THE DIFFERENCES IN THREE-DIMENSIONAL KINETICS IN LOWER LIMB JOINTS OF SPRINTERS AND NOVICE RUNNERS DURING A START DASH

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The purpose of this study was to clarify the differences in the three-dimensional joint moments of lower limbs between sprinters and novice runners. A total of 12 male sprinters and 11 healthy male college students participated in a start-dash experiment. At pushing the front starting block, in hip joint, extension moment of sprinters was significantly greater than that of novices. On the other hands, in ankle joint, not only the plantarflexion moments but also the inversion moment of sprinters was significantly greater than those of novices. Moreover, the peak value of the plantarflexion moment was positively correlated with that of the inversion moment. These results suggest that the greater ankle flexion-extension moment is achieved by coordinating with the greater inversion moments when attempting to increase acceleration ability.

KEY WORDS: joint moment, Motion capture system, Joint coordinate system.

INTRODUCTION: Since the first modern Olympics in 1986, the crouch start has been used by many athletes as the best starting position for maximum acceleration. Therefore, clarifying the characteristics of a sprinter's start-dash movement is an important factor in attempting to increase the explosive acceleration ability of not only sprinters, but also novice runners and athletes in other sports.

Most of previous studies have focused on sprint running movement from only sagittal plane because flexion-extension movement of lower limbs is mainly related to sprint performance. On the other hands, previous studies have recently found that the relationship between these flexion-extension movement and the other abduction-adduction and inner-outer rotation movements of lower limbs three-dimensionally (e.g. Ito, Ishikawa, Isolehto & Komi, 2006; Slawinski, Bonnefoy, Ontanon, Leveque, Miller, Riquet, Chèze & Dumas, 2010). For instance, Slawinski et al. (2010) found that elite sprinters reach their maximum hip angular velocity of flexion and extension with a combination of flexion-extension, abduction-adduction and inner-outer rotation movements. These previous studies highlight the importance of three-dimensional movement in lower limb joints, suggesting that the differences in three-dimensional joint moments of lower limbs would be shown between different skill runners. To the best of our know knowledge, however, no studies have examined the relationship between sprint performance and the three-dimensional joint moments in runners of differing skill level.

The purpose of this study was to clarify the differences in joint moments of lower limbs between sprinters and novice sprinters, and to provide information on effective training methods to increase acceleration ability for sprinters and athletes in other sports.

METHODS: A total of 12 male sprinters (mean ±SD; weight: 66.3 ±4.3 kg, height: 1.75 ±0.06 m) and 11 healthy male college students (weight: 68.0 ±8.4 kg, height: 1.75 ±0.07 m) participated in a start-dash experiment. The mean personal-best time of sprinters for running 100 m was 11.30 ±0.36 s (range: 10.79-11.84 s).

The experimental protocol was approved by the Research Ethics Committee involving Living Human Participants at the Biwako Kusatsu campus of Ritsumeikan University. Each subject provided written informed consent prior to participating in the study.

Sprinting movement and the ground reaction force data were captured simultaneously for each subject from pushing the starting blocks to the second step of take-off. The three-dimensional locations of 53 retro-reflective markers attached to each subject's body were determined using a 16-camera motion capture system (Raptor-E digital; Motion Analysis Corporation, Santa Rosa, CA) sampled at 250 Hz. Whole-body marker trajectory data were filtered using a fourth-order, zero-lag low-pass Butterworth filter, and the optimal cut-off frequency was determined by residual analysis (Winter, 2009). A 15-segment rigid body model was created, including a head, upper arms, fore arms, hands, trunk, pelvis, thighs, shanks, and feet. The mass properties of Dempster and Gaughran (1967), the center of mass location and the inertial properties of Hanavan (1964) based on their shapes were used in the segments. Mean horizontal velocity of the centre of mass from pushing the starting blocks to the second step of take-off was assessed as start-dash performance.

Group force data was measured with a 2×5 arrangement of 10 strain-gauge force plates (TF-4060-B; Tech-Gihan, Inc., Kyoto, Japan) sampled at 1250 Hz. Ground reaction force data were filtered using a fourth-order, zero-lag low-pass Butterworth filter with a cut-off frequency of 200 Hz, and subsequently used to determine stance time, airborne time and swing time. Step frequency was calculated by reciprocal value of taken in one step.

Except for knee joint, whose main function is flexion-extension movement, three-dimensional joint angles in the lower limbs were determined using the joint coordinate system and a Cardan sequence. The joint moments were calculated using a standard inverse dynamics approach, and were normalized by dividing by the body mass of the subject. In order to compare the changes in angles and joint moments in each stance phase between groups, we normalized these with respect to time to each percentage of the intervals of total time by cubic spline interpolation between sprinters and novices. Because a greater number of subjects used the front block with the left leg in this experiment, data of the contralateral subjects were multiplied by -1.

