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Stroke analysis of the initial acceleration phase of the wheelchair 100-m sprint in Japanese wheelchair athletes

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Abstract: The purpose of this study was to identify the characteristics of wheelchair athletes with good records by capturing the men's T54 class 100-m race at a competition in Japan and analyzing the initial acceleration phase (from the start to 13 m), focusing on the stroke. The analysis for this study included 16 Japanese male wheelchair athletes (including 3 athletes who competed in the 100-m wheelchair race at the Paralympic Games or the World Championships) in the T54 class who competed in the 2019 Kanto Para Athletics Championships or the 2024 Japan Para Championships held in Japan. The 13-m starting section was captured from the side using a high-speed camera, and stroke analysis was performed using the two-dimensional direct linear transformation method. Significant positive correlations were observed between the 13-m time and goal time (Pearson r = 0.92; P < .001) and between the stroke number and the 13-m time (Pearson r = 0.61; P = .01). Significant negative correlations were also observed between the stroke distance and 13-m time in the 2nd, 3rd, 4th, 5th, and 6th strokes. In addition, significant positive correlations were observed between stroke distance and stroke time in the 1st, 4th, 5th, and 6th strokes. These results indicate that for the first few strokes immediately after the start, it is more important to push the hand rim forcefully to the end than to increase stroke frequency.

Keywords: Para-athletics, T54, wheelchair speed, start

Introduction

The 100-m wheelchair race is included in many wheelchair classes in para-athletics. The Paris 2024 Paralympic Games featured wheelchair 100-m races in the men's and women's T33, 34, 52, 53, and 54 classes. Wheelchair track events are divided into two classes: cerebral palsy (T30–34) and amputation/motor disability including spinal cord injury (T51–54).[1] The T54 class has many more residual functions and a better record in world records than other wheelchair classes.[2]

As in the 100-m race for able-bodied athletes, the 100-m wheelchair race requires an all-out sprint from start to finish, and maximum speed is an important factor in determining the record.[3] In the 100-m race for able-bodied athletes, maximum speed is reached at around 60 m,[3,4] but in the wheelchair 100-m race, the wheelchair speed continues to increase until the finish line.[5-7] A previous study that analyzed the 100-m sprint in Japanese male wheelchair athletes (T54 class) reported that their speed in the 90–100-m segment was 93% of their maximum speed and that they did not reach their maximum speed within 100 m.[7] It has also been reported that it is difficult for wheelchair athletes to achieve maximum power within 100 m[6]; therefore, both the magnitude of maximum speed and the distance to reach it are important factors. In other words, to achieve maximum speed within 100 m, a high speed must be achieved from the first half of the race, and acceleration immediately after the start is important.

Because the wheelchair 100-m race starts from a stationary position, the wheelchair athlete must overcome inertia and then accelerate.[5-8] Achieving high acceleration from the start requires explosive power exertion (mainly in the upper limbs) and high propulsion techniques to transfer power to the hand rim. As these components are apparent as the distance traveled in one stroke (from one hand-rim contact to the next), they can be evaluated via race analysis, which has the advantage of collecting athletes' best performance data, as they try to maximize their efforts with a high level of concentration. Although many previous studies have experimentally investigated upper extremity and trunk force exertion and propulsion techniques, few reports have analyzed them using competition race data.[6] In addition, there are few reports of race analysis during the initial acceleration phase,[8,9] which is particularly important, and the characteristics of speed changes and movements have not been fully examined. Analysis of the initial acceleration phase of the 100-m wheelchair race captured in video from competitions can therefore be used to identify the characteristics of wheelchair athletes with good records, and can be used in training to achieve maximum speed within 100 m.

The purpose of this study was to identify the characteristics of wheelchair athletes with good records by capturing the men's T54 class 100-m race at a competition in Japan and analyzing the initial acceleration phase (from the start to 13 m), focusing on the stroke. We hypothesized that there was a correlation between 13-m time and goal time and a negative correlation between 13-m time and the distance traveled in each stroke.

