TOPICS IN EXERCISE SCIENCE AND KINESIOLOGY

Expedited Article

Kinematic Characteristics of Novices' Sprint Techniques at Maximum Velocity Phase

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ABSTRACT

Topics in Exercise Science and Kinesiology Volume 5: Issue 1, Article 2, 2024. Sprint performance is a crucial aspect of achieving high performance across a range of sports. However, previous studies analyzing the sprint technique of novices have yielded disparate findings regarding effective sprint techniques. For instance, Saito and Ito (1995) found no significant difference in the maximum thigh angle of the free leg between boys aged 7 to 12 and sprinters. Conversely, Katoh et al. (2001) reported that elementary school sprinters indicated a larger maximum thigh angle of the free leg than novice elementary children. Inconsistency like this makes it challenging for teachers to plan coaching strategies for refinement sprint techniques. This study aimed to clarify the kinematic characteristics of novices ranging from elementary school children to adults by reviewing previous articles. To comprehensively explore a broad range of English and Japanese articles analyzing sprint techniques of novices and athletes during the maximal velocity phase in sprint events, three search engines, namely CiNii Research, PubMed, and SPORTDiscus, were utilized. Mean values, correlation coefficients, and the results of group comparisons in these articles were compared. As the main results, novices exhibited a much smaller thigh angle of the free leg at touchdown compared to athletes. Novices indicated a larger minimum knee angle of the free leg than athletes, and this angle tended to decrease as sprint velocity increased from 5 m/s to 10 m/s. Novices exhibited a smaller maximum thigh angle of the free leg than athletes, and this angle tended to increase as sprint velocity increased from 5 m/s to 9 m/s.

KEY WORDS: Sprint performance, joint angle, segment angle

INTRODUCTION

Sprinting is a fundamental locomotion movement that enables humans to move swiftly within a brief period. In Athletics sprinting events, competitors are obliged to cover a predetermined distance in the shortest possible time to achieve their goal. Sprinting is also commonly employed in other Athletics events and other sports. Consequently, sprinting is a critical component for achieving high performance in various sports. It follows that providing learners with appropriate instructions on sprinting techniques during physical education classes, which most children and students attend, is equally important. The absence of proper instruction and lack of noticeable progress in sprinting techniques during physical education classes may lead to a negative impact not only on the acquisition of sprinting techniques but also on their participation in other physical education classes and sports activities thereafter.

In Japanese physical education classes for Athletics, the emphasis has traditionally been on holding competitions and measuring records, with skill development receiving less attention (12, 43). Additionally, there have been no reports indicating that this situation has improved to date. Given that physical fitness has a significant impact on sprint ability (20, 23), and that an individual's rank within a group, such as a class, is challenging to alter (3), sprint ability is often considered a fundamental component of physical fitness. Consequently, teachers and learners may have been unlikely to believe that improving sprint technique could lead to improved sprint ability. In fact, sprint events are not often taught in Japanese physical education classes (41).

However, it should be noted that sprint technique, a technical aspect, also significantly influences sprint ability (32, 40). Novices' sprint velocity can be significantly increased by refining their sprint techniques (42). Although enhancing physical fitness in physical education classes can improve sprint ability, the resulting improvement is likely to be temporary. Moreover, learners often struggle to maintain their motivation due to the lack of clear learning contents in physical education classes. In light of the foregoing, instructing students in sprint technique in physical education classes is not only essential for enhancing their sprinting ability but also for providing them with explicit learning contents. By doing so, the quality of physical education classes, which are often heavily focused on competitions and records, can be substantially elevated.

Numerous studies (14, 30, 34, 56) have investigated the sprint techniques of sprinters with specialized training experience. For example, Ito et al. (1998) have shown that sprinters with higher velocity have less flexion and extension of the ankle and knee joints during the support phase. On the other hand, there are also many studies analyzing the sprint techniques of novices, including children and students (19, 21, 47), and these studies have reported different findings on effective sprint techniques to improve sprinting ability. For instance, Saito and Ito (1995) found no significant difference in the maximum thigh angle of the free leg and minimum knee angle of the free leg between boys aged 7 to 12 and sprinters, leading to the conclusion that these techniques do not impact sprint velocity after age 6. Conversely, Katoh et al. (2001) compared elite elementary sixth-grade sprinters with novice elementary sixth-grade children and reported significant differences in these two parameters. Inconsistency like this among previous studies makes it challenging for teachers to determine how to refine sprint techniques in physical education classes. To address this issue, it is necessary to gather findings from previous studies on sprint techniques for both novices ranging from elementary school children and adults, and sprinters. This study aimed to clarify the kinematic characteristics of novices' sprinting by reviewing previous articles that analyzed sprint techniques. If the review of previous studies can clarify novices' sprint technique characteristics and resolve discrepancies among them, teachers can select more effective sprint techniques for instruction. This also allows teachers to develop teaching materials and coaching methods more effectively. Additionally, by comparing sprint techniques across a wide range from novice elementary school children to world-level sprinters, it is possible to understand how sprint techniques change with varying sprint velocities. This may help identify prioritized sprint techniques based on sprint velocity.

METHODS

Search engines

Three search engines, namely CiNii Research, PubMed, and SPORTDiscus were utilized to comprehensively explore a broad range of academic articles that focus on physical education and sports science in Japanese and English languages. CiNii Research was utilized for Japanese-language articles, whereas PubMed and SPORTDiscus were used for English-language articles. The search terms in Table. 1 were inputted into each search engine to retrieve relevant articles. In all search engines, the articles were searched chronologically from the oldest to the newest in the databases.

1. CiNii Research

In CiNii Research, the "Simple Search (Kanni Kensaku)" was performed to retrieve articles that contained the search terms in their title, abstract, and keywords. The article type was set to "article (Ronnbun)". Although the scope of the simple search included the journal's name, the author's name, and the author's affiliation, it was deemed that there was no issue in achieving the purpose of this study.

