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The Difference in Gait Regulation Strategies Between Successful and Failed Pole Vault Performance

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Abstract: This study aimed to investigate the difference in gait regulation strategy of pole vault approach runs between successful and failed trials. Five male junior pole vaulters completed full vaulting to 90%-95% personal best height. These trials were categorized into successful and failed trials. Step length and the distance from toe to the planting box were obtained using a two dimensional direct linear transformation procedure. In successful trials, standard deviations of the toe-box distance (SDTB) at the last step and take-off of were significantly smaller than those of failed trials ($P < 0.05$). We observed a clear difference in gait regulation strategy between successful and failed trials, thereby suggesting that to minimize the fluctuations of the toe-box distance immediately before the take-off is a key gait regulation strategy for successful pole vault performance.

Key words: Approach run, adjustment, accurate, pole vault.

1. Introduction

In the pole vault event, athletes transform kinetic energy obtained from the approach run into potential energy using the vaulting pole [1-3]. It been reported that the vaulting height and approach run velocity was moderately correlated (r = 0.69) among male pole vaulters [4]. In the meantime, pole vaulters must adapt another essential task: accurate and constant position of take-off [5]. As they pointed, it is evident that faster run ups will be useless if the positional requirements for the take-off are not fulfilled at the end of the approach run. The vaulters, therefore, meet two conflicting requirements for successful vaults: (1) to achieve the horizontal velocity of the approach run as large as possible, and (2) to obtain very accurate take-off position at the end of the approach run. Hay defined that to adjust of step length in order to fulfill these requirement as “gait regulation strategies” [6].

To date, gait strategies during the approach run gathered scant attention from researchers. Hay reported the variability of the horizontal toe positions during last 5-7 steps of the approach run in final of men’s pole vault event at 1984 Olympic Games. He demonstrated that these finalists used a gait regulation strategy similar to that of long jumpers [7]. However, as he also mentioned at the end of his report that the filming procedure used for that study seems not adequate for detailed biomechanical analysis, questions for the accuracy of the data has been still left opened. Tamura et al. modified the Hay’s procedure and analyzed the approach run steps of male pole vaulters during competition. They found that the higher performance group started to decrease their variability of the distance from toe to the planting box earlier than the lower performance group [8]. However, as the outcomes of their previous study included successful and failed trials, more representative characteristics of successful trials might be obscured. To clarify successful gait regulation strategy, it is necessary to evaluate the gait regulation aspects separately for success and failed trials. Thus, we hypothesized that there exists a distinctive difference for the timing to start the gait regulations between successful and failed trials. Therefore, the

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purpose of this study was to reveal the difference in gait regulation strategy between successful and failed trials in pole vault.

2. Methods

The subjects were five male junior pole vaulters (15.8 ± 3.3 yrs, 169.0 ± 5.2 cm, 53.8 ± 8.4 kg, and personal best record 3.58 ± 0.44 m). Before experiment, we obtained the written agreement from all the subjects for the participation of the current study. Each subject asked to conduct 11-12 full vaulting trials to a rubber crossbar for practice set 90%-95% of personal best record. All the vaulters took enough rest between the trials to minimize the effect of fatigue.

The vaulter’s approach run was videotaped using three high-speed digital cameras (Exilim EX-FC160S, Casio, Japan) operating at 120 fps. These cameras were set at the top level of spectator’s stand with even intervals. Reference makers were placed at 2 m intervals on both sides of the runway.

Experimental trials were categorized into successful or failed trials by the following definitions. Successful trials were defined as the trials, in which the vaulters cleared the height without touching or a slight touch with the crossbar. Failed trials were defined as the trials, in which the vaulters clearly hit the crossbar or failed to swing up their body to the height of the crossbar.

A digitizing system (Frame-DIAS Ⅳ, DKH, Japan) was used to digitize manually the tips of left and right toes throughout the approach run. Their two dimensional coordinates were obtained using a two dimensional direct linear transformation method [9]. The given two dimensional coordinates were digitally smoothed using a fourth-order low-pass Butterworth filter with a cut off frequency of 6 Hz.

