INVESTIGATIONS OF THE STEP LENGTH-STEP FREQUENCY RELATIONSHIP IN SPRINTING: APPLIED IMPLICATIONS FOR PERFORMANCE

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The relationship between velocity, step length (SL) and step frequency (SF) has received much attention in the biomechanical literature, but there is not a consensus on which of SL and SF is most important to performance in elite sprinting. This paper presents a series of linked studies aimed at increasing the understanding of the individualised nature of the relationship. The research has revealed that elite sprinters' velocity can be individually reliant on either SL or SF, and that the athlete's training programme also plays an important role in determining SL and SF. Furthermore, it is thought that sprinters can manipulate the SL-SF relationship throughout a maximal sprint to maintain velocity. The influence of joint kinetics on SL and SF is not yet fully understood, but further work in this area will accelerate the understanding of the biomechanics of sprint performance.

KEYWORDS: athletics, track and field, velocity, joint kinetics, single-subject design.

INTRODUCTION:

Velocity is the product of step length (SL) and step frequency (SF). At submaximal velocities the relationship between SL and SF is readily acknowledged, with SL increasing more at lower velocities and SF more at higher velocities (Luhtanen and Komi, 1978; Kuitunen et al., 2001). At maximum velocity, however, findings are inconsistent across published data. Mero and Komi (1985) and Gajer et al. (1999) suggested that SL was the most important contributor to velocity and therefore sprint performance, whilst Mann and Herman (1985) and Ae et al. (1992) suggested that it was SF that was more important. Hunter et al. (2004) studied the performance of 28 male sportsmen at the 16 metre mark of a maximal sprint acceleration. As a group, SL was significantly related to velocity, although SF was not. However, an intra-subject analysis showed that there were no significant differences in SL between the fastest and third fastest trial for each subject, whilst SF was significantly greater in the fastest trial. It is clear that, at or near to maximum velocity, the relationship between SL and SF is not yet fully understood on an individual athlete basis.

The purpose of this paper is to present a series of linked investigations into the SL-SF relationship in elite sprinters. The overall aim of these studies was to increase understanding of the individualised nature of this relationship, and to begin to explain the mechanisms that contribute to changes in SL and SF, and therefore performance in elite sprint running.

STEP LENGTH AND STEP FREQUENCY IN ELITE COMPETITION:

A unique study was designed to investigate the longitudinal within-athlete SL-SF relationship in the highest level of elite competition (Bezodis 2006; Salo, Bezodis et al., 2011). Fifty-two elite male 100 m races were analysed from publicly available television broadcasts. Races included Olympic Games, World and European Championships, IAAF Grand Prix series events and selected National Championships. From all analysed competitions, eleven athletes were included in the study, each of whom had competed in at least ten races. The slowest time in any analysed race was 10.39 s, and nine of the eleven sprinters had at least one sub-10 s performance included. Mean SL and SF were calculated for each athlete in each race and, after statistical treatment to overcome the colinearity between SL and SF, each athletes' SL and SF values were correlated with finish time across all performances.

The results revealed a range of responses across individuals (Figure 1) that showed that across athletes the best performances were associated with increases in a specific step characteristic. For those athletes that were shown to be SL reliant (i.e. performance was best when SL values were high compared to other races of the same athlete) a training programme that advocates development of SL through focus on development of greater muscular and vertical ground reaction forces (in line with the research of Weyand et al., 2000) and joint flexibility is recommended. For those athletes that were shown to be SF reliant (i.e. performance was best when SF values were high compared to other races of the same athlete) a training programme that advocates development of SF through the stimulation of a high leg turnover via neural adaptation is recommended. Increases in SF via specific training programmes have previously been demonstrated by Mero and Komi (1985). There was found to be no effect on reliance by either athlete's PB, height or wind conditions.