Table 1: Measurements of gait parameters of sprinters and novices.

	Sprinters (n = 12)		Novices (n = 11)	
	Mean	**±SD**	**Mean**	**±SD**
Stance time (s)				
Front††: when pushing the front block	0.358	±0.027	0.407	±0.055
Rear††: when pushing the rear block	0.179	±0.024	0.237	±0.055
1st: when pushing 1st step	0.188	±0.024	0.201	±0.022
2nd: when pushing 2nd step	0.166	±0.022	0.182	±0.019
Swing time (s)				
1st: rear leg landing ─ 1st step take-off	0.263	±0.029	0.255	±0.029
2nd: front leg landing ─ 2nd step take-off	0.332	±0.030	0.325	±0.044
Airborne time (s)				
1st*: front leg landing ─ 1st step take-off	0.083	±0.023	0.058	±0.029
2nd*: 1st step landing ─ 2nd step take-off	0.061	±0.023	0.065	±0.027
Step frequency (step•s^{-1})				
1st*: start─ 1st step take-off	2.25	±0.14	2.05	±0.22
2nd: 1st step take-off ─ 2nd step take-off	4.05	±0.39	3.81	±0.50
Step length (m)				
1st*: front foot ─ 1st step	1.05	±0.09	0.95	±0.09
2nd: 1st step ─ 2nd step	1.05	±0.13	1.10	±0.13
Step width (m)				
1st**: front foot ─ 1st step	0.27	±0.05	0.19	±0.06
2nd: 1st step ─ 2nd step	0.27	±0.07	0.24	±0.12
Mean horizontal velocity (m•s^{-1}) **	2.91	±0.13	2.76	±0.15

Parameters of sprinters which were statistically greater than those of novices are indicated with asterisks, *p<0.05; **p<0.01; and ***p<0.001. Those of novices which were greater than those of sprinters are indicated with double daggers, †† p<0.01. All parameters are shown as mean ±SD. An independent t-test was utilized to assess the differences in parameters between sprinters and novices. The Pearson's correlation coefficient was utilized to assess the relationship between peak values of joint moments shown below for further details. Significance was set at p<0.05.

