



# The relationship between sprint speed and sprint motion in amputee soccer players

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Received: 1<sup>st</sup> March 2019; Accepted: 24<sup>th</sup> June 2019; Published: 7<sup>th</sup> September 2019

**Abstract:** Sprint performance plays an important role in amputee soccer. Sprint motion such as step length and frequency are generally accepted as one of the determining factors of sprint performance. However, there is a paucity of sprint motion studies. Here we sought to analyze sprint motion in outfield positioned amputee soccer players using crutches and to clarify the relationship between sprint speed and sprint motion. Twelve male Japanese outfield players participated; they performed a 30-m sprint with maximum effort. Sprint times and speeds were recorded using electronic timing gates. A high-speed video camera recorded sprint motion. The time and distance of each crutch and step were determined via image analysis. Sprint speed was significantly positively correlated with body mass ( $r=0.692$ ,  $p=0.013$ ), length and frequency of one running cycle ( $r=0.817$ ,  $p=0.001$ ;  $r=0.666$ ,  $p=0.018$ , respectively), 1st-2nd step length ( $r=0.890$ ,  $p=0.001$ ), and crutch-1st step length ( $r=0.659$ ,  $p=0.020$ ). In addition, sprint speed was significantly negatively correlated with time taken for each 10-m interval as well as with contact time of first foot ( $r=-0.881$ ,  $p=0.001$ ) and crutch stance time ( $r=-0.670$ ,  $p=0.017$ ). Our results suggest that improving sprint speed requires increasing the step length within a shorter time frame in first foot step and crutch stance.

**Keywords:** sprinting; soccer; disability; high-speed camera

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## Introduction

Amputee soccer is designed for people with disabilities such as amputations and extremity dysfunctions. An amputee soccer match follows the format of two teams playing against each other with each team consisting of six outfield players and one goalkeeper. All outfield players have a lower limb amputation and/or disability. Moreover, outfield players play with two crutches; they do not wear an artificial leg during the match. They kick only with their natural/unaffected leg. The goalkeeper has an upper limb amputation and/or disability.

The World Amputee Football Federation (WAFF) standardized the rules of amputee soccer matches (Yazıcıoğlu 2007). A match must consist of two equal periods of 25 min each, with a half time interval not exceeding 10 minutes. The size of the pitch must be 55–70 m in length and 30–60 m in width. Amputee soccer rules are similar to the Fédération Internationale de Football Association rules, with some exceptions. The general rules of amputee soccer are: 1) do not kick the ball with crutches or an impaired leg, 2) do not touch the ball with an impaired arm, 3) no offside rule, 4) goalkeepers cannot leave the goal area.

Amputee soccer is gaining popularity worldwide among individuals with disabilities. The WAFF was founded in 2005 and currently has 46 member-nations. In October 2017, the European Amputee Football Federation hosted the European Amputee Football Championship for the first time; more than 40,000 spectators attended the final game. In 2018 (October 24–November 5), the World Cup was held in Mexico for the first time in 4 years; 24 countries participated. Angola came in first place with Turkey in second, Poland and Brazil advanced to be one of the last 8 teams. Moreover, the study of amputee soccer has been advanced in these countries (Guchan, Bayramlar, & Ergun, 2017; Özkan et al, 2012; Simim et al, 2013; Wieczorek, Wiliński, Struzik, & Rokita, 2015; Yazıcıoğlu 2007).

Amputee soccer matches contain various instances of rapid energy expenditure similar to those of a non-amputee soccer match. As with non-amputee soccer, sprint performance is also considered to play an important role in amputee soccer. Several studies have examined aspects of anaerobic fitness of outfield players such as sprinting and jumping (Guchan et al, 2017; Miyamoto, et al, 2018; Özkan et al, 2012; Simim et al, 2013; Wiecezorek et al, 2015; Yazıcıoğlu, Taskaynatan, Guzelkucuk, & Tugcu 2007) not only the performance of the lower limbs but also of the upper limbs are important for sprinting (Miyamoto et al, 2018; Özkan et al, 2012; Wiecezorek et al, 2015).