Methods

Subjects

The analysis for this study included 16 Japanese male wheelchair athletes (including 3 athletes who competed in the 100-m wheelchair race at the Paralympic Games or the World Championships) in the T54 class who competed in the 2019 Kanto Para Athletics Championships or the 2024 Japan Para Championships held in Japan. Data from the 2024 Japan Para Championships were used for athletes who had competed in both competitions. For athletes who had competed in the final of the Kanto Para Athletics Championships, the better time between the preliminary round and the final was used in analysis. The T54 class is the mildest disability class in wheelchair racing and is defined in the World Para Athletics[1] classification as follows: T54 class athletes usually have normal arm muscle power with a range of trunk muscle power extending from partial to normal trunk control (complete spinal cord injury at neurological level T8–S4). All analyses in this study were conducted using video data taken by the Biomechanics Support Team of the Japan Para Athletics High Performance Committee. Permission to use the video data was obtained from Japan Para Athletics. This study was approved by the research ethics committee of Takarazuka University of Medical and Health Care (approval No. 250116-1).

Data Collection and Analysis

One high-speed camera (DMC-FZ300; Panasonic, Osaka, Japan) was placed near the center of the 0–13-m section of the upper main stand of the athletic stadium (Figure 1). The high-speed camera was set to shoot at 240 fps and adjusted so the angle of view included the athletes lined up at the starting line and at the 13-m mark for all lanes. Kawabata et al[7] reported a large change in the speed curve until approximately 15 m from the start. In addition, the first hurdle of the women's 100-m hurdle is set at 13 m. Accordingly, the initial acceleration phase from the start to 13 m was used in the analysis. A two-

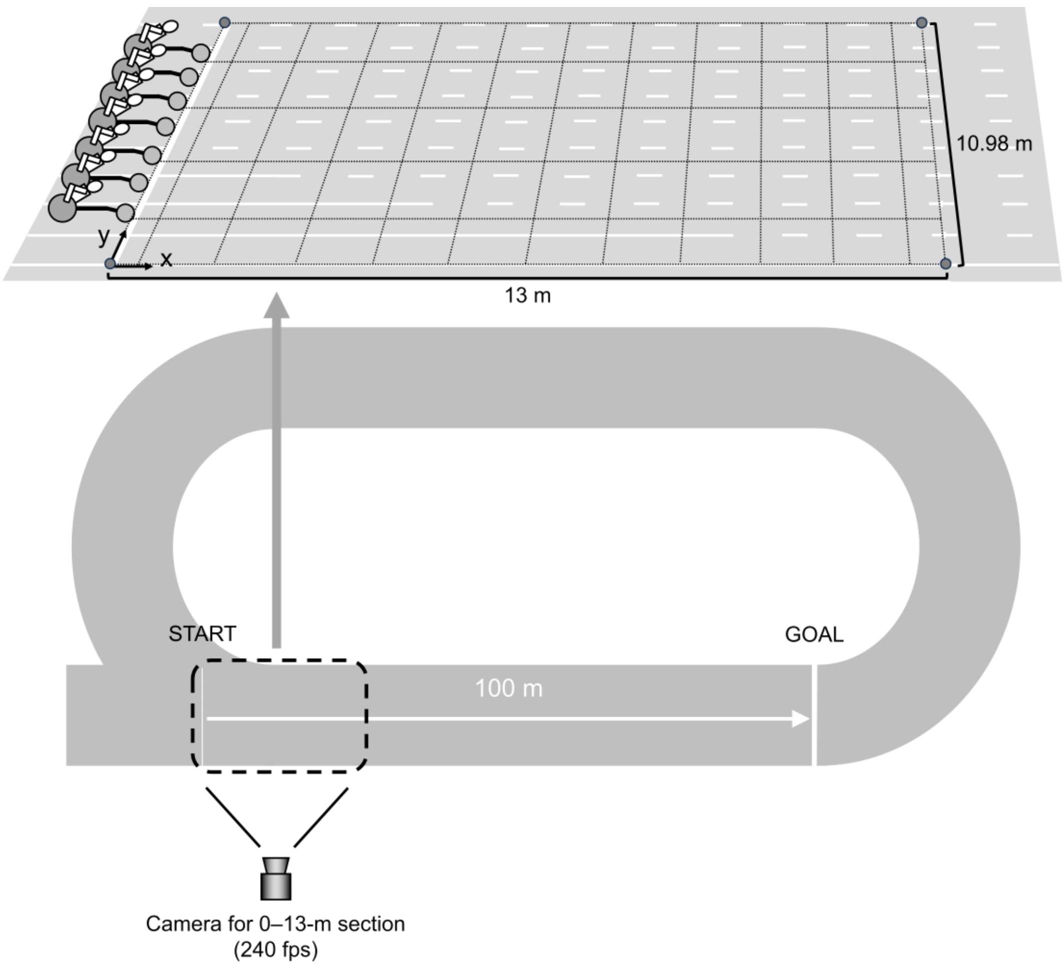

Figure 1. Camera placement and analysis area.