2. PubMed

In PubMed, the "Advanced Search" was carried out to restrict the search fields and apply logical conditions. As "Keywords" were absent in the search fields, only "Title/Abstract" was searched. English words often have multiple variations, including plurals, nouns, and adjectives. For instance, the word "kinematic" has variations such as "kinematics" and "kinematical." To accommodate such variations of English words, an asterisk (*) was appended at the end of the search terms to perform a prefix search (truncation).

3. SPORTDiscus

In SPORTDiscus, the "Advanced Search" was employed to limit the search fields and apply logical conditions. The search fields were set to "Title," "Abstract," and "Keywords." In "Search Options," "Peer Reviewed" was selected, "Country" was set to "All," "Database Subset" was set to "All," "Language" was set to "English," "Publication Type" was set to "Academic Journal," and "Document Type" was set to "Article." Truncation was carried out for the same reason mentioned in the PubMed section.

Selection criteria for articles

1. Article type

Only academic articles, excluding review, commentary, and proceeding, published in academic journals written in English or Japanese were included in the study. Bulletins published in a university or a research institute, conference abstracts, commercial journals, and books were excluded.

Table 1. The search results.

Search engine	Word 1	Logical operator	Word 2	Date	Result	1st Sc	2nd Sc	3rd Sc	
CiNii Research	走 (sprint)	and	動作 (motion)	2022 6/30	2648	61	34	28	30
			フォーム (form)		407	7	3	3	
			キネマティクス (kinematics)		81	3	2	1	
	スプリント (sprint)		動作 (motion)		166	11	7	3	
			フォーム (form)		17	1	1	1	
			キネマティクス (kinematics)		10	2	2	1	
Pubmed	sprint*	and	kinematic*	2022 7/1	531	107	16	10	16
			technique*		531	27	6	4	
			biomechanic*		399	37	9	6	
SPORT Discus	sprint*	and	kinematic*	2022 8/5	133	37	5	4	
			technique*		39	5	4	3	
			biomechanic*		47	5	1	1	
		and	kinematic*		400	100	11	6	
			technique*		367	30	8	6	
			biomechanic*		201	22	4	2	
		and	kinematic*		65	26	2	1	
			technique*		29	6	2	1	
			biomechanic*		80	9	1	1	

2. Participant

Articles that involved novices were collected in this study. In this study, "novice" is defined as an able-bodied individual ranging from an elementary school child to an adult who has no specialized training experience in a specific kind of sport event. If participants in previous articles had experience in a specific sport, they were excluded, as their sprint techniques could reflect the characteristics of that sport's sprint style. Participants for whom the Methods section of the previous article did not state specialized training experience in a specific sport were considered novices. Furthermore, experience in physical education classes was not considered specific training. Articles that included university students majoring in Physical Education or Sports Science, who are considered to have specialized experience in various sports, were excluded, even if the authors did not describe their specialized experience in a specific sport. Articles that included only able-bodied athletes who had specialized experience in sprint, hurdle, and jump events in Athletics (hereafter referred to as "athletes") were collected. [*1) However, articles that included older novices and athletes such as masters were excluded because sprint techniques change with age (6). Additionally, articles with fewer than five participants in one group were excluded.

3. Trial
The trials were maximal-effort sprints on a straight runway without any restrictions such as weights or slopes, and the sprint distance was limited to 100m or less. Articles that conducted trials only on a treadmill were excluded since sprint techniques on the ground differ from those on a treadmill (7). The type of ground surface (Tartan track or ground) was not limited. The values of pre-measurement were collected in articles in which specific training effects were identified. The type of shoes (warming up shoes or spiked shoes) was not limited. [*2)]

4. Sprinting section
Previous studies (9, 20, 23) have established a strong significant positive correlation between sprint time and maximal sprint velocity for both novices and athletes. This study collected values of parameters during the maximal velocity phase. The section ranged from 15-60 meters for novices and 30-70 meters for athletes.

5. Parameter
This study collected articles that utilized video images to digitize participants' sprint motion in the sagittal plane captured at 50 fps or higher, and calculated the joint or segment angles of the lower limbs. Articles that defined anatomical or static standing positions as 0 degrees were excluded. Joint or segment angular velocities were excluded. Articles in which simulations were utilized to calculate joint or segment angles were excluded.
The reported mean values of joint or segment angles, correlation coefficients between these parameters and sprint velocity (SV), and results of group comparisons were collected. [*3)]

Procedures for selecting articles
This study utilized the following procedures to review previous articles. These procedures were performed twice by the same researcher, with each repetition separated by at least one week.

1. First screening
The titles, abstracts, and bibliographic information of the retrieved articles were evaluated to exclude articles that did not meet the selection criteria. Articles that provided descriptions of the analysis or comparison of kinematics or sprint techniques were not excluded at this stage, even if specific parameters were not described in the abstracts.

2. Second screening
The text of the articles that passed the first screening was reviewed to ensure that they met the selection criteria. Articles that did not meet the criteria were excluded.

3. Third Screening (Selection of parameters)
The third screening involved selecting parameters based on the following criteria to obtain joint or segment angle mean values from the articles that passed the second screening, allowing for comparisons among previous articles. This is because the variety of joint and segment angles reported in previous articles is so extensive that considering each one in this single review would be challenging. Firstly, parameters affected by multiple motions were excluded, such as the hip joint which is influenced by both trunk and thigh segments, making it difficult to determine

which segment affects the hip angle. Secondly, to compare mean values across previous articles, parameters for which the number of samples indicating mean values was fewer than 10 groups were excluded. In cases where no mean values were reported, but values for each participant were reported, the mean value for the parameters was calculated.

Moreover, considering that free leg motion is easier to improve than support leg motion (39), only parameters of the free leg were analyzed in this study. Thus, the selected parameters were minimum thigh angle of the free leg (∠FT-min), thigh angle of the free leg at touchdown (∠FT-td), minimum knee angle of the free leg (∠FK-min), maximum thigh angle of the free leg (∠FT-Max), thigh angle of the support leg at touchdown (∠ST-td), and shank angle of the support leg at touchdown (∠SS-td). [*4)] The leg and foot angles of the support leg at touchdown were excluded as they were defined differently in previous articles, making comparisons difficult. The segment angle was defined as the angle between the vertical or horizontal line and the segment in previous articles. The mean values of previous articles were adjusted to the definitions shown in Figure. 1 for this study. Additionally, the sign of the correlation coefficient was also adjusted.