Step lengths and the horizontal distances from the toe to the planting box (toe-box distance) were computed in each step throughout the approach run. Then, the standard deviations of step lengths (SDSL) and those of the toe-box distances (SDTB) were compared between the successful and failed trials. Comparisons were made between the successful and failed trials for these parameters using paired t-tests and the level of significance was set at $P < 0.05$.

3. Result

Fig. 1 shows the average SDTB patterns between successful and failed trials. The successful trials consistently showed smaller SDTBs than those of the failed trials.

Fig. 2 shows the average SDSL patterns in the last 6 steps between the successful and the failed trials. It can be seen that the failed trials tend to have larger SDSLs at the last step.

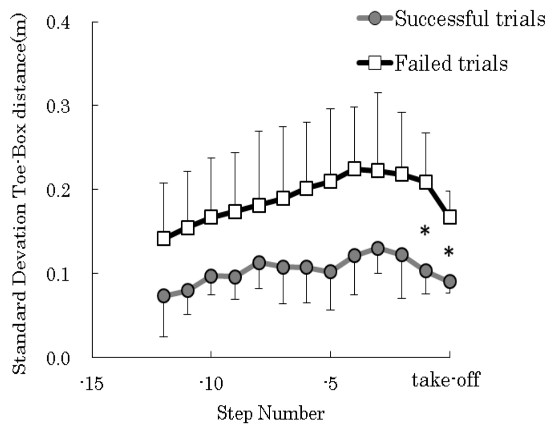

Fig. 1 Changes in the SDTB during approach run between the successful trials (*n* = 5) and the failed trials (*n* = 5).

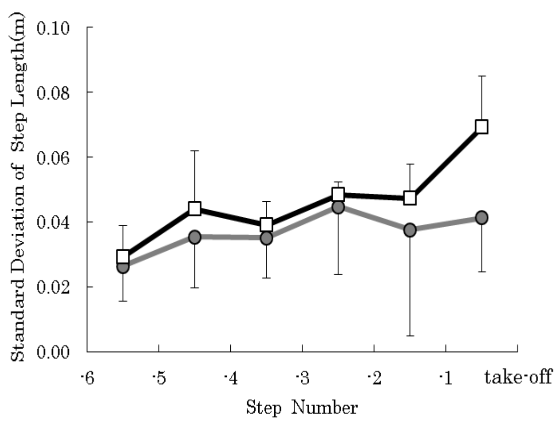

Fig. 2 Changes in the SDSL during approach run at the just prior to take-off between the successful trials (*n* = 5) and the faild trials (*n* = 5).

Table 1 Comparison of regulation gait between the successful and failed trials.

subject		$SDTB_{max}$ (m)	$SDTB_{smax}$ (steps)	$SDTB_{last}$ (m)	$SDTB_{TO}$ (m)	$SDSL_{last}$ (m)
A	successful	0.08	-3	0.08	0.08	0.05
	failed	0.33	-3	0.26	0.21	0.07
B	successful	0.20	-2	0.14	0.11	0.03
	failed	0.26	-4	0.21	0.16	0.06
C	successful	0.16	-12	0.08	0.09	0.03
	failed	0.29	-3	0.29	0.21	0.10
D	successful	0.17	-4	0.10	0.08	0.03
	failed	0.20	-2	0.18	0.14	0.06
E	successful	0.17	-7	0.13	0.09	0.06
	failed	0.13	0 (Take-off)	0.12	0.13	0.06
Mean±SD	successful	0.15±0.04	-5.6±4.0	0.10±0.03 *	0.09±0.01 *	0.04±0.02
	failed	0.24±0.08	-2.6±1.1	0.21±0.06	0.17±0.03	0.07±0.02
p value		p=0.13	p=0.20	p=0.04	p=0.01	p=0.09