Sprint motions, such as step length and step frequency, are generally accepted as one of the determining factors of sprint performance. In running and/or sprinting without the use of crutches, sprint speed is determined by the product of the step length and step frequency. An increase in one these factors results in an improvement in sprint speed, as long as the other factor remains unchanged or does not undergo a large decrease (Hunter, Marshall, & McNair, 2004). Even in cross country skiing, which uses poles, skiers can increase velocity by elevating cadence, increasing power (reflected in longer cycle lengths), and/or changing to a faster sub-technique (Marsland, Anson, Waddington, Holmberg, & Chapman, 2018). Step length and step frequency are expected to be important factors for determining sprint speed in amputee soccer. This however has not yet been clarified among the few studies that have thus far examined sprint motion in amputee soccer. Fujishita et al. (2018) have carried out a biomechanical analysis of single-leg running with crutches. They reported that higher running speed was associated with an increased forward tilt of the pelvis and a shorter crutch stance phase. However, their study subjects were not amputee soccer players. Furthermore, the influence of step length and step frequency on running speed has not yet been studied.

Therefore, the purpose of the present study was to clarify the relationship between sprint speed and sprint motion and to analyze sprint motion with crutches in outfield positioned amputee soccer players. We postulated that sprint motion in amputee soccer requires specific techniques as outfield players play with crutches and their natural/unaffected leg. Our study provides useful information for improving sprint speed in outfield players which may be valuable for coaches, researchers as well as players.

## Materials and Methods

### Participants

Twelve male Japanese outfield players volunteered to participate (body height,  $1.70 \pm 0.06$  m; body mass,  $63.4 \pm 9.6$  kg; age,  $42.3 \pm 4.6$  years). All participants belonged to the amateur amputee soccer team and had experience of participating in domestic competitions. The mean number of years of experience in amputee soccer was  $3.58 \pm 2.48$  years (range: 6 months to 7 years). Prior to the study, the participants received a verbal and written explanation regarding the objectives and methods of the study. Written informed consent was obtained from the participants. In addition, various cautionary instructions were verbally communicated to the participants throughout the course of study. The present study was conducted in accordance with the Declaration of Helsinki and was approved by the Research Ethics Committee of the Graduate School of Health and Sports Science, Juntendo University (approval number 28-4 at Graduate School of Juntendo University).

### Measurements of body mass and height

Body mass was measured using an electronic platform scale (HBF-215F, OMRON HEALTHCARE Co., Ltd., Japan). Body height was measured using an analog height stadiometer. Both measurements were made without participants wearing an artificial leg.

### Assessment of sprint performance

This study evaluated participants' sprint performance in a 30-m sprint test according to the previous studies (Özkan et al 2012; Wiecezorek et al, 2015). Participants ran with two crutches and

natural/unaffected leg (i.e., they did not wear an artificial leg). Participants were instructed to sprint as quickly as possible.

There are several running styles used when playing amputee soccer with crutches: 1) support from both crutches together for 1 step (1:1 ratio of crutches-to-foot contact), 2) support from both crutches together for 2 steps (1:2 ratio of crutches-to-foot contact), and 3) support from one crutch for 1 step. As a result of participant choice in running style, all participants were tested in a running style that supported both crutches together for 2 steps.