Duplicate articles within the same search engine and between PubMed and SPORTDiscus were excluded after the third screening.

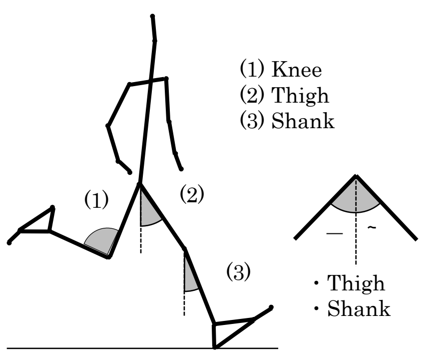

Figure 1. The definition of joint and segment angle.

RESULTS

As depicted in Table 1, a total of 46 articles met the selection criteria. These included 30 Japanese articles from Cinii Research and 16 English articles from PubMed and SPORTDiscus. Of these, 22 articles pertained to novices, comprising a total of 43 groups. The participants' ages ranged from first-grade elementary school children to graduate students, with SV ranging from 4.91 to 9.36 m/s. Additionally, 29 articles pertained to athletes, including a total of 40 groups. The participants' ages ranged from sixth-grade elementary children to world-class adult elite athletes, with SV ranging from 7.07 to 11.39 m/s. The reported mean values of the above-mentioned angles, correlation coefficients between these angles and sprint velocity, and results of group comparisons were collected. Table 2 shows in which article each joint or segment angle was reported. The numbers on the right side of Table 2 indicate the number of the previous article in the References.

Table 2. The list of previous articles.

Parameter	References										
Minimum thigh angle of the free leg	11	17	27	34	37	39	52				
Thigh angle of the free leg at touchdown	15	24	25	33	35	36	39	40	44	49	54
	56										
Minimum knee angle of the free leg	4	5	8	13	14	15	17	18	19	21	22
	24	25	26	27	28	29	30	32	33	36	40
	41	44	45	48	49	55					
Maximum thigh angle of the free leg	4	8	10	11	14	15	17	18	19	21	22
	24	25	26	27	28	29	30	32	33	34	45
	36	37	40	41	44	46	48	49	52	55	57
Thigh angle of the support leg at touchdown	1	2	7	11	33	34	37	41	44	46	49
	50	54									
Shank angle of the support leg at touchdown	1	2	5	7	31	33	34	40	41	49	50
	51	54									

Minimum thigh angle of the free leg

There were 7 articles that analyzed ∠FT-min, reporting the mean values of ∠FT-min and SV for a total of 11 groups. The mean values of ∠FT-min ranged from -34.09 to -32.22 degrees for novices and from -32.7 to -21.91 degrees for athletes. Figure. 2 displays the mean values of ∠FT-min and SV. [*5, 6)] The novice groups are represented by black dots, while the athlete groups are represented by white dots.

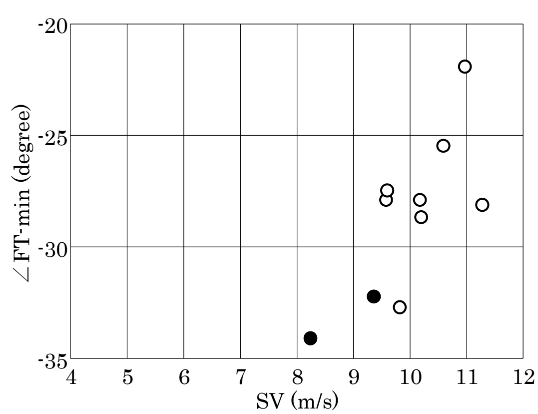

Figure 2. Relationship between SV and ∠FT-min.

Correlation coefficients between ∠FT-min and SV were reported for 6 groups. They ranged from -0.585 to 0.851 for athletes. No articles reporting correlation coefficients for novices were found. Figure. 3 shows the mean values of SV and the correlation coefficients between ∠FT-min and

SV. In this figure, black and white dots represent the groups that showed non-significant correlations for novices and athletes, respectively. The black and white squares represent the novice and athlete groups that showed significant correlations.

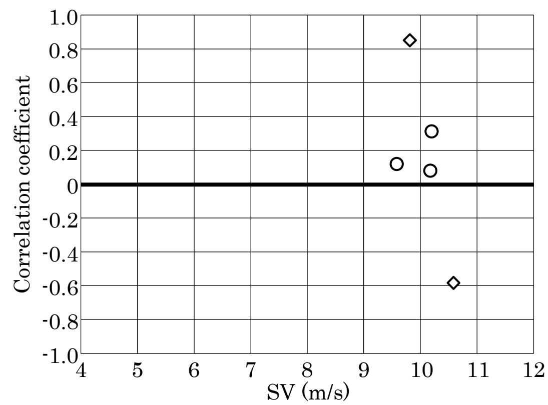

Figure 3. Relationship between SV and correlation coefficient between SV and ∠FT-min.

Thigh angle of the free leg at touchdown

There were 12 articles that analyzed ∠FT-td, reporting the mean values of ∠FT-td for a total of 21 groups. Among these, the mean value of SV was also reported in 18 groups of those. The mean values of ∠FT-td ranged from -17.26 to -4.06 degrees for novices and from -2.7 to 24.39 degrees for athletes. Figure. 4 displays the mean values of ∠FT-td and SV. [*6, 7)] Additionally, Ogata et al. (1988) reported a mean value (-8.7 ± 3.4 degrees) for male university novice students, while Toyoshima and Sakurai (2016) reported mean values (-1 ± 7 degrees and 2 ± 8 degrees) for the Stride Length-Similar and Stride Frequency-Similar groups of youth and adult sprinters, respectively.

