Original Article

Relationship between subjective effort and kinematics/kinetics in the 50 m sprint

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ABSTRACT

Purpose. This study investigated the relationship between subjective effort (SE) and kinematics/kinetics throughout an entire 50 m sprint. Methods. Fifteen male sprinters performed the 50 m sprint at 3 different levels of SE (100 %SE; maximal-effort, 90 %SE and 80 %SE, sub-maximal efforts). Kinematic and kinetic data were obtained with a digital high speed camera and 50 ground reaction force (GRF) plates placed every 1 m in the running lane. Variables recorded were sprint time, running speed, step frequency, step length, aerial time, contact time, GRF, and ground reaction impulse (GRI). Results & Discussion. Sprint times decreased with increases in SE. However, some subjects ran their fastest 50m at a sub-maximal SE. Thus, the optimal combination of step length & frequency necessary for obtaining maximum speed does not necessarily occur at maximal SE. Indeed, while step frequency significantly increased with an increase in SE, step length was usually the longest at a sub-maximal SE. The vertical GRI in the first half of the ground contact period was significantly greater at sub-maximal SEs. Vertical GRIs and horizontal GRIs in the second half of the ground contact period did not significantly differ among different SEs. Our results suggest that those runners who increase SF too much at maximal SE do so at the cost of decreasing step length (SL). Thus, applying a large force against the ground in the first half of the ground contact period would be effective for improving step length. **Keywords:** Sprint Running; Subjective Efforts; Kinematics; Kinetics.

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INTRODUCTION

In sports training it is important for coaches and athletes to understand the relationship between the athletes' subjective feeling and the actual performance. To evaluate subjective feeling, rating of perceived exertion of subjective tightness is the most widely used method (Borg-RPEs) (6-20 steps) (Borg, 1982). Many studies have shown a positive correlation between Borg-RPEs and physiological variables such as heart rate, blood lactate, and oxygen debt (Borg, 1987; Borg, Domserius, & Kaijser, 1990; Eston, Faulkner, St Clair Gibson, Noakes, & Parfitt, 2007). Another scale for rating perceived exertion (OMNI-RPEs) (0-10 steps) has also been proposed as an index of subjective tightness during exercise (Robertson et al., 2000; Robertson et al., 2003). The relationship between OMNI-RPEs and objective variables has also been studied for walking/running (Utter et al.. 2004), bicycle ergometer exercise (Robertson et al., 2003), and resistance training(Lagally & Robertson, 2006; Robertson et al., 2003). For example, Utter et al. (2004) reported that there is a positive correlation between OMNI-RPEs and physiological variables (heart rate, oxygen debt amount) for walking/running. These RPE scales produce information about individual perception. However, they are only able to reveal sensations during or after an athletic performance. They cannot be utilized to indicate the intensity of the exercise that is yet to be performed. Thus, it would be of little use for a coach to say: "Next, run 100 m at Borg-RPE 15."

In the case of training for long distance running, the intensities coaches set are often based on physiological variables such as lactate threshold values and maximum oxygen uptakes (e.g. Set the running speed at 60 % VO 2 max). In addition, coaches also set the competitor's intensity by using a running speed (ex. "Run at 3 min/km"). On the other hand, in sprinting training, athletes mostly run with maximal effort. They sometimes run with a sub-maximal effort to improve their running form, and accordingly, in such situations, coaches should indicate the appropriate running intensity. But using sub-maximal effort descriptions to indicate running speed is not practical for describing intensity, because appropriate running speeds vary considerably across individuals and are also affected by internal and external conditions. In addition, sprint events are over very quickly. Thus, coaches and athletes have to rely on subjective wording to describe running intensity.

Coaches often express running intensity with "subjective effort (SE)" scaled relative to the maximum sprint effort (100 %), such as: "Run at 90 % SE". In the last several decades, many studies by Japanese researchers have analysed the relationship between SE and objective variables such as running speed, step frequency, step length, and lower-limb motion (Ito & Muraki, 2005; Ito, Muraki, & Kaneko, 2001; Muraki, Ito, Handa, Kaneko, & Sheng, 1999; Ogura et al., 1997; Shinohara & Maeda, 2016; Sugimoto & Maeda, 2013). While running speed and step frequency generally increase with increases in SE, step length peaks at submaximal SE (Ito & Muraki, 2005; Ito et al., 2001; Muraki et al., 1999; Ogura et al., 1997; Shinohara & Maeda, 2016). Interestingly, changes in SE are mainly associated with changes in step frequency, suggesting that sprinters can obtain a given SE by controlling step frequency. Indeed, there is a linear relationship between SE and actual running speed in the SE range from 60 % to 100 %(Ito & Muraki, 2005; Ito et al., 2001; Muraki et al., 1999; Ogura et al., 1997; Shinohara & Maeda, 2016; Sugimoto & Maeda, 2013). At SEs near and at maximal (90 %, 95 %, 97.5 %, and 100% SE), Muraki et al. (1999) compared running speeds during the maximal speed phase (40-50 m) of the 50 m dash. While most subjects showed a decreased running speed at sub-maximal SEs compared to the maximal SE, some recorded their maximal speeds at sub-maximal SEs. For these sprinters, a maximal effort did not produce the highest running speed.

Although these studies analysed the effects of SE on sprint kinematics, there is no report concerning the relationship between SE and sprint kinetics such as ground reaction forces (GRFs) or ground reaction impulses (GRIs). In particular, considering that step length in sub-maximal effort sprinting tends to be longer than in maximal effort sprinting (Ito & Muraki, 2005; Ito et al., 2001; Muraki et al., 1999), it would be useful to clarify running characteristics from the viewpoint of GRFs or GRIs. These are the main determinants of step length(Hunter, Marshall, & McNair, 2005), and increased information on their characteristics would be useful for optimizing sprint performance. Previous studies on the relation between the SE and sprint performance were only performed on the maximal speed phase (30-40 m or 40-50 m) (Ito & Muraki, 2005; Muraki et al., 1999; Ogura et al., 1997; Shinohara & Maeda, 2016), or in the acceleration phase up to 15steps (0-30 m) (Ito et al., 2001). The sprinters in the above study utilized the three point start position(Korchemny, 1992), which is not used in actual sprint races.