dimensional direct linear transformation method was used to analyze the strokes. The intersection of the start line and the outside line of lane 9 was defined as the origin, with the direction to the finish defined as the positive x-axis and the direction parallel to the start line as the positive y-axis (orthogonal to the x-axis). Motion analysis software (Frame-DIAS5; Q'sfix, Tokyo, Japan) was used to downsample the video data to 60 Hz and digitize the point of contact between the tire and the ground under the vertical of the front axle when the hand contacted the hand-rim. The reason for down sampling was that the propulsive movement was slower at the start than at maximum speed, and it was difficult to identify the hand-rim contact at 240 fps.

In general, strokes should be analyzed separately during the push and recovery phases, but we could not observe hand-rim release when the athletes were lined up at the start because their hands were hidden by adjacent wheelchairs. However, as hand-rim contact could be identified in all athletes, we decided to use strokes in the present analysis. A stroke was defined as from hand-rim contact to the next hand-rim contact, and the number of strokes was counted as the number of strokes completed, not the number of hand-rim contacts. The distance traveled in one stroke (stroke distance) was defined as the distance traveled in the x-axis direction between the hand-rim contact and the next hand-rim contact. For the 1st stroke, the negative distance from the start line to the front axle was included because the front axle at the start was behind the start line. The time required for each stroke (stroke time) was calculated by multiplying the number of frames in each stroke by seconds per frame. The 1st stroke time was defined as the time between the starting gun firing frame and the next hand-rim contact. Wheelchair speed was calculated by dividing stroke distance by stroke time. The wheelchair athlete with the lowest number of strokes up to 13 m had 6 strokes. Therefore, the correlations among 13-m time, stroke distance, and stroke time were included in the analysis up to the 6th stroke. The time to pass the 13-m mark was calculated by multiplying the number of frames from the firing of the starting gun to when the front axle of the wheelchair passed the 13-m mark by the number

Table 1. Wheelchair speed, stroke time, and stroke distance for the 1st through 6th strokes

Stroke (n=16)	**Wheelchair speed (m/s) Mean ± SD**	**Stroke time (s) Mean ± SD**	**Stroke distance (m) Mean ± SD**
1st	0.84 ± 0.12	1.07 ± 0.15	0.90 ± 0.20
2nd	2.24 ± 0.31	0.52 ± 0.04	1.17 ± 0.18
3rd	2.91 ± 0.39	0.46 ± 0.05	1.35 ± 0.21
4th	3.43 ± 0.47	0.44 ± 0.04	1.52 ± 0.25
5th	3.83 ± 0.56	0.42 ± 0.04	1.63 ± 0.32
6th	4.23 ± 0.56	0.42 ± 0.03	1.76 ± 0.31

SD: standard deviation.

of seconds per frame. Goal times were taken from the official records published by the competition.

Statistical Analysis

Data were analyzed using statistical analysis software (IBM SPSS statistics version 25; IBM, Armonk, NY, USA). Pearson's correlation coefficient was used to examine the relationship between several parameters. The level of statistical significance for all tests was set at $\alpha = 0.05$.

Results

The wheelchair athletes analyzed in this study had mean goal times of 16.87 ± 1.74 s, 13-m times of 4.37 ± 0.40 s, and number of strokes for 13 m of 8.19 ± 1.17. Table 1 shows the wheelchair speed, stroke time, and stroke distance for the 1st through 6th strokes. As the number of strokes increased, wheelchair speed and stroke distance increased, while stroke time decreased.

Figure 2 shows the relationships between 13-m time and goal time, and between stroke number and 13-m time. Significant positive correlations were observed between the 13-m time and goal time (Pearson $r = 0.92$; $P < .001$), and between stroke number and 13-m time (Pearson $r = 0.61$; $P = .01$).

Figure 3 shows the change in wheelchair speed with increasing stroke number during the 0–13-m section. The athletes with the best goal time (BGT) were approximately 1 m/s higher in the 2nd stroke and 2 m/s higher in the 5th stroke than the athletes with the worst goal time (WGT). The wheelchair speed of the 11th stroke of the athlete with the most strokes in the 0–13-m section (MOS) was lower than the speed of the 5th stroke of the BGT athlete.