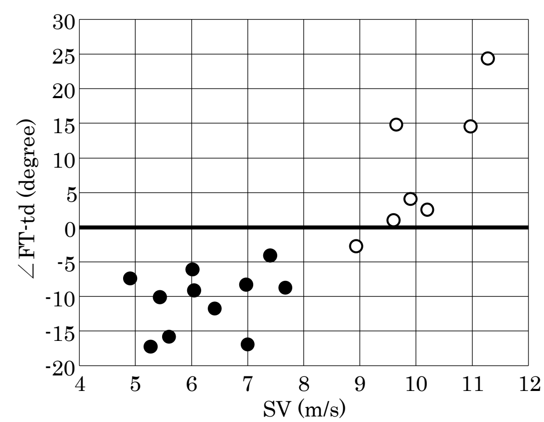

Figure 4. Relationship between SV and ∠FT-td.

Correlation coefficients between ∠FT-td and SV were reported for 7 groups. They ranged from -0.253 to 0.263 for novices and from -0.401 to 0.625 for athletes. Figure. 5 shows the mean values of SV and the correlation coefficients between SV and ∠FT-td.

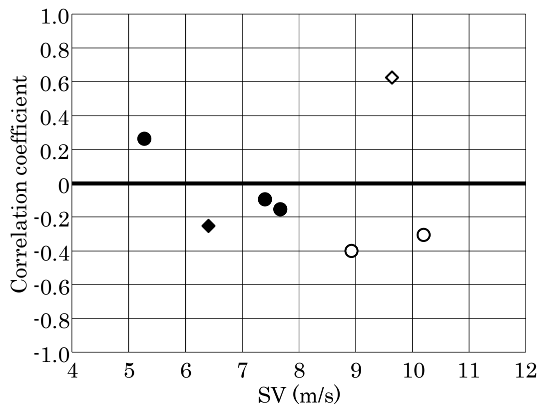

Figure 5. Relationship between SV and correlation coefficient between SV and ∠FT-td.

Iwakabe et al. (1998) reported no significant difference between novice university students and athletes, while Yada et al. (2011) reported that world-class sprinters showed a significantly larger mean value than university student sprinters.

Minimum knee angle of the free leg

There were 28 articles that analyzed ∠FK-min, reporting the mean values of ∠FK-min and SV for a total of 46 groups. The mean values of ∠FK-min ranged from 32.2 to 48.8 degrees for novices and from 29.15 to 42.1 degrees for athletes. Figure. 6 presents the mean values of ∠FK-min and SV. [*8, 9] Ogata et al. (1988) reported a mean value (36.0 ± 8.5 degrees) for male university novice students. Watanabe et al. (2003) reported a correlation coefficient (-0.09, n.s.) between SV and ∠FK-min and a mean value of SV (9.86 ± 0.26 m/s) for male athletes, but not a mean value of ∠FK-min.

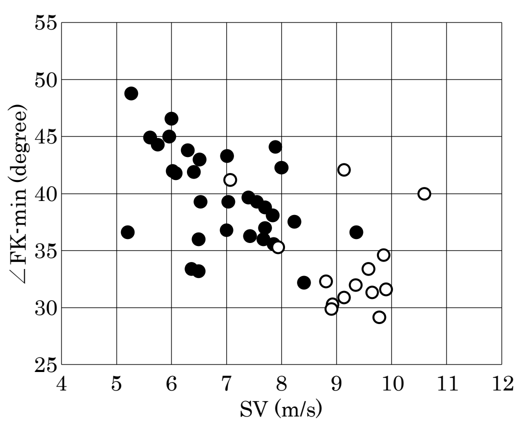

Figure 6. Relationship between SV and ∠FK-min.

Correlation coefficients between ∠FK-min and SV were reported for 31 groups. They ranged from -0.580 to 0.171 for novices and from -0.09 to 0.577 for athletes. Figure. 7 shows the mean values of SV and the correlation coefficients between SV and ∠FK-min. Ito et al. (1998) did not report mean values for ∠FK-min and SV, but reported correlation coefficients between these parameters of 0.320 (p<.05) for male sprinters, 0.063 (n. s.) for female sprinters, and 0.283 (p<.05) for male and female sprinters.

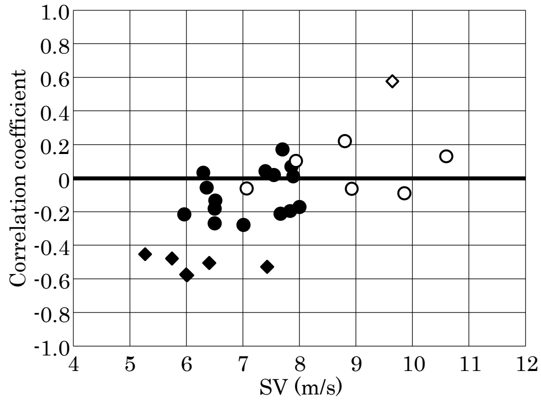

Figure 7. Relationship between SV and correlation coefficient between SV and ∠FK-min.

Miyamoto et al. (2018) found no significant difference in ∠FK-min between the Rearfoot and Fore/Midfoot groups in elementary fifth-grade boys. Nishimura et al. (2016) reported that the upper group had a significantly smaller mean value of ∠FK-min than the middle and lower groups in second-grade high school male students. Funatsu et al. (2013) compared elementary third-grade boys and girls, and reported a significantly larger mean value of ∠FK-min for girls than for boys. Bushnell et al. (2007) reported a significantly smaller mean value of ∠FK-min for athletes and long-distance runners than for other sports competitors. Katoh et al. (2001) reported that elementary six-grade elite sprinters showed a significantly smaller mean value of ∠FK-min than elementary six-grade novice children. Iwakabe et al. (1995) reported that athletes showed a significantly smaller mean value of ∠FK-min than ballplayers and novice university students.