The aim of this study was to examine the relationship between the SE and sprint kinetics (GRFs and GRIs) as well as kinematics (running speed, step frequency and step length, contact time and aerial time) for an entire 50 m sprint that begins with a crouched start. Thus, the data will be complete and also reflect the starting posture used in real races. The information derived from the above data will be useful for coaches and athletes, not only to prepare training programs, but also to plan race strategies.

MATERIALS AND METHODS

Participants

Subjects were fifteen male Japanese sprinters (Height: 177.9 ± 5.8 cm, Body weight: 69.8 ± 6.3 kg, Age: 20.1 ± 1.8 years). The mean of their best 100 m times was 10.93 ± 0.43 s (range: 10.19-11.30 s). After being explained the risks that could occur during the measurements and the purpose of the study, all subjects agreed to participate in the experiment. The experiment was approved by the Ethics Committee on Research of Waseda University and the Ethics Committee at Kanoya Sports University and was in agreement with the Declaration of Helsinki.

Procedures

All experiments were conducted in one of the straight lanes of an indoor athletic track. Subjects were allowed to wear spike shoes. After a 40 min warm-up, the subjects performed 50 m sprints at three different SEs (100 %, 90 % and 80 %), from a crouching start position with starting blocks. They started in response to an electric pistol. The 100 % SE running was always done first. Then, based on the 100 % SE, subjects were told to run at 90 % and 80 % SE, which will be denoted as "sub-maximal efforts", with a randomized order. Sufficient rest time (over 5 minutes) was taken between trials to eliminate the effects of fatigue.

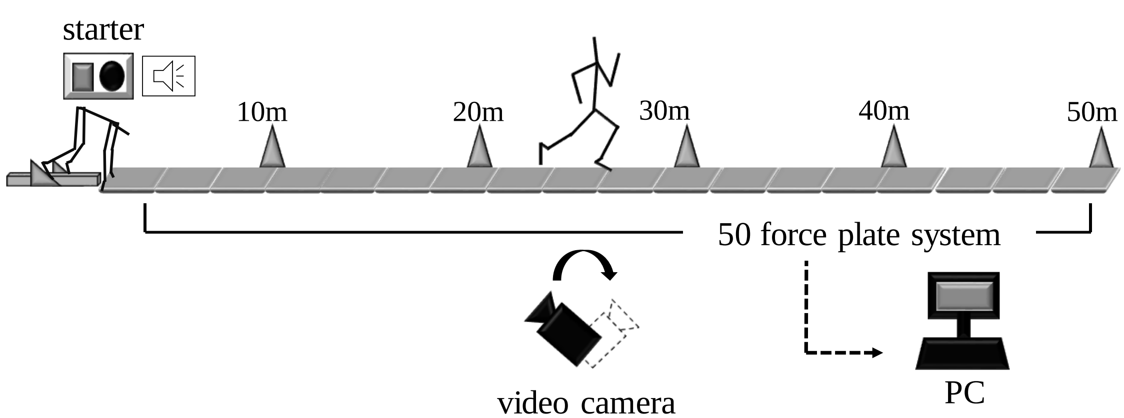


Figure 1. Experimental set up.

Running movement was recorded with a digital high speed video camera (EX-F1; CASIO Co., Japan) at a frame rate of 299.7 Hz, and shutter speed of 1000 Hz. The camera was set at 25 m from the start line and 25 m lateral to the lane so that the entire body of the subject could be captured in a frame. Markers were placed on an extension of the camera and at points every 10 m along the lane to calculate the sprint time for each interval (Figure 1). At the same time, GRF and centre of pressure (COP) data were recorded (1000 Hz) from 50 GRF plates (TF-90100, TF-3055, TF-32120; Tec Gihan Co., Japan) which were lined up every 1 m in the running lane. The force plate data were smoothed with a Butterworth low pass digital filter at 100 Hz.

In this study, we defined the first step as the point where either leg touched the ground. Since all subjects ran 50 m with more than 24 steps for all trials, analyses were made up to the 24th step. All analytical variables were calculated by averaging every two steps to eliminate fluctuation due to the difference between right and left steps (Nagahara, Mizutani, Matsuo, Kanehisa, & Fukunaga, 2017). For example, 1st and 2nd steps will be denoted as “steps 1-2 ”; step groups up to “steps 23-24 ” were analysed.

Data processing

Kinematics

We calculated contact time (Tcon), aerial time (Taer), step frequency (SF), step length (SL), running speed (RS), and the horizontal coordinate components of the centre of pressure (COP) at the middle of the contact phase.

Touch down (TD) and take-off times (TO) were obtained from the GRF data and defined as the times when the supporting leg touched and left the ground. The threshold was set at 20N of the vertical components of GRF (Nagahara et al., 2017). Then, contact time of each step was calculated as

$$\mathrm{Tcon} = \mathrm{TO} - \mathrm{TD}$$

Arial time was defined as the time period when neither leg was in contact with the ground, and was obtained by subtracting the take-off time of one leg (TO) from the time when the other leg next touched the ground (TD’). That is,

$$\mathrm{Taer} = \mathrm{TD'} - \mathrm{TO}$$

SF is the number of steps per second, and obtained as,

$$\mathrm{SF} = 1 / (\mathrm{Tcon} + \mathrm{Taer})$$

SL was defined as the distance from the place of COP average of the n^{th} step (COP_n) to that of the next step (COP_{n+1}) in the direction parallel to the lane.

$$\mathrm{SL} = \mathrm{COP}_{n+1} - \mathrm{COP}_n$$

RS was calculated as the product of step frequency and step length.

$$\mathrm{RS} = \mathrm{SF} \times \mathrm{SL}$$

We defined the time in which a subject ran through each 10 m interval as sprint time (ST) and, obtained it from the video image.

$$ST_i = (T_i - T_{i-1}) \times (1 / 299.7)$$

where T_i is the frame number for which the torso passed the extension of the cone installed at i^{th} 10 m.

