

Original Research

Effects of step switching on sprint speed and step rate in women's 400 m hurdles

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Abstract: The 400 m hurdles are considered a highly strategic event, where the step strategy (e.g. step switching (SS)) during the race has a significant effect on performance. However, many studies have focused on men's 400 m hurdles, and fewer studies are available on the women's equivalent. Therefore, the purpose of this study was to determine the effects on sprint speed and step rate before, during, and after SS in Japanese women's 400-m hurdle races. Data from 41 races of 19 Japanese athletes were analyzed. Race data were obtained from publicly available internet broadcasts. A one-way repeated measures ANOVA and post-hoc analyses were used to compare the step rate with three sections (before, during and after step switching). The step rate was found to be significantly higher during SS compared with both before and after SS ($p < 0.05$). The rate of change in sprint speed was significantly higher during SS than after SS ($p < 0.001$). These results indicate that SS contribute to stalling during women's 400 m hurdle races, which might be a strategy that significantly influences performance.

Keywords: step switching; hurdle; sports performance; race strategy; running; track and field

1. Introduction

Among track and field events, the 400 m hurdles are considered a highly strategic event, where in addition to sprinting ability and hurdling technique, step strategy (e.g., adding one stride between hurdles) is considered an important

performance factor (Morioka et al., 2005; Morioka et al., 2000; Iskra & Čoh, 2012; Iskra et al., 2021; Kakehata, Kanosue, & Iso, 2019; Pietrzak & Iskra, 2016; Schiffer, 2012). In 2022, Iskra et al. (2022) performed a race analysis to investigate changes in race strategy over time in the World Championships' 400 m hurdles from 2013–2021. The results revealed that



from 2017–2021, performance improved compared with that observed during 2013–2016, with a decrease in the number of steps in the latter half of the race. In addition, the ability to maintain stride patterns (i.e. stride rhythm) is considered crucial in 400m hurdles (Iskra et al., 2021). Within this context, “step switching (SS)” (changes in stride pattern) during the race plays a significant role. However, stalling may be attributed to SS in the race. Hase et al. (2023) compared the time loss rate between the hurdle section in which SS was implemented and the next hurdle section. The results showed that the section where the SS was implemented had a significantly higher time loss rate than the next hurdle section. Therefore, SS may affect the occurrence of stalling during the race.

There have been fewer studies on the race analysis of women’s 400 m hurdles than on men’s races. Many previous studies have focused on analyzing men’s races (Iskra et al., 2021; Iskra, Marcinów, & Walaszczyk, 2022; Ditroilo & Marini, 2001; Hase et al., 2023). Women’s 400-m hurdles is a newer event than the men’s race and was held for the first time as an official international event at the 1983 World Championships (Schiffer, 2012; Guex, 2012). Furthermore, while many studies have focused on the number of steps between hurdles (Pietrzak & Iskra, 2016; Guex, 2012), the effects on sprint speed and step rate in hurdle sections before, during, and after SS remain unclear. Most analyses of women’s 400 m hurdle races have compared races using inter-individual analyses, with very few studies comparing race strategies intra-individual analysis. Therefore, the purpose of this study was to determine the effects on sprint speed and step rate before,

during, and after SS through an analysis of Japanese women’s 400 m hurdle races. In this study, we also aimed to analyze intra-individual strategies and compare the changes in sprint speed, step rate, and number of steps during the race concerning performance. As in the men’s race, the rate of decrease in sprint speed may be higher during SS than during the next section of the race. We also hypothesized that the number of steps would increase in races with bad performance (BP) compared with those with good performance (GP).

2. Materials and Methods

Participants - The analysis was based on participants who ran within the qualifying time (60.00 s) women’s 400-m hurdles for the five Japan Grand Prix Series in 2021. The relevant events consisted of 41 races in which 19 participants competed. The mean best recorded time for the 19 participants was 58.56 ± 0.82 s. Table 1 indicated the time, number of steps, and sprint speed in each section recorded when the participants achieved their best performance in the specified competition (Table 1). Of the 19 participants, 10 recorded two or more races within the five analysed Grand Prix Series. We defined the GP and BP for participants competing in multiple races. Among the participants in two or more races, the race with the shortest race time (i.e. best performance) was defined as the GP, while the race with the longest race time (i.e. worst performance) was defined as the BP. The mean race time for GP and BP was 58.16 ± 0.77 s and 58.89 ± 0.86 s, respectively.