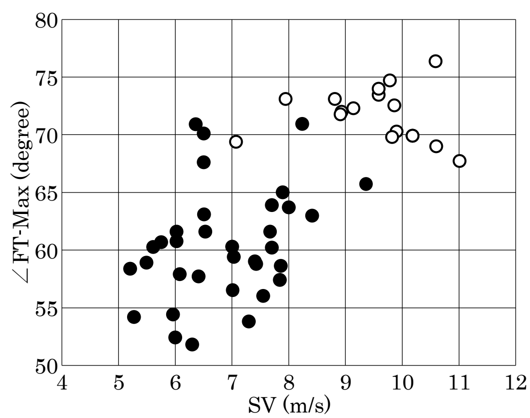

Figure 8. Relationship between SV and ∠FT-Max.

Maximum thigh angle of the free leg

There were 33 articles that analyzed ∠FT-Max, reporting the mean values of ∠FT-Max for a total of 52 groups. Among these, the mean value of SV was also reported in 51 groups of those. The mean values of ∠FT-Max ranged from 51.8 to 70.93 degrees for novices and from 67.7 to 76.4

degrees for athletes. Figure. 8 illustrates the mean values of ∠FT-Max and SV. [*5, 8, 9, 10] Furthermore, Ogata et al. (1988) reported a mean value (61.6 ± 4.5 degrees) for male university novice students. Additionally, Watanabe et al. (2003) reported a correlation coefficient (0.09, n. s.) between SV and ∠FT-Max and a mean value of SV (9.86 ± 0.26 m/s) for male athletes, but not a mean value of ∠FT-Max.

Correlation coefficients between ∠FT-Max and SV were reported for 34 groups. They ranged from -0.297 to 0.663 for novices and from -0.122 to 0.598 for athletes. Figure. 9 shows the mean values of SV and the correlation coefficients between SV and ∠FT-Max. Ito et al. (1998) did not report mean values of ∠FT-Max and SV but reported that the correlation coefficients between these parameters were 0.078 (n.s.) for male sprinters, 0.002 (n.s.) for female sprinters, and 0.165 (n.s.) for male and female sprinters.

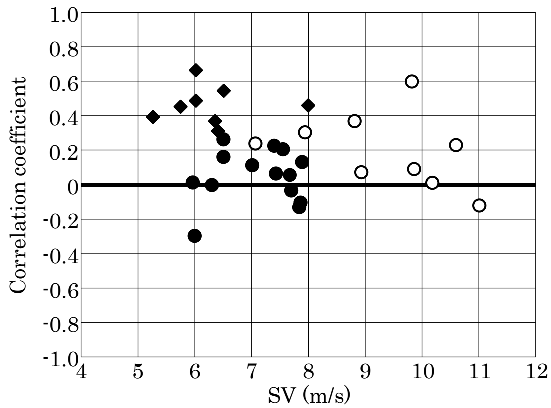

Figure 9. Relationship between SV and correlation coefficient between SV and ∠FT-Max

Miyamoto et al. (2018) reported no significant difference in ∠FT-Max between the Rearfoot and Fore/Midfoot groups in elementary fifth-grade boys. Nishimura et al. (2016) reported that the upper group exhibited a significantly larger mean value of ∠FT-Max than the middle and lower groups in second-grade high school male students. Funatsu et al. (2013) compared elementary third-grade boys and girls, and reported no significant difference in ∠FT-Max. Katoh et al. (2001) reported that elementary sixth-grade sprinters showed a significantly larger mean value of ∠FT-Max than elementary sixth-grade novice children. Iwakabe et al. (1995) reported that athletes showed a significantly larger mean value of ∠FT-Max than ballplayers and novice university students.

Thigh angle of the support leg at touchdown

There were 13 articles that analyzed ∠ST-td, reporting the mean values of ∠ST-td for a total of 18 groups. Among these, the mean value of SV was also reported in 15 groups of those. The mean values of ∠ST-td ranged from 27.6 to 40.8 degrees for novices and from 28.9 to 34.3 degrees for athletes. Figure. 10 presents the mean values of ∠ST-td and SV. [*5)] Ogata et al. (1988) reported a mean value (32.9 ± 3.8 degrees) for male novice university students, and Toyoshima and Sakurai (2016) reported mean values (34 ± 4 and 33 ± 4 degrees) for the Stride Length-Similar group and Stride Frequency-Similar group of youth and adult sprinters, respectively.

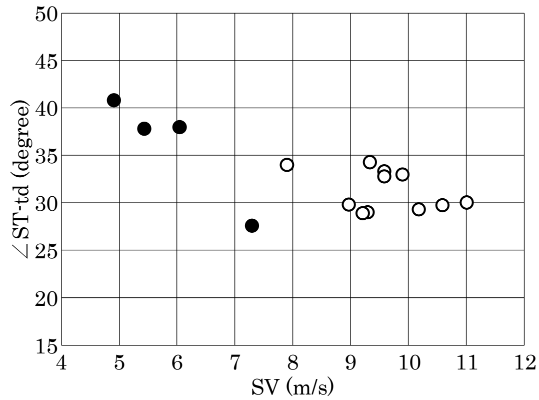

Figure 10. Relationship between SV and ∠ST-td.

Correlation coefficients between ∠ST-td and SV were reported for 4 groups. Haugen et al. (2017) reported a non-significant correlation coefficient (0.04) between SV (10.18 ± 0.25 m/s) and ∠ST-td (29.3 ± 3.3 degrees) in adult male athletes. Murphy et al. (2021) reported that correlation coefficients for these parameters in the male athlete (10.59 ± 0.44 m/s, 29.76 ± 3.17 degrees) and female athletes (9.58 ± 0.27 m/s, 33.32 ± 3.36 degrees) were not significant. There was a non-significant correlation coefficient (0.725) between these parameters in the world and Japanese elite male sprinters (11.01 ± 0.53 m/s, 30.0 ± 6.4 degrees) (34). However, no articles that reported correlation coefficients for novices were found.

Nishimura et al. (2016) reported that no significant difference was found between the upper, middle, and lower groups in second-year high school male students. Yada et al. (2011) reported that no significant difference was found between world-elite sprinters and university student sprinters.