Kinetics

As in the previous study (Fukuda & Ito, 2004; Hunter et al., 2005; Morin et al., 2015), GRFs were divided into horizontal and vertical components (Figure 2). The horizontal GRF (GRF H) was further divided into a negative phase (braking GRF: GRF H-) and a positive phase (propulsive GRF: GRF H+). On the other hand, the vertical GRF (GRF V) is always positive throughout the contact period. In this study, the GRF V was also divided into GRF V- and GRF V+ by utilizing the time at which GRF H crossed the zero value. The ground reaction impulse (GRI) was obtained by integrating the GRF with time from the touch down (TD) to the take-off (TO). The GRI was also divided into two components as was described above for the GRF (Figure 2).

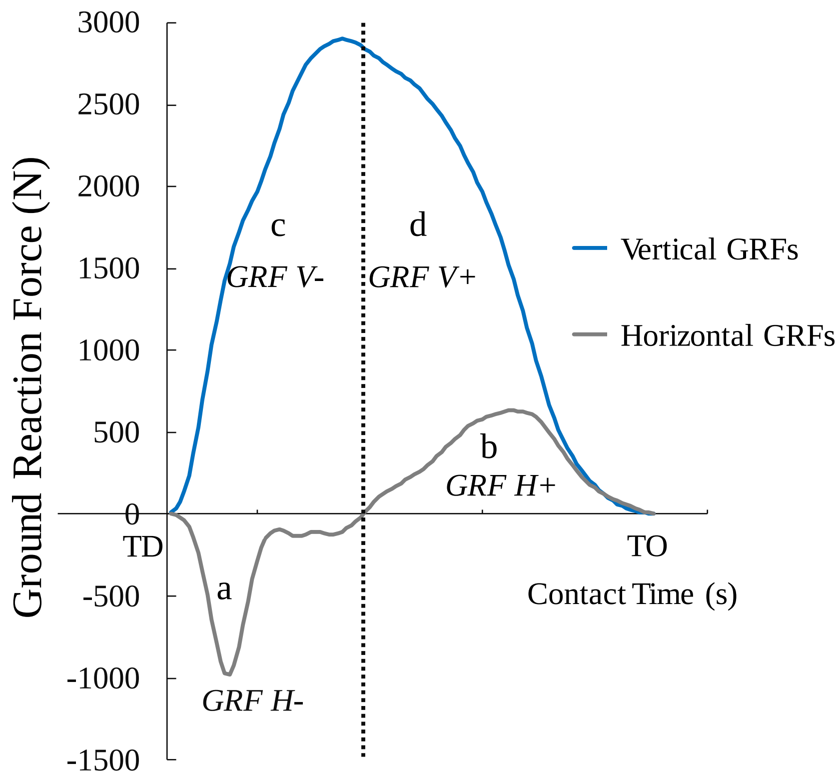


Figure 2. Ground reaction force (GRF) divided into components. Horizontal GRF was divided into GRF H- (a), the braking impulse, and GRF H+ (b), the propulsive impulse. The vertical GRFs are also divided into GRF V- (c) and GRF H- (d) with the time point when the horizontal GRF crosses zero.

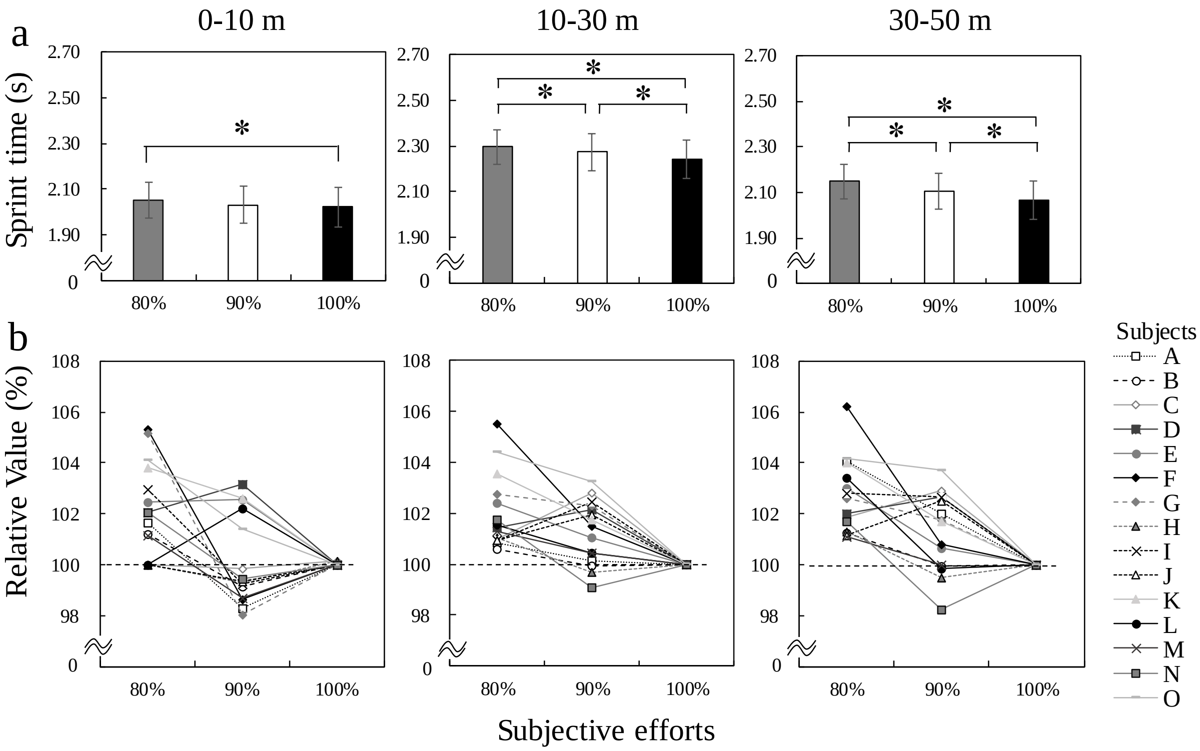
Statistical Analysis

For statistical analyses we used SPSS (IBM SPSS Statistic ver. 21.0 for Windows; IBM, USA). A two-way factor ANOVA (SEs × steps) was utilized to test differences in ST, RS, SF, SL, Tcon, Taer, or GRIs. Differences in these variables among the three SEs at each step group were determined using a repeated ANOVA. We use the Bonferroni post hoc test if a significant main effect or interaction was obtained. All statistical significance levels were set at $p < 0.05$.

