KINEMATICS OF THORAX AND PELVIS DURING MAXIMAL ACCELERATED SPRINTING

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Changes in thorax and pelvis movements during acceleration phase of maximal sprinting, which relate to acceleration ability, are still unknown. This study aimed to clarify the changes in thorax and pelvis movements during maximal accelerated sprinting and its relation to better acceleration ability. Twelve sprinters performed a 60-m sprint, during which 3D kinematics of the sprinters were obtained. The same patterns of motions were maintained for thorax and pelvis respectively throughout the entire acceleration phase, although phase profiles of relative movements between thorax and pelvis in three planes differed. Moreover, results indicated that effective acceleration is characterised by suppressed trunk bend, delayed trunk rotation, and forward tilted pelvis in the middle acceleration section and suppressed trunk bend in the final acceleration section.

KEY WORDS: posture, locomotion, athletics, running, trunk.

INTRODUCTION: Acceleration ability is a critical factor for performance in a 100-m sprint race (Doolittle & Tellez, 1984) and field sports (Sayers, 2000), and the ability is largely affected by a posture of an athlete (Kugler & Janshen, 2010). In contrast to constant speed sprinting, there is a substantial change in the trunk posture from crouched to upright position during maximal accelerated sprinting (Plamondon & Roy, 1984). Furthermore, the trunk posture changes step to step during the entire acceleration phase (Celik & Piazza, 2013). Whereas the trunk segment was treated as a rigid segment in aforementioned studies (Plamondon & Roy, 1984; Celik & Piazza, 2013), upper (thorax) and lower (pelvis) part of the trunk actually moves individually. Although several studies have illustrated the kinematics of thorax and pelvis during running (e.g. Debaere et al., 2013; Schache et al., 1999), all the studies were executed with a constant speed protocol or an experiment at the specific location of the acceleration phase. Thus, there is still a lack of knowledge of how sprinter's thorax and pelvic motions change step to step during the entire acceleration phase of maximal sprinting. Examining the changes in kinematics of thorax and pelvis during an actual accelerated sprinting would bring greater understanding of the nature of the human locomotor system and the knowledge to help the training for improving sprint acceleration ability. The purpose of this study was to clarify the changes in thorax and pelvis movements during maximal accelerated sprinting and its relation to better acceleration ability.

METHODS: Twelve well-trained Japanese male sprinters (mean ± SD: age, 21.6 ± 2.6 years; stature, 1.74 ± 0.04 m; body mass, 68.1 ± 4.2 kg; personal best 100-m time, 10.71 ± 0.33 s, ranging from 10.38 to 11.29 s) participated in this institutionally approved study. All participants were healthy and free from injuries at the time of the experiment and provided written informed consent prior to participation.

After warm-up, the participants performed maximal effort 60-m sprint two times. The sprint was treated as a 100-m race with starting blocks, and the participants used their own crouched starting position. Sixty infrared cameras (250 Hz) connected to single computer (Vicon Motion Systems, Oxford, UK) captured three-dimensional coordinates of 47 retro-reflective markers affixed to the participant's body with a volume of approximately 50 m × 1.5 m × 2 m (length × width × height). The time of the 60-m sprint was recorded with a photocell system (HL2-35, Tag Heuer, La Chaux-de-Fonds, Switzerland) and the coordinate data of the best trial was used for this study.

The coordinates of attached markers were smoothed using a Butterworth low-pass digital filter at cut-off frequencies based on the residual method of Wells and Winter (1980). The

cut-off frequencies ranged from 17.5 to 22.5 Hz. Using the coordinates of markers which were placed on the anterior and posterior of suprasternal notch and xiphoid process for the thorax and anterior and posterior superior iliac spines (right and left) for the pelvis, three-dimensional kinematics of thorax and pelvis segments in the laboratory coordinate system and that of the thorax in relation to the pelvic coordinate system were calculated. The orientations of the thorax and pelvis segments were described using the sequence which corresponds to tilt (sagittal plane), rotation (transverse plane), and obliquity (coronal plane). The trunk presented three degrees of freedom of the thorax with respect to the pelvis segment describing flexion/extension, rotation, and bending. The position of the whole body centre of gravity (CG), estimated using the body segment parameters of Japanese athletes (Ae, 1996), was calculated. Running speed was calculated as the first derivative of the position of CG in anterior-posterior direction with respect to time.
For testing the relationship of acceleration ability with the thorax and pelvis kinematics, Pearson's product-moment correlation coefficients between rate of change in running speed (RCS) and mean values of the kinematic variables were calculated. For the correlation analysis, the following procedures were conducted. Changes in running speed during sections (initial, from the 1st to 4th step; middle, from the 4th to 15th step; and final, from the 15th to 25th step) which were determined based on a previous study (Nagahara et al., 2014) were linearly approximated in relation to time, and the coefficients of the gradients, representing RCS in each section, were obtained. Although running speed does not change linearly in each section, the gradients represent the tendency of the entire change in speed during the respective sections; thus, the procedure was used. For the kinematic variables, mean values, representing mean orientations of the thorax and pelvis segments and relative angles between these, at the foot strike (FS) and toe-off (TO) during respective sections were computed. Statistically significant correlation was identified at a $p < 0.10$ level.