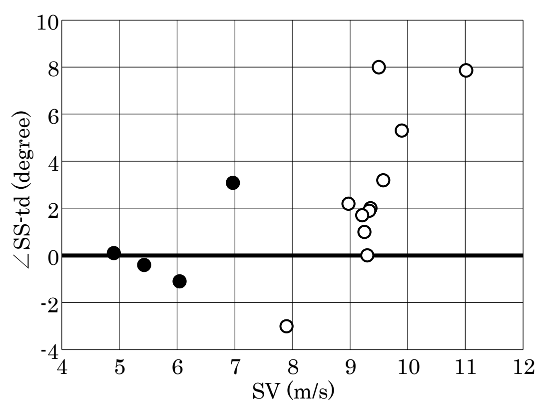

Figure 11. Relationship between SV and ∠SS-td.

Shank angle of the support leg at touchdown

There were 13 articles that analyzed ∠SS-td, reporting the mean values of ∠SS-td for a total of 17 groups. Among these, the mean value of SV was also reported in 15 groups of those. The mean values of ∠SS-td ranged from -1.1 to 3.1 degrees for novices and from -3 to 8 degrees for athletes. Figure. 11 presents the mean values of ∠SS-td and SV. [*5)] Toyoshima and Sakurai (2016) reported mean values (4 ± 4 and 2 ± 5 degrees) for the Stride Length-Similar group and Stride Frequency-Similar group in youth and adult sprinters, respectively.

Correlation coefficients between ∠SS-td and SV were reported for 1 group. There was a non-significant correlation coefficient (-0.351) between these parameters in the world and Japanese elite male sprinters (11.01 ± 0.53 m/s, 30.0 ± 6.4 degrees) (34). However, no articles that reported correlation coefficients for novices were found.

Nishimura et al. (2016) reported that the upper and middle groups of second-year high school male students had significantly smaller shank angles than the lower group. Yada et al. (2011) found no significant difference between world-elite sprinters and university student sprinters.

DISCUSSION

The purpose of this study was to review previous articles and identify the kinematic characteristics of novice sprint techniques. Multiple search engines were used to review previous articles, and the mean values, correlation coefficients with SV, and results of group comparisons of the previous articles were collected for six joint and segment angles. As a main result, the range of mean values for novice and athlete groups, and the relationship between each angle and SV were clarified. Each of these is discussed below.

Minimum thigh angle of the free Leg

The mean values of ∠FT-min ranged from -34.09 to -32.22 degrees in novices and from about -30 to -25 degrees in most athlete groups (Figure. 2). As SV increased, ∠FT-min tended to increase. These suggest that novices need to quickly pull their free leg forward after taking off. Similar to the present study, large ∠FT-min has been reported as characteristic of excellent sprinters (34). Additionally, sprinters with higher SV moved their legs and feet quickly backward at touchdown (14, 39). These findings suggest that by increasing ∠FT-min, sprinters can quickly move their leg forward after release, resulting in a rapid swing backward. However, due to the limited number of novice groups (only 2) and the relatively small number of athlete groups (eight), the range of values for this parameter remains unclear. Thus, future studies should aim to collect data on ∠FT-min over a wider range of sprint velocities.

Regarding the relationship between SV and correlation coefficients between ∠FT-min and SV (Figure. 3), only five groups were reported and no clear trend was found, with one significant positive and negative correlation reported, respectively. Naito (2015) conducted a cluster analysis and classified male adult sprinters into three groups based on the ratio of stride frequency and stride length. The three groups were Stride Length-Type sprinters (large stride length and low stride frequency), Mid-Type sprinters (medium stride length and stride frequency), and Stride Frequency-Type sprinters (small stride length and high stride frequency). Comparing the three groups, Stride Length-Type sprinters had a smaller thigh angle of the free leg from takeoff to the time after takeoff than Stride Frequency-Type sprinters. This may be due to Stride Length-Type sprinters tilting their thighs more anteriorly to gain longer takeoff distance. As the value of ∠FT-min is influenced by the Step-Type [*11)], it is likely that there were one significant positive and negative correlations in the collected article.

We have not identified any previous articles providing instruction on ∠FT-min for novices and analyzing changes in this angle. In contrast, Miyashita et al. (1986) reported that world elite athletes had a larger ∠FT-min, along with a larger thigh angle of the support leg at takeoff compared to elite Japanese athletes. Considering the sequence of these movements, it may be possible to enhance ∠FT-min by instructing athletes to increase the thigh angle of the support leg at takeoff.

Thigh angle of the free leg at touchdown

The mean values of ∠FT-td were negative for all novice groups and positive for most athlete groups (Figure. 4). Notably, the maximum value for novices (-4.06 degrees) was smaller than the minimum value for athletes (-2.7 degrees). Despite Iwakabe et al.'s (1998) finding that there is no significant difference between novice university students and athletes, the mean values depicted in Figure. 4 indicate that athletes have a larger ∠FT-td than novices. Furthermore, recent research by Nishimura et al. (2020) has shown that ∠FT-td increased, and SV improved when participants were instructed to pull the thigh up and flex the knee joint of the free leg. These findings suggest that novices can enhance SV by pulling the thigh of the free leg more forward at touchdown. The reason for this, as mentioned in the section on the ∠FT-min, is that the leg is carried forward quickly after release, which increases ∠FT-td and leads to a quick swing backward of the free leg.

On the other hand, although novices have a much smaller ∠FT-td than athletes, there was no clear correlation between ∠FT-td and SV in only the novice groups (Figure. 4). Notably, the only significant correlation found in the novice group was negative (Figure. 5). This implies that improving the forward pulling motion of the free leg may be challenging for novices without intentional instruction.

In contrast, for athlete groups, ∠FT-td increased as SV increased (Figure. 4). Moreover, Yada et al. (2011) reported that world elite sprinters exhibited a significantly larger mean value than university student sprinters. Thus, even for athletes with higher SV than novices, increasing ∠FT-td remains important in enhancing SV.