Figure 4 shows the relationship between stroke distance and 13-m time in the 1st through 6th strokes. Significant negative correlations were observed between stroke distance and 13-m time in the 2nd (Pearson $r = -0.53$; $P = .04$), 3rd (Pearson $r = -0.53$; $P = .04$), 4th (Pearson $r = -0.67$; $P = .01$), 5th (Pearson $r = -0.74$; $P = .001$), and 6th (Pearson $r = -0.69$; $P = .003$) strokes.

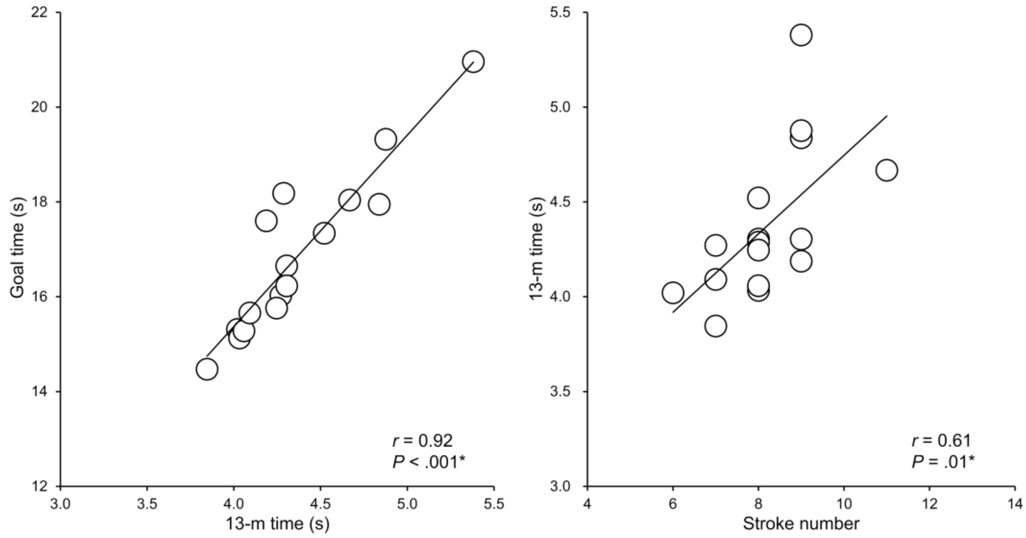

Figure 2. Relationships between 13-m time and goal time (left), and between stroke number and 13-m time (right). *$P < 0.05$.