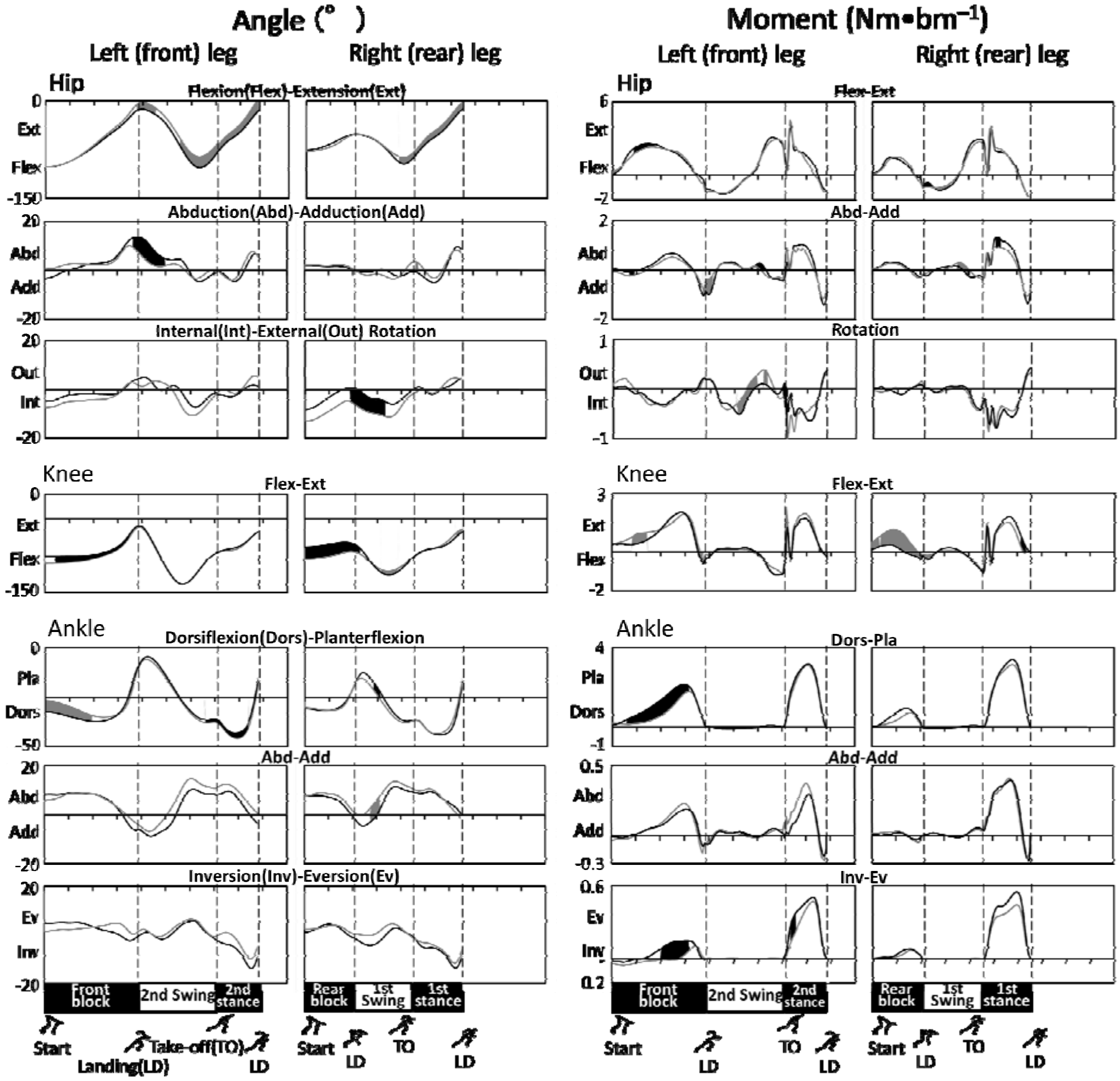

Figure 1: Three-dimensional changes in joint angles and moments in lower limbs of sprinters and novices normalized with respect to time between groups. Black and gray lines show the time-series data of sprinters and novices, and the areas shaded black or gray indicate time-series data in which significantly greater values were found compared to the other group.

RESULTS: The data for gait parameters are shown in Table 1. From pushing the starting block to the first step, step frequency, step length and step width of sprinters were significantly greater than those of novices, but those gait parameters from the first step to the second step. Front and rear stance time of sprinters was significantly shorter than those of novices, but both 1st and 2nd stance and swing time. 1st airborne time of sprinters was significantly longer than that of novices, but 2nd airborne time.
The normalized time-series data of joint angles and moments are shown Figure 1. Significant differences were found for all the normalized time-series data of joint angles and moments between sprinters and novices, except for ankle rotation angle and abduction-adduction moment.

DISCUSSION: Running speed during sprinting can be represented by the product of step length and step frequency. In this study, both 1st step frequency and step length of sprinters were significantly greater than those of novices, while there were no significant differences in both 2nd step frequency and step length between sprinters and novices. This result suggests

that sprinters can sprint faster than novices because of mainly a greater ability to push the starting blocks. Thus, we focus on the sprint performance of both groups from pushing the starting blocks to the first step.
After assuming the static starting position, a runner is required to output greater extension force of their lower limbs in a briefer stance time to achieve higher running speeds. Correspondingly, at pushing the front starting block, the hip extension moment of sprinters; whose peak value was greatest in any moments in three joints, was significantly greater than that of novices. Then, sprinters could increase similar hip extension angle in a briefer time compared to novices. On the other hands, just before significant differences of the hip extension moment were seen, the hip adduction moment of novices was also significantly greater than that of novices. However, the correlation coefficient between the peak value of the hip extension moment; which accelerates runners' speed, and that of abduction moment was 0.181, and no relationships between those peak values of hip moments of were found. Moreover, the peak value of hip extension moment was first occurred in both groups, followed by those of inner rotation and abduction moments. These suggest that the hip extension moment is outputted independently of own abduction or outer rotation moments at pushing the front block.
In contrast, in ankle joint, the dorsiflexion movement was generated after once generated plantarflexion movement at pushing the front starting block. Then, the ankle plantarflexion moment of sprinters was significantly greater than that of novices, therefore, sprinters had the smaller excessive plantarflexion movement compared to novices. At the same time, the eversion moment of sprinters was significantly greater than that of novices. The correlation coefficient between the ankle peak moments of the plantarflexion and eversion was 0.470 ($p < 0.05$). Furthermore, the peak values of three moments of ankle joint were simultaneously occurred. These results suggest the importance of coordinating greater extension and eversion moments three-dimensionally for higher acceleration performance.

CONCLUSION: These results suggest that the coordinating the greater ankle moments of extension and eversion is necessary, and the extension moment in hip joint should be generated independently of own abduction and outer rotation moments, when attempting to increase acceleration ability.

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