Step switching (SS) - All participants ($n = 19$) ran between hurdles, taking 15–19 steps, and the total number of SS for all participants

was 37 times. To ensure consistent comparison, two types of SS events were excluded from the analysis:

- SS in which the number of steps increased by two or more steps ($n = 1$)
 - SS occurring in the H9–H10 section ($n = 4$), as there was no subsequent section for comparison
- There were eight from 15 to 16 steps, 17 from 16 to 17, five from 17 to 18, and two SS from 18 to 19 steps.

Procedures - This study analysed races using internet broadcast videos, as done in previous studies (Hobara et al., 2016; Hobara, Kobayashi, & Mochimaru, 2015; Otsuka & Isaka, 2019; Salo et al., 2011). Data for this study were obtained from publicly available internet broadcasts. All internet broadcast videos showed the flash of the starting pistol. The video images obtained from the races were analysed using video playback software (QuickTime for Windows 7.7.9, Apple Inc., Cupertino, CA, USA).

The section from the start to the first hurdle was defined as S-H1, each subsequent hurdle section was defined as H1-H2...H9-H10, and the section from the tenth hurdle to the finish line was defined as H10-G (Fig. 1).

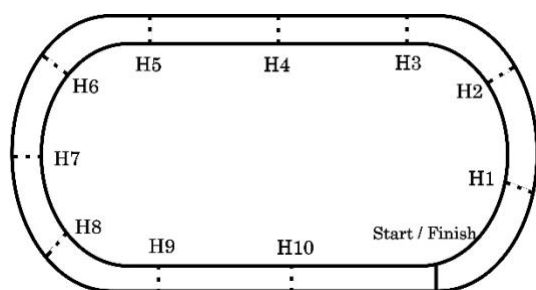


Figure 1. Hurdle section definition

The hurdle section during which the SS took place (the section in which the number of steps (n steps) increased from the previous section) was denoted as “switch”

while the hurdle sections before and after the switch were denoted as “switch-1” and “switch+1,” respectively. Fig. 2 shows the section definitions when the number of steps changes from n to $n+1$.

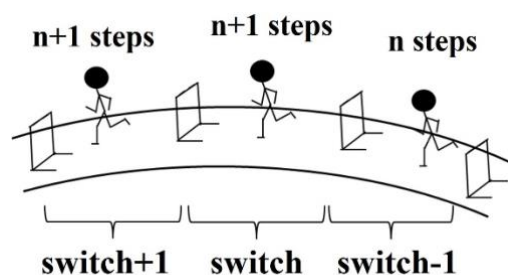


Figure 1. Definition of “switch+1,” “switch,” and “switch-1”

Measures - The sprint speed (m/s) was calculated by dividing the time required from the touchdown of the lead leg immediately after hurdle clearing to the touchdown of the lead leg immediately after the next hurdle cleared by the distance of the section (S-H1: 45 m; each hurdle section: 35 m; H10-G: 40 m). The step rate (Hz) was calculated as the number of steps divided by the elapsed time in the section, from the grounding of the trailing leg immediately after touchdown to before the touchdown of the next hurdle. In other words, the sections included only running and excluded hurdling time. The number of steps was calculated from the touchdown of the lead leg immediately after clearing the hurdle to the grounding of the trailing leg immediately before the touchdown of the next hurdle. The rate of change in sprint speed (s) (%) was calculated from switch-1 to switch using the below equation. The same principle was used to calculate the rate of change from switch to switch+1.