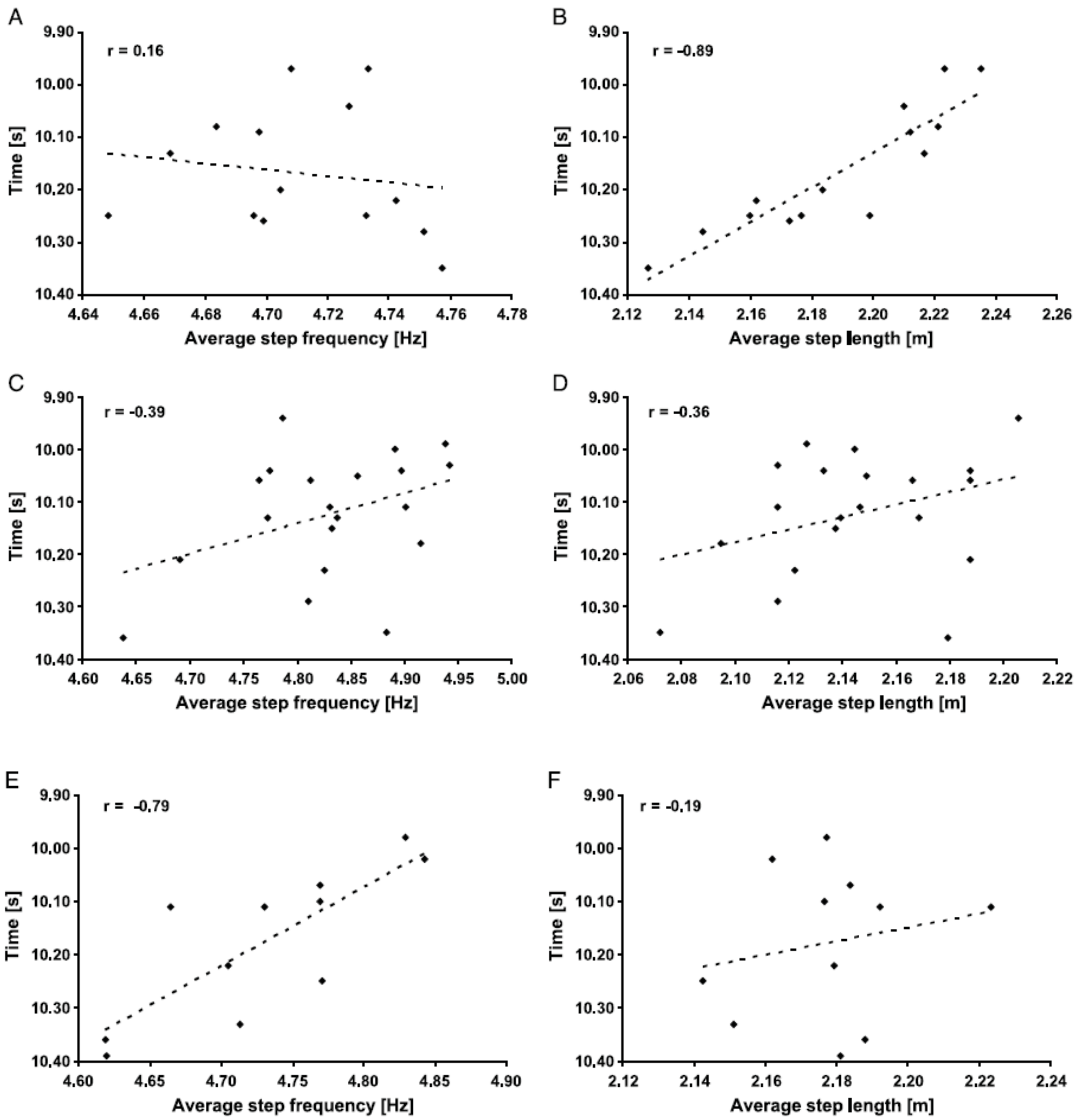

Figure 1: Three athletes' SF and SL as a function of race time: a SL reliant athlete (A and B), an athlete showing no reliance (C and D) and a SF reliant athlete (E and F). Adapted from Salo, Bezodis et al. (2011).