RESULTS

Relationship between SE and Kinematics

Figure 3a shows the averaged STs for the three intervals of 0-10 m (initial acceleration phase), 10-30 m (transition phase), and 30-50 m (maximal speed phase) at the three SEs. Figure 3b depicts changes in the relative STs within each individual with the ST at 100 % SE as the standard. The averaged STs were significantly shorter at greater SEs for 10-30 m and 30-50 m intervals. However, there was a significant difference in 0-10 m ST only between 100 % SE and 80 % SE. Note that some subjects had a shorter ST at 90 % SE than at the 100 % SE (0-10 m: 9 subjects, 10-30 m: 3 subjects, 30-50 m: 3 subjects).



*: Significantly difference between SEs

Figure 3. Sprint times (a) and their relative values (b) at three different SEs.

Figure 4a shows the influence of SE on RS, SF and SL from the start to the 23-24 step group. Significant differences in RS were found between the 100 % SE and the 80 % SE at the 9-24 step groups. However, there was no significant difference between 100 % SE and 90 % SE, nor between 90 % SE and 80 % SE. Significant differences in SF were observed between the 100 % SE and the 80 % SE for the 3-24 step groups, and between the 100 % SE and the 90 % SE for the 9-24 step groups. SL showed significant differences between 100 % SE and 80 % SE for the 3-24 step groups. Figure 4b shows changes in T_{aer} and T_{con} across steps. There were significant differences in T_{aer} between 100 % SE and 80 % SE for the 7-24 step groups, and between 100 % SE and 90 % SE for the 12-24 step groups. Significant differences in T_{con} were observed between the 100 % SE and the 80 % SE for the 7-10, 13-14, and 19-24 step groups.

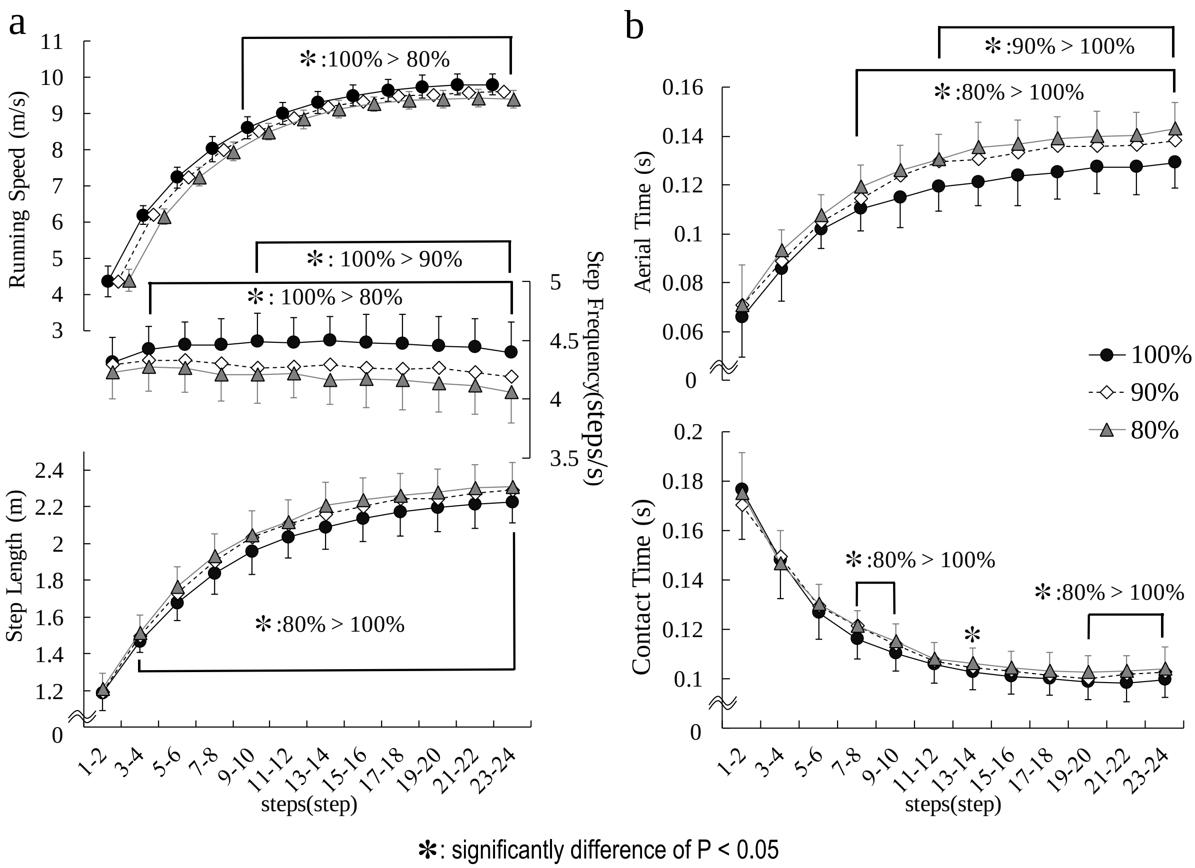


Figure 4. Kinematic variables (Running Speed, Step Frequency, Step Length, Aerial Time, and Contact Time) at three SEs.

Figure 5 illustrates the relationship between step frequency and step length at three SE levels for all of the 1-24 step groups (a), and individual data of averaged step frequency (horizontal axis) and step length (vertical axis) at 90 % and 100 % SE for 1-8, 9-16 and 17-24 step groups (b, c, and d), respectively. No subject had a greater SF in 90 % SE as compared to 100 % SE (b-d). On the other hand, SL in some subjects was longer at 90 % SE than 100 % SE. In other words, SL did not necessarily change with a change in SE.