Rate of change in sprint speed from switch-1 to switch:

$$(1) \text{ Rate of change (\%)} \\ = \frac{(s_{\text{switch}} - s_{\text{switch-1}})}{s_{\text{switch}}} \times 100$$

Equation (1)

Where: s ; sprint speed (m/s) (%)**Table 1.** Spatiotemporal variables in competition

	S-H1	H1-H2	H2-H3	H3-H4	H4-H5	H5-H6	H6-H7	H7-H8	H8-H9	H9-H10	H10-G
Time (s)	6.74 ±0.13	4.48 ±0.11	4.58 ±0.10	4.69 ±0.10	4.86 ±0.11	5.01 ±0.09	5.15 ±0.14	5.30 ±0.14	5.47 ±0.13	5.67 ±0.13	6.61 ±0.21
Number of steps		15.68 ±0.57	15.74 ±0.55	16.00 ±0.73	16.21 ±0.69	16.58 ±0.67	16.89 ±0.72	17.21 ±0.77	17.42 ±0.82	17.63 ±0.93	
Sprint speed (m/s)	6.68 ±0.13	7.81 ±0.19	7.65 ±0.17	7.47 ±0.16	7.20 ±0.17	6.99 ±0.13	6.80 ±0.18	6.61 ±0.17	6.40 ±0.15	6.18 ±0.15	6.06 ±0.19

Mean ±SD. Abbreviations: SD, standard deviation.

2.6. Statistical analyses

The Shapiro–Wilk test for normality revealed that 48 of 66 variables (sprint speed, step rate, steps, and rate of change) were normally distributed ($p > 0.05$). A one-way repeated-measures analysis of variance (ANOVA) was used for all SS prior to testing for differences in the mean sprint speed and step rate for switch-1, switch, and switch+1. Post-hoc analyses were conducted using the Bonferroni correction when a main effect between tasks was observed. A paired t-test was used to compare the rate of change in sprint speed from switch-1 to switch and from switch to switch+1. For the GP and BP intra-individual race comparisons, tests of the means of sprint speed from start to finish (2 conditions × 11 sections) and step rate and number of steps from H1-H10 (2 conditions × 9 sections) were performed using a two-way repeated measures ANOVA. Post-hoc analyses were conducted using the Bonferroni correction when a main effect between tasks was observed. A probability level of $p < 0.05$ was used to detect statistical differences for all measures. SPSS version 27 (IBM Inc., Armonk, NY, USA) was used for all statistical analyses.

3. Results

Sprint speed and step rate for switch-1, switch, and switch+1 - We found a main effect of the section factor on sprint speed ($F(2, 62)$

$= 404.65$, $p < 0.001$). Post hoc testing revealed significant differences in sprint speed between all sections, with a gradual decrease from switch-1 to switch and switch ($p < 0.05$) (Fig. 3).

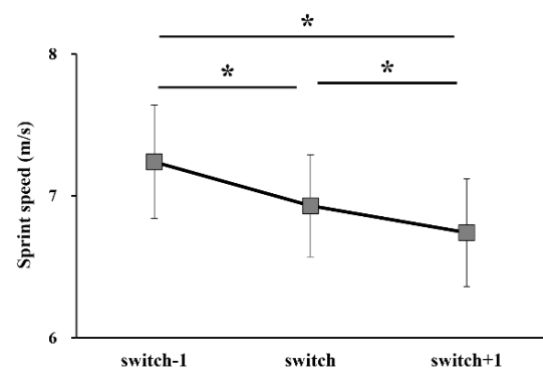


Figure 3. Change in sprint speed for switch-1, switch, and switch+1; * $p < 0.05$

A one-way ANOVA was also conducted for the change in step rate in the switch-1, switch, and switch+1 sections, and a main effect of the section factor was found ($F(2, 62) = 77.50$, $p < 0.001$). Post-hoc testing revealed a significantly higher step rate during switch compared with both switch-1 and switch +1 ($p < 0.05$) (Fig. 4).

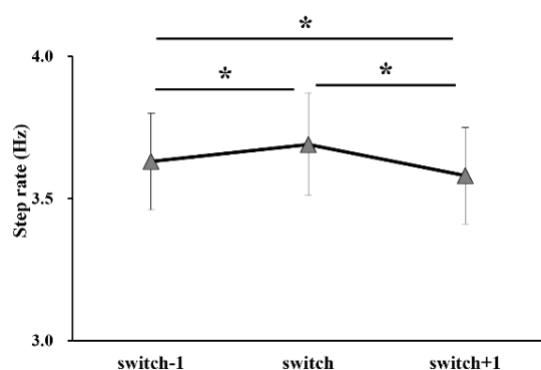


Figure 4. Change in step rate for switch-1, switch, and switch+1; * $p < 0.05$

Rate of change in sprint speed - The rate of change in sprint speed from switch-1 to switch was significantly greater (more negative) than that from switch to switch +1 ($t(31) = -3.66$, $p < 0.001$, $d = -0.65$) (Fig. 5).