RESULTS and DISCUSSION: To our knowledge, this study is the first to investigate the thorax and pelvis movements during the entire acceleration phase of sprinting, in order to provide understanding of actual step-to-step changes and its relation to better performance. Figure 1 shows serial changes in thorax and pelvis angles in the three different planes for a typical participant during the entire acceleration phase (ca. 50-m). Figure 2 is presenting the

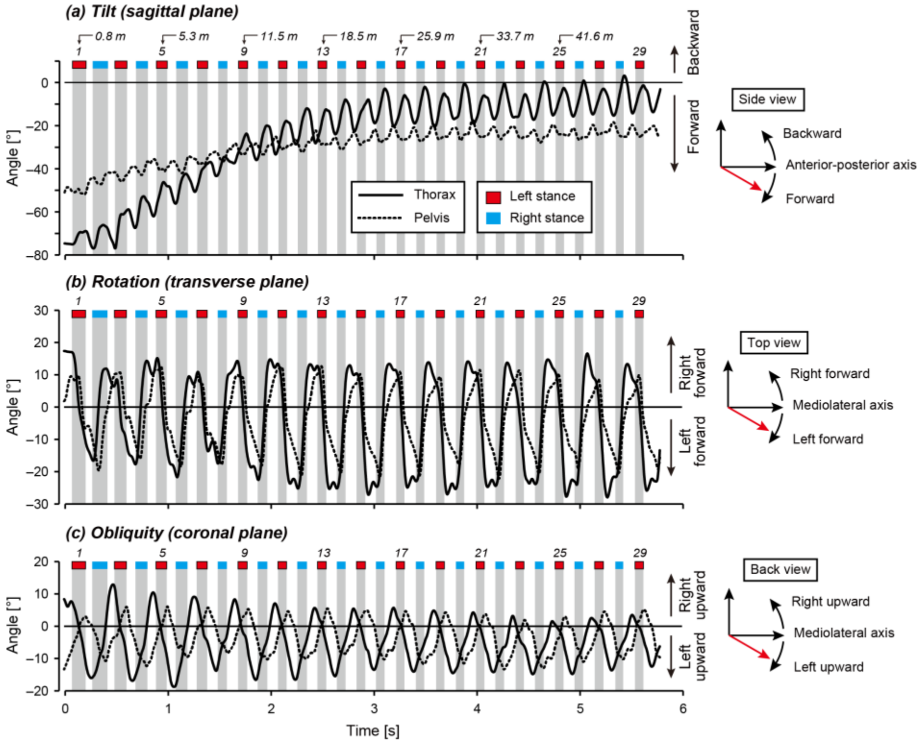

Figure 1: Typical changes in three-dimensional angles (a, tilt; b, rotation; c, obliquity) of thorax and pelvis during the acceleration phase. Grey back-ground shows stance phase.

changes in three-dimensional angles of the thorax and pelvis as well as thorax-pelvis joint at FS and TO during the acceleration phase. Even though the tilt angles in the thorax and pelvis largely changed through the acceleration, the three-dimensional movement patterns of the segments in each stride, unexpectedly, did not change during the entire acceleration phase (Figure 1), and these profiles of changes in angles during one stride are in line with previously presented results (Debaere et al., 2013; Schache et al., 1999). On the other hand, it was revealed that the relative movements between thorax and pelvis in three different planes showed different phase profiles during the entire acceleration phase (Figure 1 and 2); thorax and pelvis tilted out-of-phase, rotated in phase (thorax rotation preceded pelvis one slightly), and listed with quarter phase delay of the pelvis. This result indicates that plane specific trunk strength-power training is requisite for developing the sprinting ability through improving trunk strength. Moreover, when focusing on the stance phase, the angular displacements of thorax were larger than that of the pelvis and the thorax-pelvis joint extended (thorax tilted backward in relation to the pelvis), rotated inward (stance side thorax moved forward in relation to stance side pelvis), and medially bent (stance side thorax moved contralateral side in relation to stance side pelvis) (Figure 2). Based on these results, it can be recommended as strength training that one simultaneously extend, inner rotate, and medially bend a trunk to acquire the fundamental strength of the trunk region for the stance phase of maximal effort sprinting.

Results of correlation analysis, presented in Figure 3, revealed that the stance side thorax and pelvis positioned backward, pelvis tilted forward, small upward obliquity of the stance side pelvis and small lateral bending (stance side) of the thorax-pelvis joint at FS and delayed thorax rotation at TO are important for effective acceleration during the middle section (from 4th to 15th step) of the acceleration phase (Figure 3b). Nagahara et al. (2014) identified that acceleration in the middle section is associated with increase in step length. The pelvic forward tilt, stretching hamstrings, and delayed thorax and pelvis, stretching the gluteus maximus, at FS would enhance a production of propulsive force during the stance phase which brings long step length. Thus, these supposable relationships of thorax and pelvis postures with the propulsive force probably resulted in the importance of pelvic forward tilt and delayed thorax and pelvis at FS for effective acceleration during the middle