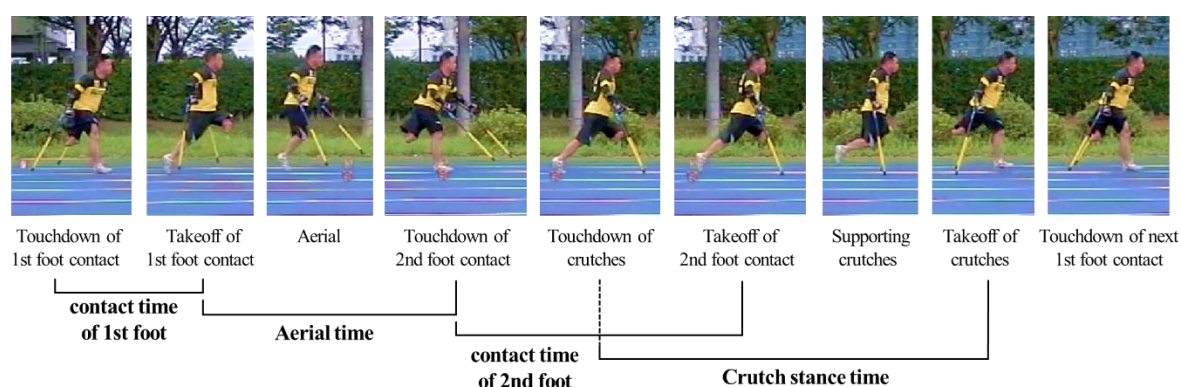
The 30-m sprint test time and times taken for each 10 m interval were recorded using electronic timing gates (TC Timing System, Brower Timing Systems, USA) located every 10 m between the start and finish lines. Sprint speed was determined from 10 m to 20 m according to the analysis of sprint motion. The fastest sprint time from two trials was used as the actual assessment time. The interclass correlation coefficient indicated a high reliability of 0.981 between the two 30-m sprint test trials.

### *Recording sprint motion*

Sprint motion was recorded using a high-speed digital video camera (EXILIM EX-F1, CASIO COMPUTER CO., LTD., Japan; frame rate, 300 fps; shutter speed, 1/1000 s; resolution, 640 × 480 pixels; light sensitivity, ISO 400; aperture, F 2.8) positioned at the sagittal plane on the healthy leg side (distance from the runway, 8 m; height, 0.85 m). The field of view spanned a total of 6 m (covering 3 m either side of a line positioned 15 m from the starting line). The high-speed camera was fixed onto a tripod such that the optical axis was perpendicular to the runway.

### *Analysis of sprint motion*

The images recorded by the high-speed video camera were used to determine the time for each foot step and crutch stance (Figure 1). Four measures for determining sprint motion were assayed. First, the contact time of the first foot was defined as the time from the touchdown of first foot following takeoff of the crutches to takeoff. Second, aerial time was defined as when neither the foot nor crutches were in contact with the ground. Third, the contact time of the second foot was defined as the time from touchdown of second foot after the aerial phase to takeoff. Lastly, crutch stance time was defined as the time from touchdown of crutches to takeoff. Each time was calculated from the number of frames in the recorded high-speed video using playback software (Quick Time Player Ver. 7, Apple Computer, USA). One running cycle was defined from the first foot contact to the next first foot contact. The frequency of one running cycle was calculated from the time required for one running cycle.