Nishimura et al. (2020), as described above, instructed novice male high school and university students to flex the knee joint of the free leg and pull the thigh high by having them perform high knees using mini hurdles. They reported that ∠FT-td also increased as well as ∠FT-Max. Ogata et al. (1988) similarly reported an increase in ∠FT-td and ∠FT-Max by practicing high knees for male university students. However, Nishimura et al. (2020) also had the other group perform high knees using thin bars. This group was instructed to ground the shank perpendicular to the ground with the forefoot. Consequently, there was no change in ∠FT-td in this group. Based on these findings, it may be effective to increase ∠FT-Max through exercises such as high knees in which both legs are quickly swapped with instructions to pull the thigh high.

Minimum knee angle of the free leg

Novice groups showed values ranging from about 35 to 45 degrees, while athletes had ranges of about 30 to 35 degrees (Figure. 6). Additionally, previous articles have shown that athletes were significantly smaller than novices and other sports athletes in elementary sixth-grade and university students (5, 15, 21). One study (47) which does not apply to the criteria of this study, reported that sprinters, novice children aged 6-12 years, and university students had almost the same values. However, the present study suggests that novices have a larger ∠FK-min than athletes.

Figure. 6 shows that ∠FK-min tends to decrease as SV increases from 5 m/s to 10 m/s. Nishimura et al. (2016) found that novice male high school students with higher SV showed a significantly smaller value than novice male high school students with average and lower SV. Additionally, previous articles have reported that instructing knee flexion improved SV in novice elementary sixth-grade children, and high school and university students (24, 40). Based on these results, teaching novices to flex the knee joint of the free leg more would be effective in enhancing their SV.

On the other hand, Seki et al. (2016) have argued that the knee joint of the free leg is flexed as a result of quickly pulling the thigh forward, and therefore, instructing pulling the thigh of the free leg should be prioritized over knee flexion. While it has been shown that teaching novices to reduce ∠FK-min improved their SV (24, 40), no study has yet tested the effectiveness of instruction based on Seki et al.'s (2016) idea. Therefore, the importance of instructing knee flexion of the free leg cannot be disregarded.

Figure. 7 shows that as SV increases from 5 m/s to 11 m/s, the correlation coefficients tend to change from negative to positive values. All significant negative correlations were found in novice groups, and all significant positive correlations were found in athlete groups. These results suggest that ∠FK-min should be smaller for novices and larger for athletes. Kigoshi et al. (2012) proposed that the negative correlation between ∠FK-min and SV in novices is due to the immaturity of their hip flexor muscle groups. Therefore, novices need to flex their knee joints to reduce the moment of inertia of the entire free leg around the hip center to quickly pull their free leg forward. [*12)] Based on the above, it is evident that ∠FK-min which is effective for increasing SV depends on the learner's SV.

Kigoshi et al. (2012) developed an assistant tool (an oval cushion with a small whistle) to reduce ∠FK-min. The tool is attached to the posterior surface of the thigh. When the knee joint is bent, air is released from the cushion and a sound is made, providing immediate feedback on whether the knee joint of the free leg is bent deeply or not. After one instructional session of practicing high knees and sprinting with the aid of this tool, there was a significant reduction in ∠FK-min among elementary school students who initially demonstrated a large ∠FK-min. In a study conducted by Nishimura et al. (2020), novice male high school and college students were instructed to perform high knees, aiming to flex the knee and pull the thigh high to prevent the free leg from hitting 10cm and 15cm mini hurdles. As a result, SV increased, and ∠FK-min decreased. These findings suggest that offering immediate feedback to learners on whether they flex the knee of the free leg using tool and mini hurdles, is effective in enhancing this sprint technique.

Maximum thigh angle of the free leg

The majority of novice groups exhibited a ∠FT-Max that was less than 65 degrees, whereas most athlete groups demonstrated an angle ranging from 70 to 75 degrees (Figure. 8). All groups that had SV exceeding 9 m/s displayed an angle larger than 65 degrees. Previous articles (15, 21) reported that athletes were significantly larger than novices among elementary sixth graders and university students. While one previous study (47), which does not apply to the criteria of this study, demonstrated that novice children aged 6-12 years exhibited nearly the same value as sprinters, the present study's results suggest that novices have a smaller ∠FT-Max than athletes.

As shown in Figure. 8, ∠FT-Max tends to increase as the SV increases from 5 m/s to 9 m/s. No group with SV of 9 m/s or higher exhibited a ∠FT-Max less than 65 degrees, regardless of whether they were novices or athletes. In Figure. 9, positive correlations were found in some novice groups, and all significant correlations were positive. Additionally, novice male high school students with higher SV showed a significantly larger value than those with average and lower SV (41). Moreover, previous articles (24, 40) have reported that SV of novice elementary six-grade children, and male high school and university students increased by instructing knee flexion and pulling the thigh of the free leg up. Nishimura et al. (2020) observed an increase in the angular velocity of the thigh of the support leg at touchdown by providing such instruction and speculated that pulling the thigh higher increases the distance required to accelerate the thigh to touchdown, resulting in quicker swing of the thigh backward. These results suggest that instructing novices to pull the thigh of the free leg up should be effective for improving SV. In contrast, no previous article has reported a significant correlation between SV and ∠FT-Max in athlete groups. This different trend may be attributed to the decrease in stride frequency caused by pulling the thigh up higher. Although pulling the thigh higher increases the distance required to accelerate the thigh backward to touchdown (40), it also lengthens the time it takes for the free leg to make contact with the ground, leading to a reduction in stride frequency. Thus, athletes seem to choose to accelerate the thigh or increase stride frequency after pulling their thighs up higher than novices to ensure the minimum required distance to accelerate the free leg backward.

Kigoshi et al. (2012) speculate that since the hip flexor muscle group of novice elementary school children is considered immature compared to that of athletes, a smaller ∠FK-min reduces the moment of inertia around the hip joint and allows a larger ∠FT-Max for novice elementary school children. They also reported a significant negative correlation between ∠FK-min and ∠FT-Max. Nishimura et al. (2020) also reported a significant decreasing trend in ∠FK-min ($p < 0.10$) and a significant increase in ∠FT-Max for novices after practicing high knees using mini hurdles. Based on the above, it would be effective to teach novices to flex the knee of the free leg in addition to pulling their thighs high by practicing high knees. On the other hand, Ogata et al. (1988) found no significant difference in ∠FK-min and a significant difference in ∠FT-Max after practicing high knees. The reason for this seems to be that, as a result of long-term instruction (8 weeks, 24 sessions), the strength of the hip flexor group also improved, which allowed ∠FT-Max to be increased without decreasing the ∠FK-min.