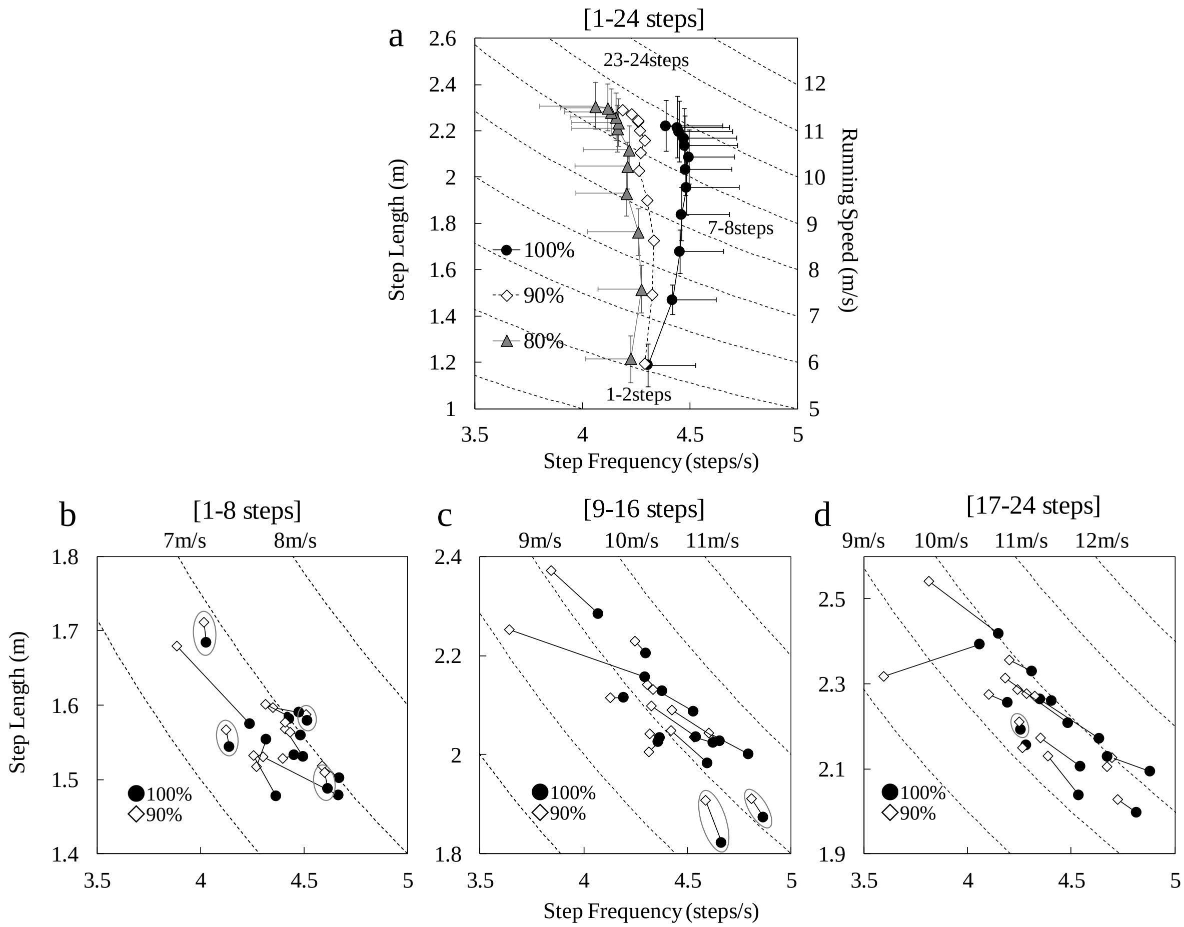


Figure 5. **a**; relationship between step frequency and step length at three SE levels for the entire 1-24 step groups. **b**, **c** and **d**; individual data of averaged step frequency (horizontal axis) and step length (vertical axis) at 90 % and 100 % SE for1-8, 9-16 and 17-24 step groups, respectively. Grey circles indicate the subjects whose running speed at 90 % SE was higher than that of 100 % SE. The dashed lines are iso-velocity curves, that is SF×SL = constant.

Relationship between SE and Kinetics

Figure 6 shows examples of the GRFs during the 50 m sprint of the fastest runner (Subject E, fastest100 m time: 10.19 sec) (a) and the slowest runner (Subject I, fastest 100 m time: 11.30 sec) (b). Both subjects showed an increase in peak GRF V with time. Figure 6 c and d show the averaged change in GRF V of the 17-24 step groups for the same two subjects of Figure 6 a and b. The fastest sprinter attained peak GRF at an earlier point (25.8 % of the T_{con}) than that of the slowest sprinter (37.7 % of the T_{con}).