Table 1 summarizes the maximum value of SDTB ($SDTB_{max}$) and its occurrence time ($SDTB_{smax}$) measured as the number of steps from take-off, SDTB at the last step ($SDTB_{last}$), SDTB at take-off ($SDTB_{TO}$), and SDSL at the last step ($SDSL_{last}$). While the average $SDTB_{max}$ showed no significant differences in the successful and failed trials (P = 0.13), the average $SDTB_{last}$ and $SDTB_{TO}$ of the successful trials were significantly (P < 0.05) smaller than those of the failed trials. There was no significantly difference for the step of SDTBmax between successful and failed trials (P = 0.20). Additionally, the average values of $SDSL_{last}$ in the two conditions were marginally different (P = 0.09), in which that of the failed trials tend to be larger than that of the the successful trials.

5. Discussion

The purpose of this study was to investigate the difference in gait regulation strategies of pole vault approach runs between successful and failed trials. We found that the successful trials had consistently smaller SDTBs than those of the failed trials throughout the run up (Fig. 1). The average $SDTB_{last}$ and $SDTB_{TO}$ of the successful trials were significantly smaller than those of the failed trials. Moreover, the average $SDSL_{last}$ was marginally larger in the failed trials while there were no significant differences for $SDTB_{smax}$ and SDSLs between the two conditions (Fig. 2). Thus, our hypothesis that there exists a distinctive difference for the timing to start the gait regulations between successful and failed trials was rejected. However, it can be suggested that successful trials had smaller variability of toe to planting box distance than failed trials.

Hay examined gait regulation strategies during the approach runs of 47 elite male and female long jumpers using a similar method of this study [6]. The study of Hay demonstrated a criterion to evaluate the accuracy of the approach run, in which approach runs with no more than 0.20 m of $SDTB_{max}$ to be judged as “good” whereas approach runs showing more than 0.25 m of $SDTB_{max}$ to be assessed as “poor” [10]. While there was no significant difference for $SDTB_{max}$ between the successful and failed trials, we made an attempt to evaluate those approach runs from the criterion made by Hay [10]. $SDTB_{max}$ of the successful trials (0.15 ± 0.04 m) fall within the range of “good” run ups. On the other hand, $SDTB_{max}$ of the failed trials (0.24 ± 0.08 m) showed approximate values to be judged as "poor" run ups. As shown in Fig. 1, the successful trials consistently showed smaller SDTBs than those of the failed trials, and also $SDTB_{last}$ and $SDTB_{TO}$ of the successful trials were significantly smaller than those of the failed trials. Moreover, the failed trials tend to have a larger deviation of the last step length (Fig. 2). These findings suggest that in failed run ups, excessive step length errors are accumulated at the final phase of run ups and vaulters are somehow to adjust their last stride to meet the positional requirements for take-off. In other words, to minimize the step length regulation during the final phase of approach runs is a key factor for successful vaulting.

Lee et al. showed a general pattern of SDTBs towards take-off for long jumpers. After an increase of SDTBs, those values decreased from a few steps before take-off [11]. From the given result, they defined the last moment of the upslope of SDTBs as the starting point of gait regulation towards take-off. Bradshaw et al. demonstrated that a moderate positive correlation (r = 0.67) exists between the starting point (the number of steps from take-off) and resultant long jump distances [12]. From this study, it can be suggested that it is important for long jumpers to start step length adjustments from some earlier point of approach runs. Tamura et al. also found that the higher performance pole vaulters started to decrease their approach run variability earlier than the lower performance counter pair [8]. In this study, the starting points were also compared between the successful and failed trials as the number of steps from $SDTB_{max}$ to take-off. The result was not in line with the previous findings because there was no significantly difference for $SDTB_{smax}$ between the two conditions. It can be suggested that pole vaulters start their gait regulation at similar points of the approach runs either in successful or failed trials. This may imply that the timing have little influence on the resultant outcomes within individuals.

5. Conclusion

It can be concluded that (1) there was no difference for the timing to start the gait regulations between successful and failed trials, and (2) successful trials showed significantly smaller variability of the last step and take-off step than those of the failed trials.

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