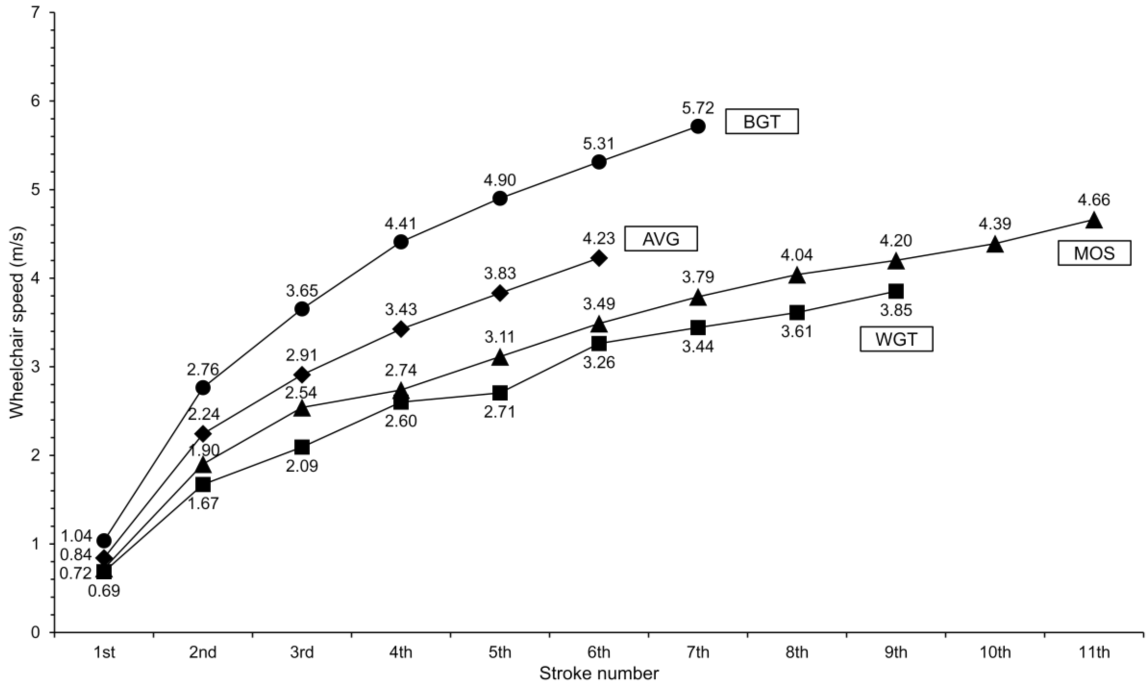

Figure 3. Change in wheelchair speed with increasing stroke number.

BGT: athlete with the best goal time, WGT: athlete with the worst goal time, MOS: athlete with the most strokes, AVG: average of all athletes.

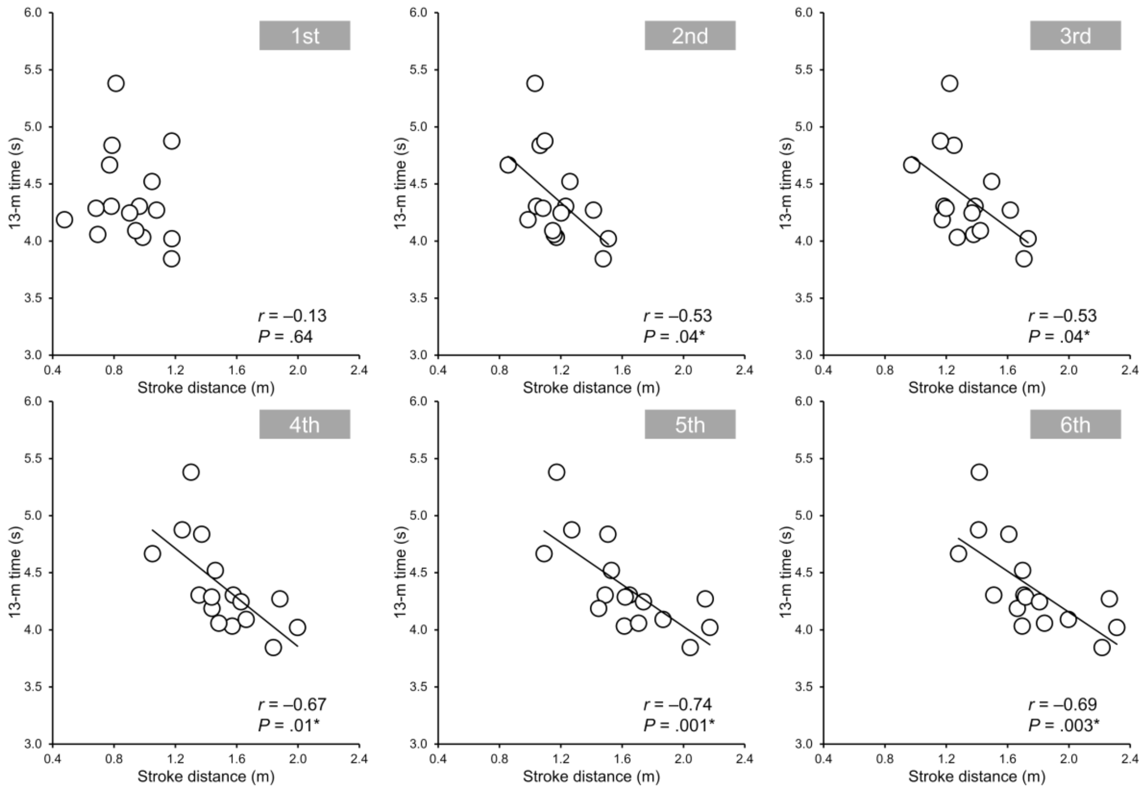

Figure 4. Relationships between stroke distance and 13-m time in the 1st through 6th strokes.

*$P < 0.05$.