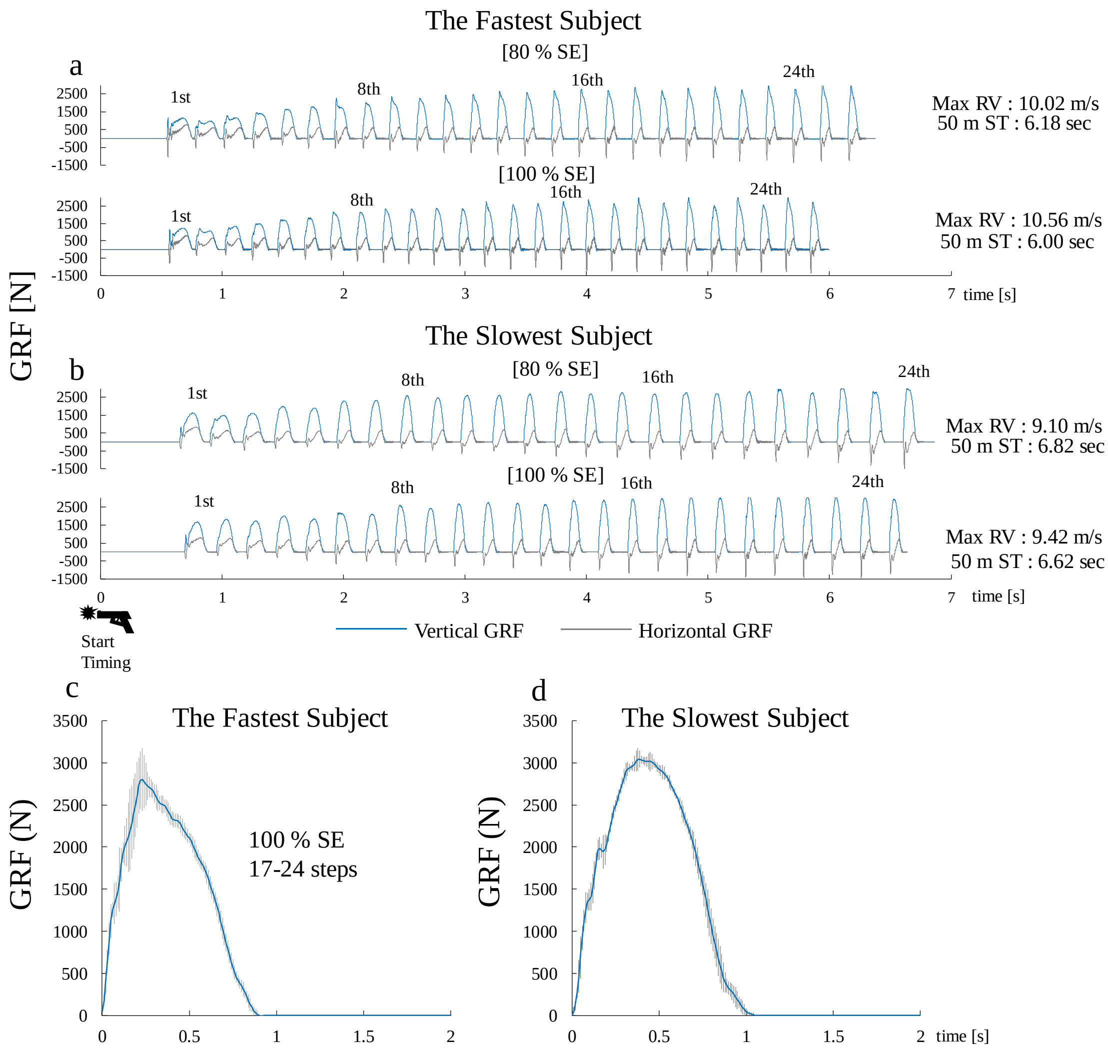


Figure 6. Ground reaction forces (GRFs) of the entire 50 m sprint for two sprinters. The fastest sprinter obtained the maximal running speed at 100 % SE (**a**), while the slowest sprinter obtained it at 80 % SE (**b**). Blue and Grey lines indicate the GRF V and GRF H, respectively. c and d; the averaged GRF V (blue lines) and standard divisions (grey lines) of 17-24 step groups for two sprinters (**c**: the fastest subject, **d**: the slowest subject).

The effects of different SEs on the GRI components are shown in Figure 7. The total GRI differed significantly between 100 % and 80 % SEs for the 13-24 step groups (80 % SE > 100 % SE) (Fig. 7a). An interaction was not observed between the SEs and steps in the vertical GRI (Fig. 7b), but a main effect was recognized for the SEs (80 % SE > 100 % SE). The vertical GRI for the first half of the contact period (GRI_{V-}) was significantly greater for 80 % SE than for 100 % SE for the 7-10 step groups and the 13-24 step groups (Fig. 7c). There was no significant difference in the latter half of the contact period (GRI_{V+}) among the SEs (Fig. 7d). The net horizontal GRI (GRI H) was significantly greater for the 100 % SE than for the 80 % SE for the 13-22 step groups (Fig. 7e). Significant differences between 100 % SE and 80 % SE also occurred in the 13-22 step groups in the impulse for the first half of the contact period (GRI H-) (Fig. 7f). On the other hand, there was no significant difference in the GRI for the latter half of the contact period (GRI H +) among the SEs (Fig. 7g).

