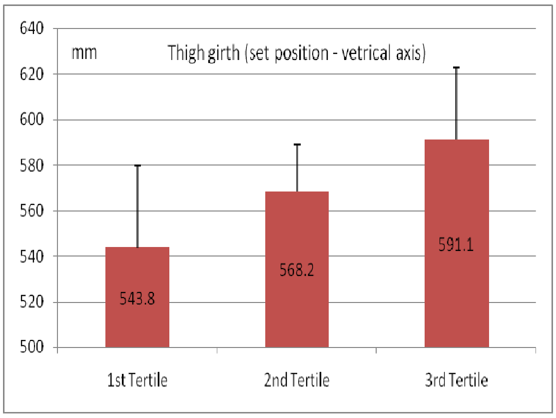

Figure 3: The vertical position of the body CG in the set position according to CCG and CTG tertiles.

It is assumed that sprinters in the third tertile with higher age and skeletal muscle mass would also show high calf and girth circumferences. However, no significant differences were obtained for the anterior-posterior position of the CG according to the calf and thigh girth. These results can be explained according to the results of Mero et al. (1983) who indicated that the horizontal distance of the CG to the starting line is more affected by the arm and shoulder muscle strength. In this way, Mero et al. (1983) suggested that the arm strength of the athletes affects the horizontal distance from the starting line (the stronger the arms the shorter the distance to the starting line). Therefore, according to the Mero study [14], it can be assumed that either the higher values of the calf and thigh girth in the top tertiles has been offset by the lower values of the shoulder and arm muscle strength in that group, or, the calf or thigh girth only affected the vertical position of the CG instead of the frontal situation.

CONCLUSION

In the present study, the horizontal distance of the CG from the starting line, as expected, was shorter than with adults. However, the height of the CG, unexpectedly, was comparable with the data for adult sprinters. Athletes with higher age and skeletal body mass showed a higher CG position which was also closer to the start line at the set position. This is regarded as an optimal start position at the set position as bringing the sprinters CG as close as possible to the forward edge of the base of support (starting line) causes minimal delay for leaving the blocks.

REFERENCES

[1] Coh M, Tomazin K. (**2006**) *New studies in athletics* 21: 23-33.
[2] Harland M.J, Steele J.R. (**1997**) *Sport Med*. 23 (1):11-20.
[3] Hakkinen K, Kraemer W.J., Newton R.U., Alen M. (**2001**) *Acta Physiol Scand* 171: 51-62
[4] Richburg, **1990**; … Korhonen M.T., Cristea A., Alen M., Hakkinen K., Sipilia S., Mero A., Viitasalo J.T., Larsson L., Suominen H. (**2006**) *J Appl Physiol*. 101(3):906-17.
[5] Tellez T, Doolittle D. (**1984**) *Track Technique*, 88:2802-5.
[6] Gordon D., Robertson E. (**1986**) Contributions of the ankle and knee muscles to sprint starting. Proceeding of North American Conference on Biomechanics I (CSB IV), Montreal.
[7] Mero A., Komi P.V. (**1990**) *Eur J Appl Physiol* 61:73-80.
[8] Isak, **2001**. International standards for anthropometric assessment, Published by the :International Society for the Advancement of Kinanthropometry, School of Physical Education, Exercise and Sport Studies, University of South Australia.
[9] McClay I., Manal K. (**1999**) *Med. Sci. Sports Exerc*. 31(11): 1629–1637.
[10] Hamilton N., Luttgens, K. (**2002**) Kinesiology, Scientific Basis of Human Motion, 10th ed. Boston: McGraw-Hill.
[11] Dempster WT (**1955**) Space requirements for the seated operator (WADC Technical Report 55-159). Wright-Patterson Air Force Base, OH: Wright Air Development Center.
[12] Hertzberg H.T.E. (**1972**) Engineering anthropology in Human engineering guide to equipment design. Eds: H.P Van cott and Kinkale R.G. 2nd Edition, McGraw Hill Company .
[13] Rowland T.W. (**2005**) Children’s Exercise Physiology. Human Kinetics.
[14] Mero A., Luhtanen P., and Komi P.V. (**1983**) *Scand. J. Sports Science*. 5(1): 20-28.
[15] Baumann W. (**1976**) Kinematics and dynamic characteristics of the sprint start. In Biomechanics V-B (Ed. P.V. Komi), University Park Press, Baltimore. 194 199.
[16] Sargeant A.J. (**2000**) Anaerobic performance. In: Pediatric exercise science and medicine. Armstrang, W. van Mechelen (Eds): Oxford: Oxford University Press,143-152.
[17] Chelly S.M, Denis C (**2001**) *Med Sci Sports Exerc* 33:326-333.