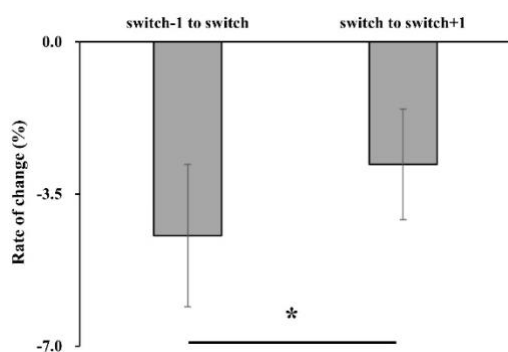


Figure 5. Rate of change in sprint speed from switch-1 to switch and from switch to switch+1; * $p < 0.05$

Comparison of intra-individual BP and GP - Using race data from 10 participants who competed in multiple races, a two-way ANOVA was used to test the difference in mean sprint speed from start to finish between GP and BP, and a significant condition $\times$ section interaction was found ($F(10, 90) = 4.26$, $p < 0.001$). Post-hoc testing between individual races showed that in the H8-G section, BP races had a significantly lower sprint speed than GP races ($p < 0.05$) (Fig. 6).

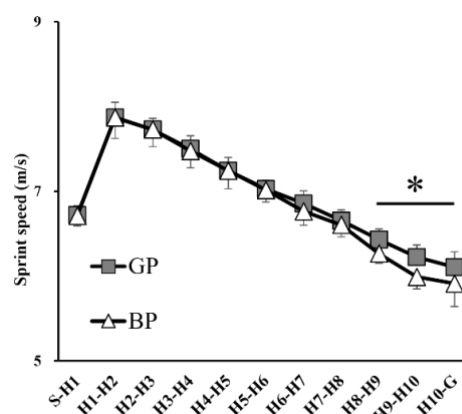


Figure 6. Variation in sprint speed in BP and GP races

In the analysis of mean step rates (nine sections from H1 to H10), we found a significant condition $\times$ section interaction ($F(8, 72) = 2.24$, $p = 0.034$). Post-hoc testing between individual races showed that the mean H7-H10 step rate was significantly lower ($p < 0.05$) in BPs than in GPs (Fig. 7).

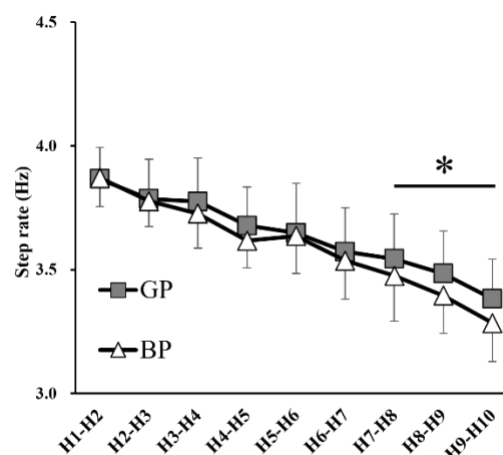


Figure 7. Variation in step rate in BP and GP races

As for the mean number of steps (nine sections from H1 to H10), there was a significant main effect of the section factor; conversely, we found no significant main effect of condition (condition, $F(1, 9) = 0.03$, $p = 0.876$; sections, $F(8, 72) = 38.04$, $p < 0.001$), and there was no significant condition $\times$ section interaction ($F(8, 72) = 1.15$, $p = 0.340$).

(Fig. 8).