Thigh angle of the support leg at touchdown

Novice groups exhibited a range of 27.6 to 40.8 degrees for ∠ST-td, while athlete groups ranged about 30 to 35 degrees (Figure. 10). However, due to limited research on novices, it is difficult to conclude whether novices have a larger ∠ST-td than athletes. On the other hand, Yada et al. (2012) reported that sprinters with higher SV exhibited a larger thigh angular velocity of the support leg at touchdown. Decreasing ∠ST-td can increase the distance to accelerate the thigh of the free leg backward during the flight phase. Additionally, Tanigawa et al. (2008) have shown that athletes tend to have shorter touchdown distance than novice university students. Miyamoto et al. (2018) found that the Forefoot/Midfoot group with higher SV has shorter touchdown distance than the Rearfoot group with lower SV. Decreasing ∠ST-td can lead to shortened touchdown distance. These findings suggest that decreasing ∠ST-td may effectively improve SV. However, as previous articles reported limited values for novices, it is necessary to determine the range of values exhibited by novices in future research.

We have not identified any previous articles that provided instruction on ∠ST-td for novices and analyzed changes in this angle. However, by referring to the reports of previous studies already mentioned (32, 53), it may be possible to reduce ∠ST-td by instructing forefoot landing and grounding close to the body.

Shank angle of the support leg at touchdown

∠SS-td indicated a range of -1.1 to 3.1 degrees for novice groups, and -3 to 8 degrees for athlete groups. While the values of athletes varied widely, they tended to be larger than those of novices (Figure. 11). Additionally, athletes tended to exhibit a larger angle as their SV increased. Generally, novices and junior sprinters are instructed to ground their feet close to directly under the body (16), this study found that athletes tended to have a larger angle than novices. This can be attributed to the fact that sprinters and novices with higher SV quickly swing their feet backward at touchdown and tilt their shank forward just after touchdown (20, 23, 56), which appears to result in the shank being placed perpendicular immediately just after touchdown, despite being more posteriorly inclined at touchdown. Previous studies on novices have demonstrated that tilting the shank backward at touchdown does not enhance SV. Nishimura et al. (2016) classified novice male high school students into three groups based on their SV and found that the upper and middle groups had smaller shank angles of the support leg at touchdown than the lower group. Additionally, Nishimura et al. (2020) speculated that a smaller ∠SS-td increased the distance required to accelerate the shank backward during the flight phase, resulting in a quicker swing of the shank backward at touchdown. Based on these findings, it can be concluded that grounding the shank perpendicular at touchdown is effective in improving SV for novices.

Nishimura et al. (2020) reported that novice male high school and male university students practiced high knees using thin bars to keep their shank perpendicular at touchdown and improved this technique. On the other hand, Ogata et al. (1988) also made university students perform high knees, but found no significant difference in the leg angle of the support leg at touchdown, a similar kinematic parameter to ∠SS-td. In Nishimura et al. (2020), the high knees were first performed at a slower speed and gradually transitioned to quicker high knees. It may be effective for novices to practice at a slower speed first, since the foot is the end of the body and moves quickly. Additionally, Nishimura et al. (2016) reported a significant positive correlation between ∠SS-td and the trunk angle at touchdown in novice male high school students. This suggests that getting the trunk vertically may help grounding with the shank perpendicular to the ground.

THE LIMITATION OF THIS STUDY

The experimental conditions such as age, gender, surface of the running track, type of shoes used, sprint distance, and starting style (crouching or standing) in each article collected in this study were different. Furthermore, each group in each article had a different sample size. Thus, one of the limitations is that these factors were not taken into account, which could have affected the results. In addition, because this study collected articles in English and Japanese, language bias may have affected the results of this study.

CONCLUSION

This study successfully clarified the kinematic characteristics of novices' sprinting through comparisons within novices and with athletes. Furthermore, in novice groups, the maximum thigh angle of the free leg increased with SV, whereas this trend was not observed in athlete groups. This suggests that the desired sprint techniques vary between novices and athletes, and should be selected based on each learner's sprint ability.

NOTE

1) The values of athlete groups were collected irrespective of their level of performance.
2) Manabe and Ogata (2002) reported that there were no significant differences in the free and support leg motions at touchdown between warming-up shoes and spike shoes trials.
3) Articles that showed results of only multiple regression or multivariate analyses were not included.
4) The thigh and shank angle of the support leg at touchdown are defined as the motions of the free leg in this study because they refer to the angles at touchdown.
5) Miyashita et al. (1986) analyzed nine elite sprinters, comprising five males and four females. The mean values of the five male sprinters were utilized to exclude the influence of gender.
6) Nakata et al. (2003) recruited seven university students, comprising six males and one female. The mean values of the six male participants were utilized to exclude the influence of gender, and mean values for elite athletes in this article, calculated by adding data from previous articles, were also employed in this study.
7) Mizushima et al. (2018) reported results for shoe-wearing and barefoot trials. In this study, the mean values of the shoe-wearing trial were utilized.

8) Manabe and Ogata (2002) compared trials in which participants wore spike shoes and warming-up shoes. In this study, the mean value for the warming-up shoes trial was used.
9) Koyama et al. (1999) analyzed the sprinting motion from the 5 m point to the 65 m point in the 100 m sprint. The mean values of the 65m point where the maximal SV was achieved were utilized in this study.
10) Yoshida et al. (2021) reported mean values for both the left and right legs. In this study, the mean value for the right leg was utilized.
11) Naito (2015) defined the Step -Type as the significance of stride frequency or stride length.
12) The desired value of ∠FK-min for athletes also varies according to their Step-Type. For example, Miyashita et al. (1986) reported that Stride Length-Type athletes tend to flex the knee joint of the free leg more.

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