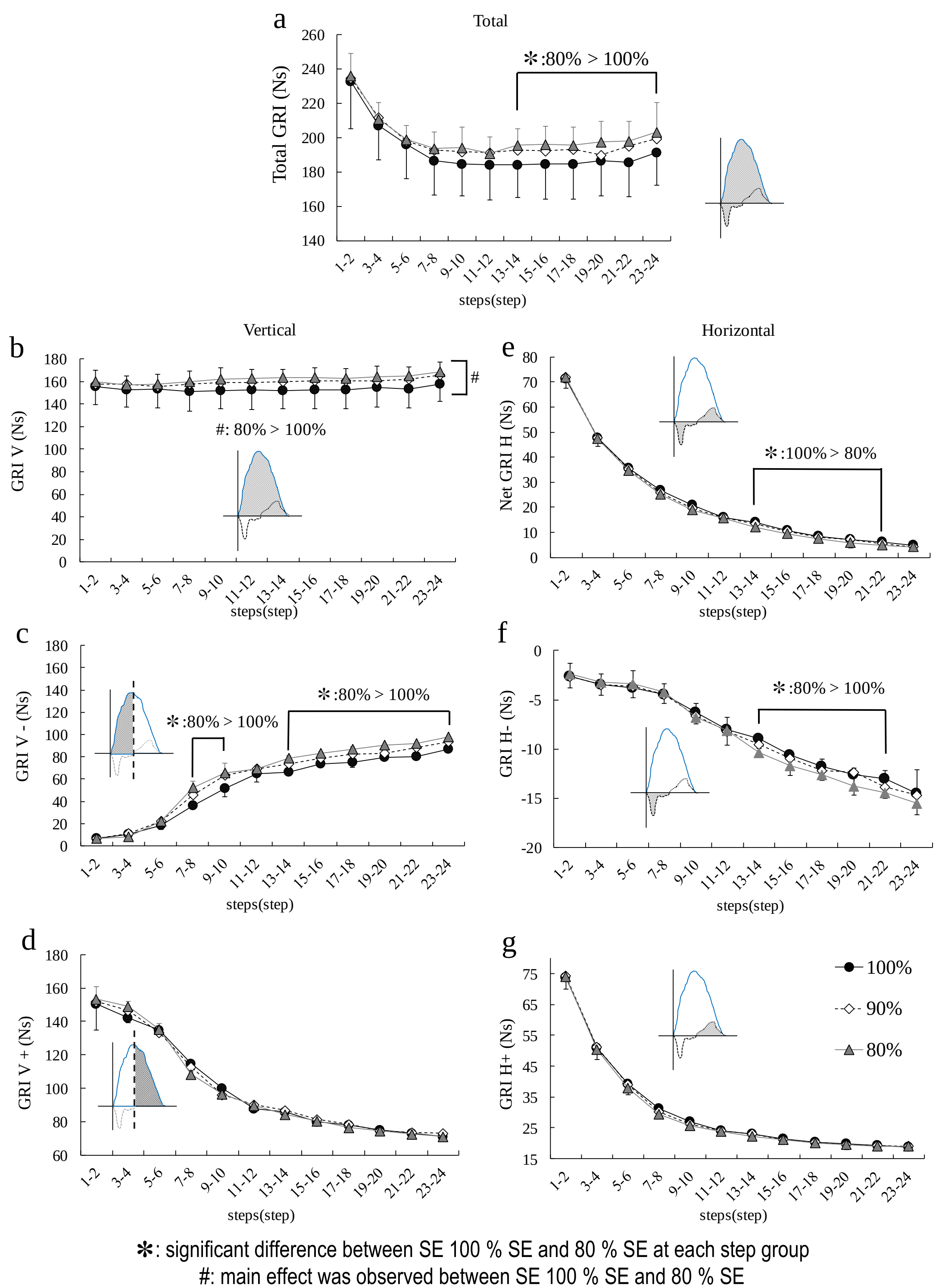


Figure 7. GRI and its components at three SEs, total GRI (**a**), vertical GRIs (**b-d**), and horizontal GRIs (**e-g**). – and + denote the first and second parts of GRI, respectively, which are separated with the time point of horizontal GRF crossing zero.

DISCUSSION

Kinematics

The group average of ST significantly decreased with an increase in SE. This is consistent with previous results which indicate that SEs and STs strongly correlate (Ito & Muraki, 2005; Ito et al., 2001; Muraki et al., 1999; Ogura et al., 1997; Shinohara & Maeda, 2016; Sugimoto & Maeda, 2013). However, there are different tendencies among individuals. That is, STs are not always shortest at 100 % SE (Figure 3b); they also depend on the section of the race being run. Interestingly enough, for the 0-10 m section the ST was shortest at 90% SE in 9 of the 15 subjects. The result that ST is not necessarily the shortest at 100 % SE was also shown in previous studies that analysed the acceleration phase (0-30 m) in the SE range of 80 % to 100 % (Ito et al., 2001) and the maximal-speed phase (40-50 m) in the SE range of 90 % to 100 % ((Muraki et al., 1999).

There was no difference in RS among the three SEs for the first 1-8 steps (about 10 m) (Figure 4a). Meanwhile, SF and SL showed significant differences among different SEs for the 3-4 step group as well as afterwards: That is, SF significantly increased at the maximal SE as compared to the sub-maximal SEs (100 % SE > 90 % SE, 100 % SE > 80 % SE), while the SL decreased (80 % SE > 100 % SE). This is agreement with the previous studies(Ito & Muraki, 2005; Ito et al., 2001; Muraki et al., 1999; Ogura et al., 1997). These results show that a change in SE mainly reflects changes in SF.

SL usually decreases and SF increases when SE changes from sub-maximal to maximal. Thus, it can be said that SF contributes relatively more to the increase in RS for maximal effort running. We thus term maximal effort running as “SF superior running”. On the other hand, since SL contributes relatively more to RS at sub-maximal efforts, we term running at sub-maximal SEs as “SL superior running”. Previous studies have reported a positive correlation between RS and SL in the initial acceleration phase for field sport athletes, this occurs in the 0-10 m section (Lockie, Murphy, Jeffriess, & Callaghan, 2013), at the 16 m point for sprinters and field sports athletes (Hunter, Marshall, & McNair, 2004), and at the 0-20 m section for elite world class sprinters (Mackala, 2007). Since some subjects obtained a higher RS at the 90 % SE level with a longer SL (Figure 5), SL superior running with a sub-maximal effort might result in better performances than with a maximal effort in the initial acceleration phase.

Studies on sprinting have typically analysed average values of the various groups. However, group analysis can mask the individual differences of variables such as SF or SL (Salo, Bezodis, Batterham, & Kerwin, 2011). Individual differences in these variables could be important when considering performance, especially in elite runners. In the 100 m dash a difference of 0.01 sec can be critical, and winning and losing have on occasion been determined by a difference as small as 0.001 sec. It is thus important for both coaches and athletes to be aware of not only averaged variables but also of individual athletes’ optimal combination of SL and SF. To this end we examined individual relations between the SE and RS-SF-SL characteristics for every 8 step group (Figure 5 b, c, d). 1-8 steps is about 10-12 m from the starting point, 9-16 steps about 10-32 m, and 17-24 steps about 28-50 m (Figure 5 b, c, d). All subjects showed a decrease in SF at 90 % SE as compared to 100 % SE for all three sections. On the other hand, SL showed an increase at 90 % SE for most subjects. It should be noted that the magnitude of changes in SF and SL differed across individuals. As a result, RS, the product of SF and SL, also changed differently across individuals. To gain maximal speed, then, each individual would have a different optimal combination of SF and SL (Debaere, Jonkers, & Delecluse, 2013; Hunter et al., 2004; Kunz & Kaufmann, 1981; Salo et al., 2011). Thus, it is expected that improvement of SL, while minimizing the decrease in SF at a sub-maximal SE might lead to a higher RS. Coaches should understand this and thus, when appropriate, could give advice such as "Run with a lower

SE" to those sprinters who increase SF too much at the maximal effort at the cost of decreasing SL. This situation is illustrated in Figure 8.