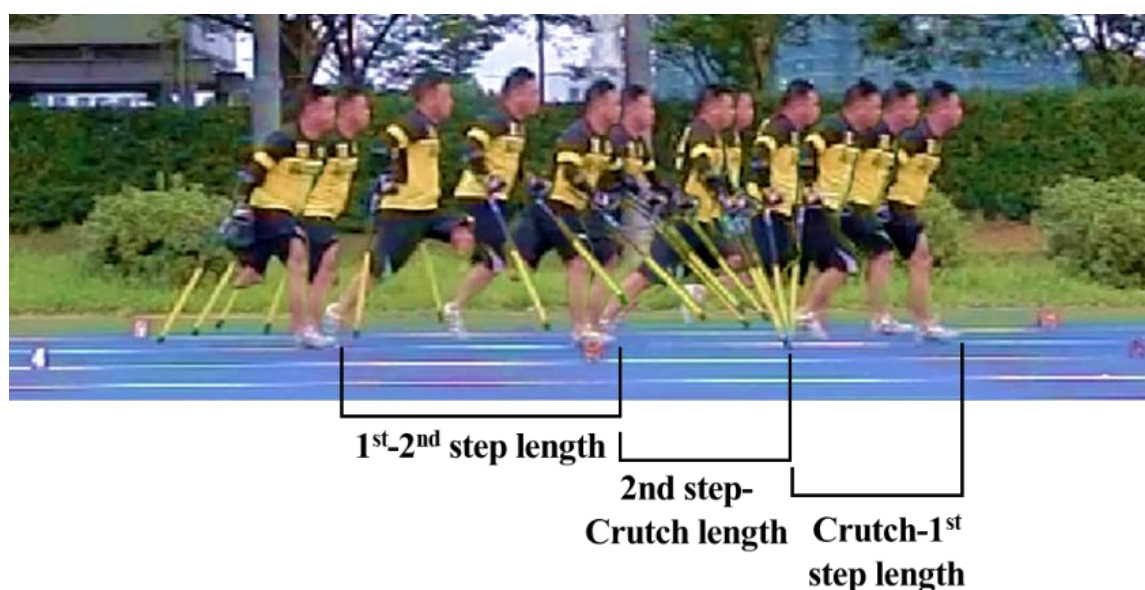


**Figure 1.** Definition of each step time

Using a kinematic analysis software (Frame-DIAS IV; DKH Inc., Tokyo, Japan), two landmarks (toe and the tip of the crutch on the camera side) were manually digitized from the images recorded by the high-speed camera (300 Hz). Two-dimensional coordinates (x and y) were then extracted. Calibration was performed according to the 2D-4Points method implemented in the kinematic analysis software. This utilized the positioning of the calibration markers placed along each side of

the runway (every 6 m along the x-axis, 2.44 m in depth; Figure 1) in order to interpolate the position of each landmark in the 2D space. The aspect ratio of the image was measured by placing a square frame (1 m × 1 m) in the center of the image. The 2D position data were smoothed using a Butterworth digital low-pass filter with a cut-off frequency of 10 Hz. To evaluate the reliability of 2D measurements via this method, the same researcher repeated the sprint motion analysis of each participant 10 times; the coefficient for variation in these data was below 3%.

Each step length was determined as follows: 1st-2nd step length: distance from the toe from the first foot contact to the second foot contact; 2nd step-crutch length: distance from the toe at the second foot contact to the tip of the crutch on the camera side at touchdown; crutch-1st step length: distance from the tip of the crutch on the camera side at touchdown to the toe at the next first foot contact (Figure 2).



**Figure 2.** Definition of each step length

### Statistical analysis

All measurement values are presented as mean  $\pm$  standard deviation. Pearson's correlation analysis and simple linear regression were used to assess the relationships between sprint speed and all other variables. All statistical analyses were performed using SPSS statistical software (SPSS Statistics, version 24.0; IBM Corp., Armonk, NY).

### Results

Table 1 shows data of measurements and the Pearson's correlation coefficients with sprint speed. The features of participants are shown below. The mean body height was  $1.70 \pm 0.06$  m (range: 1.63 m to 1.81 m). The mean body mass was  $63.4 \pm 9.6$  kg (range: 50.0 kg to 83.0 kg). The mean age was  $42.3 \pm 4.6$  years, ranging from 33 years to 50 years. The lower extremity amputation status among participants was as follows: the knee joint or above (above knee player), 9 players and below the knee joint but above the ankle (below knee player), 3 players.