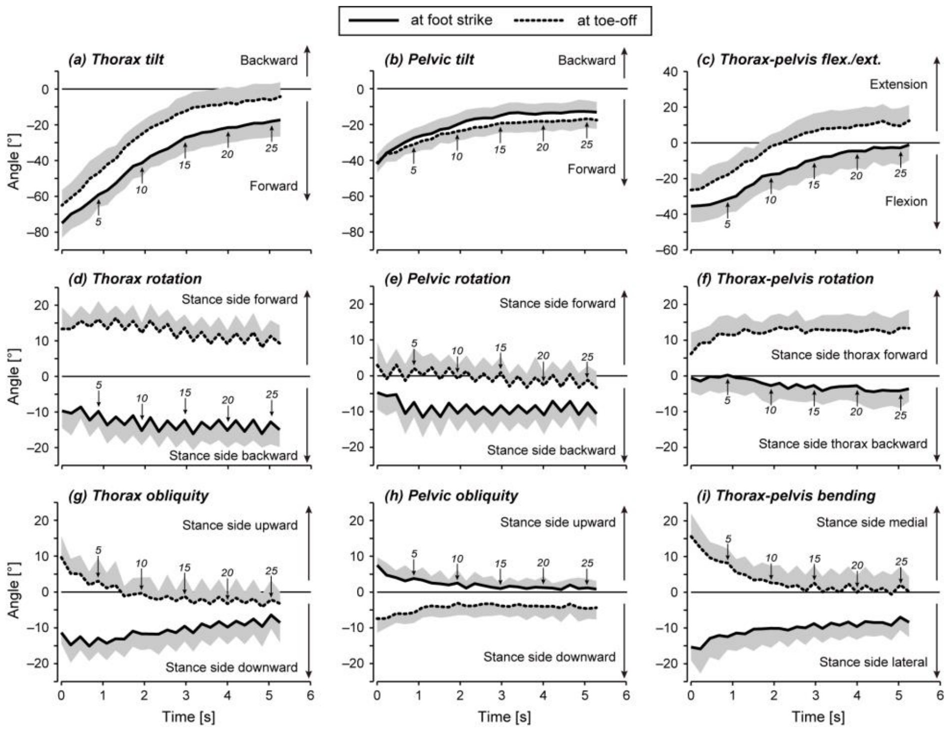

Figure 2: Changes in three-dimensional angles of thorax and pelvis as well as thorax-pelvis joint at the foot strike and toe-off during the entire acceleration phase. Upward and downward short arrows show averaged time point of each step number from the first foot strike.

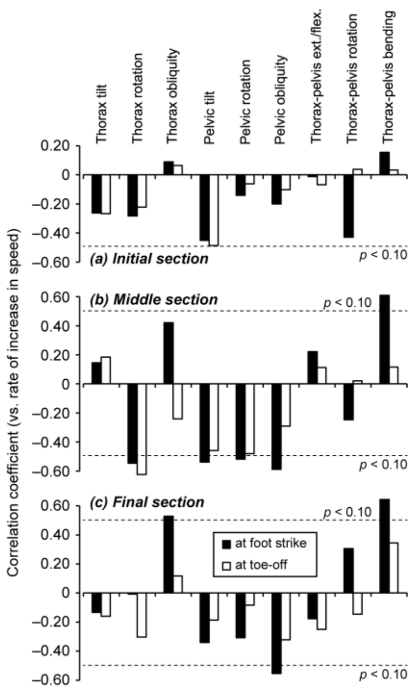

Figure 3: Relationship between rate of changes in speed and mean values of thorax and pelvis angles at foot strike and toe-off during the initial, middle and final section. Dotted horizontal lines show the significance level.

acceleration section. During the middle section, the stance time gradually becomes short and the magnitude of the vertical ground reaction force (GRF) increases (Plamondon & Roy, 1984), while the trunk rises to an upright position. A flexed trunk is not ideal for producing large vertical GRF within limited stance time. This may lead the importance of straightened trunk in the coronal plane at FS during the middle section. During the final section (from 15th to 25th step), RCS was associated with small stance side thorax downward obliquity, small stance side upward pelvic obliquity, and small lateral bending (stance side) of the thorax-pelvis joint at FS, presenting a practical importance of suppressing mediolateral movement in the trunk at FS for effective acceleration. These associations are likely resulted from the above mentioned relationship between vertical GRF and the thorax and pelvis positions in the coronal plane.

CONCLUSION: This study demonstrated that the thorax and pelvis respectively maintain the same pattern of motion throughout the entire acceleration phase, although phase profiles of relative movements between the thorax and pelvis differ in the three planes. Moreover, to accelerate effectively, straightened trunk in the coronal plane, delayed trunk rotation and forward tilted pelvis in the middle acceleration section, and straightened trunk in the coronal plane in the final section, are important technical characteristics. It is advantageous for a practitioner to know the general features of thorax and pelvis movements in each stride during the entire acceleration phase, and the findings of important kinematic characteristics in each acceleration section would help technical training of sprinters, when addressing development of acceleration ability.

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