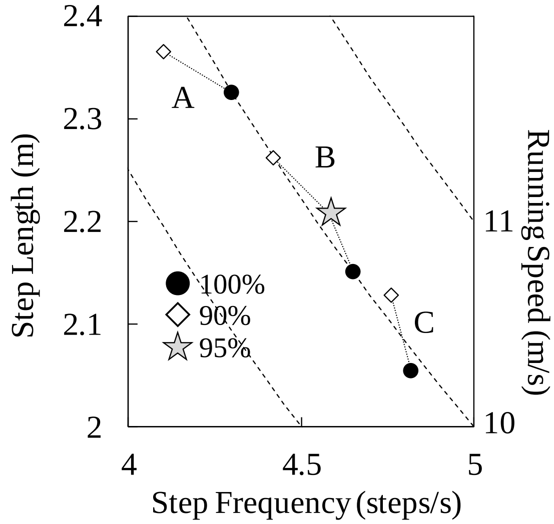


Figure 8. Relationships among step frequency, step length and running speed at three subjective efforts for three hypothetical runners (A-C). Runner-A has a higher running speed at 100 % SE than 90 % SE. On the other hand, the runner C is slower at 100 % SE than 90 % SE because of a decrease in SL as compared to 90 % SE. Runner B has the same running speed at 90 % and 100 % SEs, and he would likely to have a higher running speed somewhere between 90-100 % SE, for example at 95 % SE.

Relationship between changes in the subjective efforts and kinetics

At 80 % SE, a significantly larger total GRI than at 100 % SE was obtained in step groups 13-24 (Figure. 7a). The GRIs were obtained by integrating the averaged GRFs along T_{con}. T_{con} at 80 % SE was significantly longer than at 100 % SE (step groups 7-10, 13-14 and 19-24). Thus, the longer T_{con} in 80 % SE increased the total GRI. On the other hand, the total GRI at 90 % SE was not significantly different from that at 100 % SE (Figure 7). Considering that T_{con} there was no significant difference between 100 % SE and 90 % SE, 100 % SE and 90 % SE would be expected to have similar patterns of force application to the ground. Indeed, force application to the ground for 90 % SE running did not significantly change from that at 100 % SE (figure 7). Since there was no difference in SL between 90 % SE and 100 % SE, SE alone would reflect SF. On the other hand, T_{con} at 80 % SE was longer than at other SEs (Figure 4b).

The GRI H+ did not change with changes in SE at any of the step groups (Figure 7g). On the other hand, GRI H- at 80 % SE was significantly more negative than 100 % SE at the 13-22 step groups (Figure 7f). Thus GRI H significantly decreased at 80 % SE at the 11-22 step groups (Figure 7e). Fukuda & Ito (2004) point out the importance of both horizontal GRF components, because amplitudes of both GRF H- and GRF H+ are greater for high level sprinters than average sprinters. In addition, the ability to produce a greater GRF H+ with a short contact time, which makes the body move faster, is also important. Consequently, horizontal GRFs or GRIs are good indicators of a sprinter's ability (Hunter et al., 2005; Mero & Komi, 1986; Morin et al., 2015). Our results revealed that GRI H+ was not significantly different among the three SEs that we utilized. It has been demonstrated that the horizontal speed of the centre of gravity at take-off decreases in sub-maximal effort sprinting (Ito & Muraki, 2005). Thus, GRI H decreases at 80 % SE due to an increase of the

GRI H- negative value in the first half of the contact period, and not due to a decrease of GRI H+ for the second half of the contact period.

Although an interaction was not obtained between the SEs and GRI V, a main effect was recognized between the trials (80 % SE > 100 % SE). This effect significantly increased through all steps for 80 % SE (Figure 7b). This is in line with a previous report that in sub-maximal sprinting, vertical speed of the centre of gravity at take-off is comparable to maximal effort sprinting (Ito & Muraki, 2005). A greater vertical speed at take-off in sub-maximal running would help SL to increase. Since SL is the moving distance during the aerial period (Hunter et al., 2004), an increase in SL at sub-maximal effort might be caused by an increase in T_{aer}. On the other hand, at maximal SE a shorter T_{con} would decrease total GRI at the 13-24 step groups as compared to sub-maximal SEs. Most likely, athletes compensate for a smaller total GRI in maximal effort sprint running by increasing SF and thus moving faster.

The GRI V- significantly differed at the 7-10 and 13-24 step groups (80 % SE > 100 % SE) (Figure 7c). However, there was no significant difference in the GRI V+ at any of the step groups (Figure 7d). To summarize the above, at sub-maximal SEs, GRI H- and GRI V- increased, but GRI H+ and GRI V+ did not - as compared with the maximal SE. According to Clark & Weyand (2014), in high level competitive sprinters GRF peaks in the first half of the contact period during the high speed sprint on a treadmill. In the second half of the contact period, the waveform pattern does not change as RS increases (Clark & Weyand, 2014). These profiles of the vertical GRFs cannot be explained with a simple-spring mass model. Competitive sprinters apparently use an asymmetrical pattern of force application to maximize GRFs and thereby attain faster speeds(Clark, Ryan, & Weyand, 2017; Clark & Weyand, 2014). Similarly, our results showed that while the fastest sprinter's (whose fastest 100 m time was 10.19) GRF waveforms were asymmetric, the slowest sprinter's (whose fastest 100 m time was 11.30) GRF waveforms were symmetric (Figure 7c, d). Therefore, when sprinters changed their sprinting SE, SL was influenced by a change in GRI for the first half of the contact period, but not in the second half of the contact period. This indicates that sprinters do not produce a large force by pushing the ground more strongly in the second half of the contact period. We suggest that it is important to apply a large force in the vertical direction during the first half of the contact period in order to improve SL.

CONCLUSIONS

1. Compared to maximal effort running, SL at sub-maximal effort levels of sprinting was longer, and until the 7-8 step groups (about 10 m) the same RS was obtained regardless of the SE. On the other hand, after the 9-10 step groups, the greater the SE, the higher the SF.

2. Athletes who were able to improve SL while minimizing the decrease in SF had steps with a higher RS at 90 % SE than at 100 % SE. In other words, for sprinters who excessively increase SF, it is possible to obtain a higher RS, contrary to the supposition (gut feeling) of the runners, by instructing them to reduce SE.

3. An increase in SL at the sub-maximal effort of 80 % SE was due to the GRI V in the first half of the contact period and to an increase in T_{aer} (90 % SE and 80 % SE). In order to increase SL, we suggest that instruction or consciousness be utilized to motivate the sprinter to apply a large force to the ground in the vertical direction in the first half of the contact period.

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