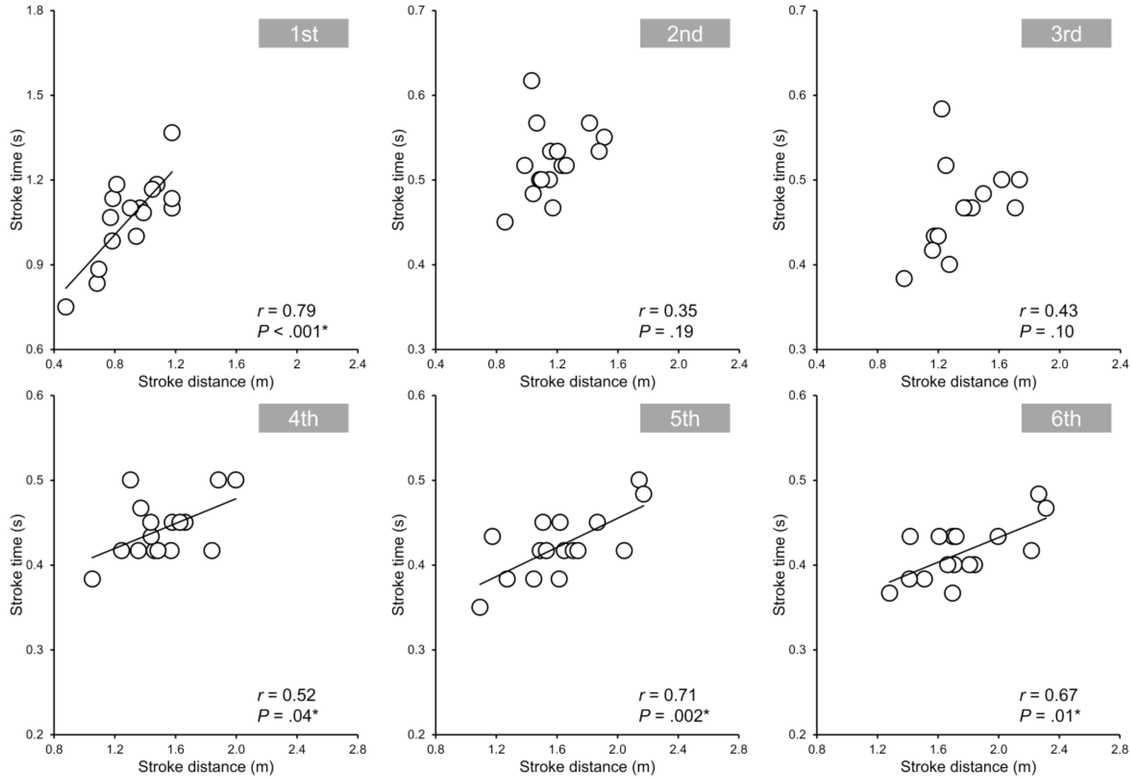

Figure 5. Relationship between stroke distance and stroke time in the 1st through 6th strokes.
*$P < 0.05$.

Figure 5 shows the relationship between stroke distance and stroke time in the 1st through 6th strokes. Significant positive correlations were observed between stroke distance and stroke time in the 1st (Pearson $r = 0.79$; $P < .001$), 4th (Pearson $r = 0.52$; $P = .04$), 5th (Pearson $r = 0.71$; $P = .002$), and 6th (Pearson $r = 0.67$; $P = .01$) strokes.

Discussion

In this study, we analyzed the initial acceleration phase (from the start to 13 m) of the men's T54 class 100-m race at a competition in Japan and identified the characteristics of athletes with good records, focusing on their stroke.

Our results showed a significant positive correlation between 13-m time and goal time. This finding means that athletes with shorter 13-m times also had shorter goal times, suggesting the importance of acceleration in the initial acceleration phase. Kawabata et al[7] reported a significant negative correlation between 100-m time and 15–20-m speed, confirming the importance of acceleration from the start, as in the present study. There was also a significant positive correlation between the stroke number and 13-m time. This result indicates that athletes with fewer strokes had shorter 13-m times, and thus a greater distance traveled per stroke. The athlete with the lowest number of strokes in this study had 6 strokes, and the BGT athlete had 7 strokes. The MOS athlete had 11 strokes and the 4th slowest goal time. These results suggest that increasing the distance traveled per stroke is better than increasing stroke frequency to gain speed during the initial acceleration phase.