The mean sprint speed was  $4.96 \pm 0.59$  m/sec (range: 3.98 m/sec to 5.68 m/sec), while the 30-m sprint test time was  $6.61 \pm 0.87$  seconds (range: 5.62 seconds to 8.09 seconds). Sprint speed was significantly and positively correlated with body mass, length and frequency of one running cycle, 1st-2nd step length, and crutch-1st step length (Table 2). Among these significant correlations, 1st-2nd step length showed the highest positive correlation with the sprint speed ( $r=0.890$ ,  $p=0.001$ ). In addition, sprint speed was significantly and negatively correlated with the time taken for each 10-m interval as well as with contact time of first foot and crutch stance time. The contact time of first foot time was significantly and negatively correlated with the sprint speed. ( $r=-0.881$ ,  $p=0.001$ ).

**Table 1.** Data of measurements and the Pearson's correlation coefficients with sprint speed

	Mean	±	SD	<i>r</i>	<i>p</i>
Sprint speed (m/sec)	4.96	±	0.59	1.000	
30-m sprint test time (sec)	6.61	±	0.87	-0.992	0.001
Time taken from 0-m to 10-m (sec)	2.48	±	0.31	-0.943	0.001
Time taken from 10-m to 20-m (sec)	2.04	±	0.26	-0.996	0.001
Time taken from 20-m to 30-m (sec)	2.09	±	0.32	-0.969	0.001
Length of one running cycle (m)	3.65	±	0.39	0.817	0.001
Frequency of one running cycle (Hz)	1.36	±	0.07	0.666	0.018
1st-2nd length (m)	1.53	±	0.19	0.890	0.001
2nd-crutch length (m)	1.06	±	0.15	0.229	0.475
Crutch-1st step length (m)	1.06		0.18	0.659	0.020
Contact time of 1st foot(sec)	0.153	±	0.022	-0.881	0.001
Aerial time (sec)	0.201	±	0.016	0.236	0.461
Contact time of 2nd foot(sec)	0.149	±	0.018	-0.490	0.106
Crutch stance time (sec)	0.254	±	0.038	-0.670	0.017
Body height (m)	1.70	±	0.06	0.034	0.917
Body mass (kg)	63.4	±	9.6	0.692	0.013
Age (years)	42.3	±	4.6	-0.362	0.248

SD, standard deviation

## Discussion

The present study analyzed sprint motion with crutches in outfield positioned amputee soccer players and attempted to clarify the relationship between sprint speed and sprint motion. Our results indicate that both the length and frequency of one running cycle are important for determining sprint speed in outfield players. In studies on running and/or sprinting without the use of crutches, sprint speed is determined using the product of the step length and frequency (Hunter et al, 2004). We show that this equation also applies when amputee soccer players are running with crutches. It can be said that length of one running cycle is particularly important ( $r=0.817$ ,  $p=0.001$ ). However, it should be noted that sprint motion with crutches includes several steps within one running cycle. The present study examined a running style that included participants being supported by both crutches together for 2 steps. In total, this running cycle included 3 steps from the first foot contact to the next first foot contact.

The results of the present study indicated a significant positive correlation of sprint speed with the 1st-2nd step length and the crutch-1st step length. Additionally, contact time of first foot and crutch stance time were significantly and negatively correlated with sprint speed. These results suggest that improving sprint speed requires increasing step length within a shorter time frame. To achieve this, anaerobic fitness would need to be at a high level. The first foot step following takeoff of the crutches, in particular, can be inferred as a determinant of muscular strength and power in the leg because the movement is similar to that in single-leg hopping. Özkan et al. (2012) reported that sprint performance was related to jump performance in an evaluation of leg muscular strength and power in amputee soccer players. In our study, the 1st-2nd step length encompassed approximately 42% of one running cycle and about 1.5 times that of the other evaluated step lengths. Therefore, the first foot step was considered particularly important for the sprint speed.