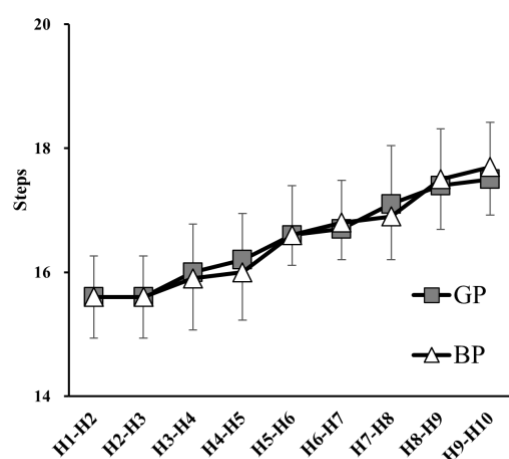


Figure 8. Variation in steps in BP and GP race

A significant difference in sprint speed between BP and GP was observed from H8 to the finish (Fig. 6). Thus, a comparison was made of the number of SS during H8–H10. The results revealed that the number of SS in H8-H10 was significantly higher in BPs than GPs ($t(9) = -2.45$, $p = 0.037$, $d = -0.05$) (Table 2).

Table 2. Number of SS in H8-H10

Participants	GP	BP
A	1	1
B	0	1
C	0	0
D	0	0
E	1	1
F	0	1
G	0	1
H	0	1
I	1	1

J	0	0
Mean	0.30	0.70
SD	0.48	0.48
P	0.037	

Abbreviations: GP, good performance; BP, bad performance; SD, standard deviation. H8-H10: Hurdle section from 8 to 10

4. Discussion

Sprint speed and step rate during switch-1, switch, and switch+1 - Changes in speed between hurdle sections due to SS showed that the fastest section was switch-1, followed by switch and switch+1, with significant differences between all sections. Speed has been reported to decrease from H1-H2 to the finish line during the 400 m hurdles event (Morioka et al., 2000; Ditroilo & Marini, 2001; Iskra et al., 2021; Guex, 2012; Graubner & Nixdorf, 2011). In line with a previous study, the races of Japanese women 400 m hurdles included in this study showed an increase in sprint speed from the start to H1-H2, followed by a continuous decrease until the finish line (Fig. 6). In addition, all SS in the present study occurred after H2-H3. The factors that cause decreasing speed may be influenced by physiological mechanism such as muscle fatigue and a decrease in creatine phosphate, as well as running mechanics changes such as a decrease in step length and step rate (Graubner & Nixdorf, 2011; Hirvonen et al., 1992). Therefore, the changes observed in this study, in which sprint speed decreased gradually from switch-1 to switch and then to switch +1, might be affected the decrease in sprint speed that occurs after H1-H2 in the entire races.

In contrast, the step rate was higher during switch, followed by switch-1 and switch+1, with significant differences between all sections (Fig. 4). Similar to a previous study of men's 400 m hurdle races (Hase et al., 2023), the results of the present

study revealed that switch+1 had a significantly lower step rate compared with switch. The step rate during switch+1 was significantly lower than during switch-1, a trend not observed in the men (Hase et al., 2023). Sprint speed is the product of step length and step rate (Hay, 1993; Hunter, Marshall, & McNair, 2004). Therefore, it is conceivable that switch section with a decreased step length increase the step rate to maintain sprint speed. However, in the next hurdle section, the step rate could not be maintained. In other words, the decrease in step length and step rate due to an increase in the number of steps might be affected to a decrease in sprint speed.

Rate of change in sprint speed according to the SS - In this study, we tested the hypothesis that the rate of decrease in sprint speed would be greater in switch than in switch+1. The results revealed that the rate of decrease in sprint speed was significantly higher for the switch section than for the switch+1 section (Fig. 5), thereby supporting this hypothesis. The results of the present study align with those of Hase et al. (2023), which showed that in men's 400 m hurdles, the section where the SS was implemented had greater stalling than the next section in which the SS was not implemented (Hase et al., 2023). In addition, as in previous studies (Ditroilo & Marini, 2001; Hase et al., 2023; Iskra et al., 2021), SS might be affected a decrease in sprint speed. However, race strategies that delay or reduce the number of SS require high skill and must be introduced carefully (Otsuka & Isaka., 2019), taking into consideration the characteristics of the athletes and their race patterns (Iskra et al., 2021). Therefore, although a race strategy that reduces the number of times SS is performed is recommended, when SS is unavoidable, it is important to increase the step rate during switch+1 to limit the loss in speed.