Regarding change in wheelchair speed from the start, the BGT athlete increased his speed with each stroke, and by the 5th stroke was 2 m/s faster than the WGT athlete. Examination of the relationship between stroke distance and 13-m time, as well as stroke distance and stroke time, to determine the cause of the speed difference during the initial acceleration phase revealed a significant negative correlation between stroke distance and 13-m time for the 2nd through 6th strokes. In addition, a significant positive correlation between stroke distance and stroke time was found for the 1st, 4th, 5th, and 6th strokes. These results show that athletes with shorter 13-m times tended to increase the stroke distance, even if they had to increase the time of the stroke. Although we could not examine the push phase time or recovery phase time in this study, Moss et al[9] reported a high percentage of push phase time up to the 1st and 2nd strokes. The 1st stroke, in particular, must overcome inertia because it starts from a stationary position. Therefore, to accelerate the wheelchair immediately after the start, it is necessary to increase the impulse to the hand-rim. These findings suggest that the present athletes with shorter 13-m times may have been making movements that applied large forces to the hand-rim for as long as possible in the 1st and 2nd strokes in order to increase the impulse. However, this study analyzed a small number of Japanese male wheelchair athletes, and the existence of athletes who exhibit high acceleration at high pitches cannot be denied. To generalize our findings, it will be necessary to perform analysis using more data, including those from international competitions.

No significant correlation was found between stroke distance and 13-m time in the 1st stroke, or between stroke distance and stroke time in the 2nd and 3rd strokes. The former may be related to the position of the hand on the hand rim at the start, and the latter to the reproducibility of the contact position for athletes with low propulsion technique. The present study was unable to determine the factors for which no correlation was found. Further detailed investigation is necessary to elucidate these factors.

Moss et al[9] reported that stroke time decreases with increasing strokes, and that after the 5th stroke, stroke time is approximately the same. They also reported that the decrease in stroke time is due to a decrease in push phase time, with push phase time and recovery phase time being approximately equal in percentage. Similar to the report by Moss et al,[9] the present athletes also showed a decrease in stroke time with an increase in the number of strokes. In other words, to accelerate the wheelchair during the initial acceleration phase, a large amount of force must be transmitted to the hand-rim in a limited amount of time, which requires training for explosive power. As the triceps (push phase) and pectoralis major (late recovery phase to early push phase) muscles have been reported to be active during the push phase,[10,11] explosive power training using these muscle groups would be effective.

Regarding improvement of wheelchair acceleration during the initial acceleration phase, training focused on the acceleration phase is clearly important, but training focused on maximum speed might also be effective. Chow and Chae[5] and Kawabata et al[7] reported that athletes with higher wheelchair speeds at the finish line were already faster than others from the start. In other words, increasing the maximum speed may increase the speed of the initial acceleration phase. Based on these considerations, it would be necessary to train not only to increase the speed in the initial acceleration phase, but also to increase the maximum speed in parallel.

Wind speeds during each race at the Kanto Para Championships were +2.7 m/s for the first heat in the preliminary round and +1.7 m/s in the final (there were no athletes to analyze for the second heat in the preliminary round), and –1.5 m/s for the Japan Para Championships final (no preliminary round). The mean 13-m times analyzed in the present study were 4.34 s for the Kanto Para Championships (first heat in the preliminary round and final) and 4.40 s for the Japan Para Championships (final). Although it is difficult to compare 13-m times due to the effect of wind speed because different athletes competed in these two competitions, the data analyzed in our study were in the low-speed range of the initial acceleration phase and the athletes' propulsive movements were in a forward leaning posture, which suggests that the effect of wind speed was small. However, wind speed may possibly have affected the analyzed data, and this is a limitation of this study. When analyzing data from multiple competitions, it would be desirable for the conditions (e.g., weather, temperature, wind speed) to be the same whenever possible.

Conclusion

In the initial acceleration phase of the 100-m wheelchair sprint, shorter 13-m times were associated with longer stroke distances, which, in turn, were linked to longer stroke times. We concluded that for the first few strokes immediately after the start, it is important to push the hand rim forcefully to the end, rather than to increase stroke frequency. Because we were unable to include international wheelchair sprinters in our analysis, our data cannot be generalized. The inclusion of world-class data would be of great interest to many coaches and athletes. In future work, it will be necessary to collect data from world-class wheelchair sprinters to further evaluate the contribution of stroke in the initial acceleration phase.

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Author contributions

Study design: KK; Data collection: KK, TT, KW, MS, TT, TU, KF; Data analysis: KK; Writing – original draft preparation: KK; Writing – review and editing: TT, KW, MS, TT, TU, KF, RH. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest with respect to the research, authorship, and publication of this article.

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