**Table 2.** Associations between the sprint speed and other variables by simple linear regression analysis

Variables	UC		SC	<i>t</i>	<i>p</i>	95% CI for Beta	
	B	SE	Beta			Lower	Upper
(Constant)	9.401	0.177		53.147	0.000	9.007	9.795
30-m sprint test time (sec)	-0.671	0.027	-0.992	-25.296	0.000	-0.730	-0.612
(Constant)	9.430	0.503		18.747	0.000	8.309	10.551
Time taken from 0-m to 10-m (sec)	-1.800	0.201	-0.943	-8.946	0.000	-2.248	-1.352
(Constant)	9.538	0.137		69.866	0.000	9.234	9.842
Time taken from 10-m to 20-m (sec)	-2.239	0.066	-0.996	-33.771	0.000	-2.386	-2.091
(Constant)	8.661	0.300		28.873	0.000	7.992	9.329
Time taken from 20-m to 30-m (sec)	-1.772	0.142	-0.969	-12.465	0.000	-2.089	-1.455
(Constant)	0.504	1.001		0.503	0.626	-1.727	2.735
Length of one running cycle (m)	1.220	0.273	0.817	4.476	0.001	0.613	1.827
(Constant)	-2.410	2.614		-0.922	0.378	-8.234	3.415
Frequency of one running cycle (Hz)	5.423	1.921	0.666	2.823	0.018	1.144	9.703
(Constant)	0.733	0.689		1.064	0.312	-0.802	2.267
1st-2nd length (m)	2.758	0.446	0.890	6.183	0.000	1.764	3.752
(Constant)	4.014	1.288		3.115	0.011	1.143	6.884
2nd-crutch length (m)	0.894	1.204	0.229	0.743	0.475	-1.789	3.578
(Constant)	2.632	0.852		3.090	0.011	0.734	4.530
Crutch-1st step length (m)	2.196	0.793	0.659	2.770	0.020	0.429	3.963
(Constant)	8.268	0.761		10.868	0.000	6.573	9.963
Contact time of 1st foot(sec)	-21.619	4.928	-0.811	-4.387	0.001	-32.599	-10.639
(Constant)	3.267	2.217		1.473	0.171	-1.673	8.208
Aerial time (sec)	8.427	10.993	0.236	0.767	0.461	-16.068	32.922
(Constant)	7.276	1.311		5.548	0.000	4.354	10.198
Contact time of 2nd foot(sec)	-15.574	8.764	-0.490	-1.777	0.106	-35.102	3.954
(Constant)	7.604	0.935		8.129	0.000	5.520	9.688
Crutch stance time (sec)	-10.400	3.645	-0.670	-2.853	0.017	-18.521	-2.279
(Constant)	4.383	5.404		0.811	0.436	-7.659	16.424
Body height (m)	0.003	0.032	0.034	0.107	0.917	-0.067	0.074
(Constant)	2.269	0.898		2.527	0.030	0.268	4.269
Body mass (kg)	0.042	0.014	0.692	3.031	0.013	0.011	0.074
(Constant)	6.927	1.610		4.302	0.002	3.339	10.514
Age (years)	-0.046	0.038	-0.362	-1.227	0.248	-0.131	0.038

UC, unstandardized coefficient; SE, Standard Error; SC, standardized coefficient; CI, confidence interval.

The present study clarified that crutch stance is also an important factor for affecting sprint speed. This finding is in agreement with that of a previous study that demonstrated that a higher



running speed was associated with a shorter crutch stance phase (Fujishita et al, 2018). Upper limb muscle strength is pertinent for determining crutch stance. For example, Miyamoto et al. (2018) reported that sprint performance was significantly and positively correlated with the number of push-ups performed within 60 seconds. Among two contrasting studies, Simim and colleagues (2016; 2018) reported that amputee soccer matches cause decreased upper limb performance, as assessed by push-up and medicine ball throwing tests. However, Wieczorek et al. (2015) reported that there was no statistically significant relationship between hand grip strength and 30-m sprint time. In general however the results from earlier studies support the importance of muscular strength and endurance in the chest, shoulder, and triceps' muscles for using crutches.