Comparison of race strategies among individuals - We tested the hypothesis that BP

rates may have an increased number of steps compared with GP races. However, the results of this study showed that there was no significant difference in the number of steps between GP and BP races; conversely, there was a significant difference in step rate. Therefore, this hypothesis was not confirmed.

Overall sprint speed gradually decreases during the latter half of the race due to fatigue, and our results indicate that the most significant stalling occurs in the final 100 meters – approximately the last quarter of the race – particularly between H8-H9 and the finish line (Fig. 6). The time spent in the last half of the race affects race performance more than in the first half of the race (Iskra & Čoh, 2012; Iskra, Marcinów, & Walaszczyk, 2022; Ditroilo & Marini, 2001; Otsuka & Isaka, 2019). Therefore, this suggests that the performance difference between BP and GP is especially sensitive to fatigue-induced declines in sprint speed during the last quarter of the race. Consequently, strategies aimed at preserving sprint speed in the final 100 meters may be crucial for competitive success.

A comparison of the number of steps in the GP and BP groups showed no significant differences. In contrast, a comparison of step rates showed that the H7-H10 step rates were significantly lower in the BP than in the GP races (Fig. 7). Sprint speed is defined as the product of step length (i.e. steps) and step rate (Hay, 1993; Hunter, Marshall, & McNair, 2004). In other words, within-participant performance differences were found to be in the sprint speed during the last quarter of the race, to decrease/increase in the step rate. In addition, 3 out of 10 participants in GP races performed a SS, whereas 7 out of 10 participants in BP races executed a SS during H8-H10 (Table 2), when a significant difference in sprint speed was observed. Thus, the switch section had a significantly higher rate of decrease in sprint speed than the switch+1 section (Fig. 5). During switch, the step rate temporarily

increased, but at the next hurdle section, the step rate significantly decreased to a value lower than that of switch-1 (Fig. 4). These results suggest that the decrease in sprint speed owing to the decrease in step rate in the last quarter of the race may have been influenced by SS.

5. Practical Applications.

The results of this study will be useful to coaches and sports scientists in developing a race strategy for the women's 400 m hurdle races. SS is one of the race strategies used by many athletes. In this study, it was found that SS increased the rate of decrease in sprint speed and decreased the step rate. Conversely, it is necessary to consider that SS may have both a strategic adaptive aspect and an inevitable aspect due to fatigue. In this study, it was revealed that athletes performed SS even in a fatigued state to maintain sprint speed, temporarily increasing their step rate (Fig. 4). Additionally, SS in the last 100 meters, as observed in BP races, may further exacerbate the decline in sprint speed (Table 2). However, race strategies that delay or reduce the number of SS require high skill and must be introduced carefully (Otsuka & Isaka, 2019), taking into consideration the characteristics of the athletes and their race patterns (Iskra et al., 2021). Therefore, SS should be considered as both a partial strategic adaptation and an unavoidable consequence of fatigue.

One limitation of this study is that the interval before and after SS was used as the basis for comparison. As the timing of SS differed among the athletes, the fatigue state differed greatly and may have affected the results. In the future, it will be necessary to analyse data from more athletes and include the timing of SS as a factor. The possibility that SS are unavoidable due to fatigue must also be considered. Therefore, race strategies to reduce the implementation of SS should be determined and implemented by coaches

and athletes, taking into account a variety of factors, including athletes' physical characteristics and race patterns.

6. Conclusions

The purpose of this study was to clarify the changes in sprint speed and step rate during and after SS by analysing women's 400 m hurdle races in Japan. In addition, we compared changes in sprint speed, step rate, and number of steps in GP and BP races within individuals. The main findings of this study are as follows.

- (1) The step rate was highest during the switch section, followed by the switch-1 and switch+1 sections, with significant differences between all sections.
- (2) The rate of decrease in sprint speed was significantly higher in the switch section than in the switch+1 section, in which the participants sprinted using the same number of steps.
- (3) Sprint speed in the last quarter of the race was significantly lower in BP races than in GP races. This was not due to the number of steps taken but because of the step rate.
- (4) These results indicate that SS contribute to stalling in women's 400 m hurdles and is a strategy that significantly influences performance.

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Conflicts of Interest: The authors declare that there is no conflict of interest.

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