Running with crutches is a unique movement performed by outfield positioned amputee soccer players. Therefore, crutch use 'technique' is itself important. Our results show that sprint speed was significantly and positively correlated with crutch-1st step length. On the other hand, there was not such a relationship between the 2nd-crutch length and sprint speed. As such, it would be more effective to move the body further forward during the crutch stance position instead of placing crutches at a greater forward distance in an effort to improve sprint speed. This finding could be indicative of a useful technique for outfield players and coaches looking to improve sprinting speed.

We also found that body mass was associated with sprint speed. This could be influenced by the degree of amputation (above / below knee). In the present study, the mean 30-m sprint test time was 5.96 seconds for the below knee players (n=3), and 6.83 seconds for the above knee players (n=9). Body mass was higher for the below knee players (body mass;  $69.2 \pm 9.1$  kg) vs. above knee players (body mass;  $61.5 \pm 9.4$  kg). However, due to the small sample size we could not explain the influence that the degree of amputation had on our results. This should be an area of interest for future studies.

The participants in the present study were all Japanese players whose sprint ability was lower in comparison to non-Japanese players. Ozkan et al. (2012) reported that Turkish players had an average 30-m sprint test time of  $5.4 \pm 0.7$  seconds. Similarly, Wieczorek et al. (2015) reported an average of  $5.47 \pm 0.29$  seconds in Polish players. Thus, the average 30-m sprint test time in the present study (5.62 seconds) was almost 1 second slower than that in the other studies (Ozkan et al, 2012; Wieczorek et al, 2015). One contributing factor to this difference may be the age of the participants; the average age was approximately 25 years in the previous studies (Ozkan et al, 2012; Wieczorek et al, 2015) but was 42.3 years in our study. Casajus and Castagna (2007) have reported that 50-m sprint performance decreased with age, beginning at 30–40 years. Other contributing factors may be the training frequency and competitive level; the participants in the present study were amateur players. In contrast, the participants in the study by Ozkan et al. (2012) were in the Amputee Super League and trained five times/week. From these findings, sprinting ability is considered to be an important index of competitive level. It has also been noted that the number of years since amputation affects the sprint performance (Miyamoto et al 2018). For further insight, future studies should consider the background of players to better evaluate measures of sporting performance.

The limitation of the present study is the narrow scope of the participants. Future studies should strive to profile more players whilst expanding their scope and targets, because it is necessary to examine the influence due to the degree of amputation and the background of players. We expect that appropriate sprint motion may differ according to the degree of amputation and physical fitness. Moreover, running with crutches encompasses several running styles. Our study analyzed only one running style, using the support from both crutches once every two steps. We think that other styles should be examined in future studies.

### Perspectives

Amputee soccer is designed for people with disabilities such as amputations and extremity dysfunctions. Outfield players play using crutches and their natural/unaffected leg. Several studies on aspects of the anaerobic fitness of outfield players have been conducted but only a few have examined motion. Thus, the purpose of the present study was to clarify the relationship between sprint speed and sprint motion and to analyze sprint motion with crutches in outfield positioned amputee soccer players. We found that the length and frequency of one running cycle were important

for determining sprint speed. Moreover, our results suggest that improving sprint speed requires increasing the step length with a shorter time frame in the first foot step and the crutch stance. Additionally, we found that it was more effective to move the body further away during a crutch stance than to place the crutches at a greater distance forward. The technique of using crutches was not only important as the unique movement in outfield players but also contributed to players' actual sprint speed. We believe our findings will help to better understand and improve the sprint motion of outfield players and will be of value to coaches, players, and researchers.

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**Author Contributions:** Conceptualization, AM & TY; Methodology, AM & TY; Writing-Original Draft Preparation, AM; Writing-Review & Editing, MH & TY.

**Funding:** This research was funded by JSPS KAKENHI (grant number JP 16 K 16528).

**Acknowledgments:** We are grateful for the cooperation of the amputee soccer players and the NPO Japan Amputee Football Association. In addition, we thank Juntendo University for providing the research environment.

**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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