THE INFLUENCE OF TRAINING ON STEP LENGTH AND STEP FREQUENCY:
The investigation of SL and SF in elite competition provided a novel insight into the influences of step characteristics on velocity at the highest level of performance. However, due to restrictions imposed by the nature of the data being analysed, it was only possible to investigate changes on a race-by-race rather than step-by-step basis. In order to develop a greater understanding of how the interaction influences an individual athlete a study was designed to analyse SL, SF and step velocity (SV) in the maximum velocity phase of individual sprinters, longitudinally across a training season (Bezodis et al., 2008b). A training group of four sprinters were monitored during speed work sessions undertaken over five months of training. Data (SL, SF and SV) were gathered from individual steps in a nine metre window within the maximum velocity phase of each sprint trial and a mean value for SL, SF and SV was calculated for each training session. Data from one athlete is presented in Figure 2 as a representative of the training group.

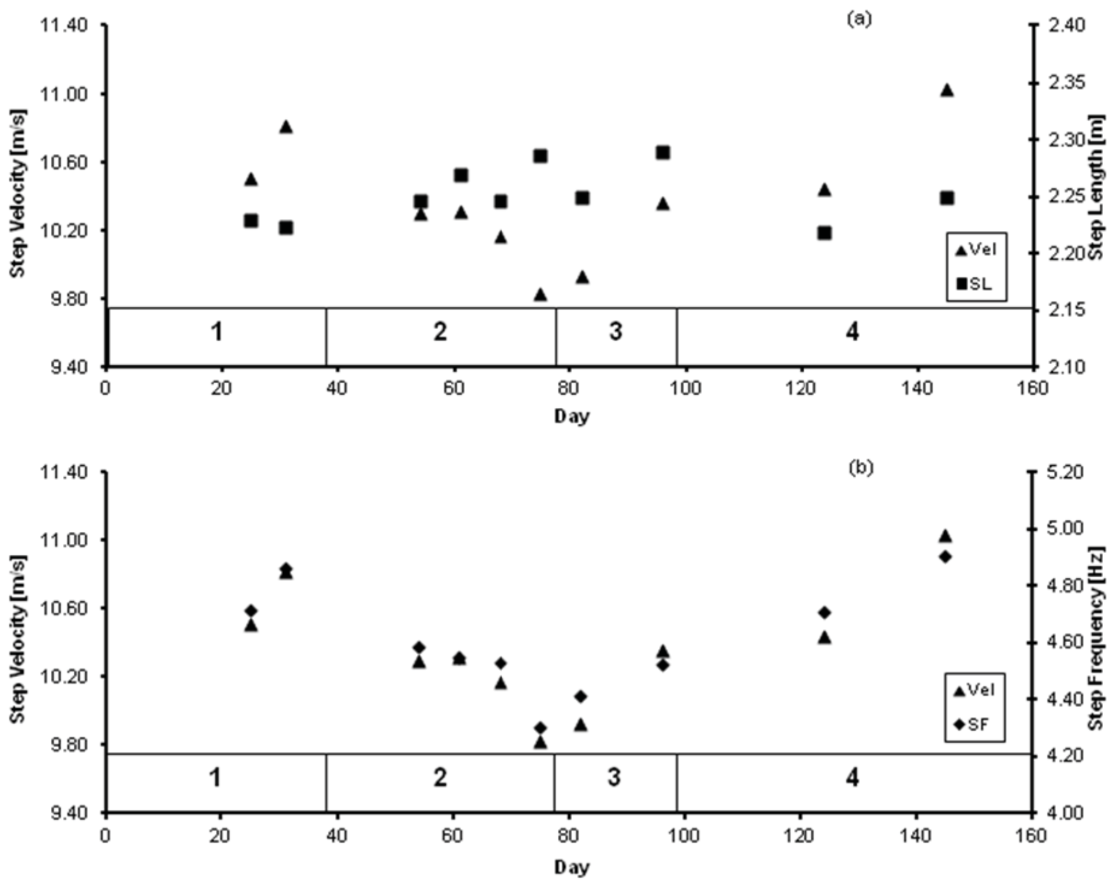

Figure 2: Chronological representation of (a) mean step velocity and SL; and (b) mean step velocity and SF for each individual training session. Numbered blocks represent training phases; 1: indoor competition season, 2: basic training, 3: outdoor preparation, 4: specific outdoor preparation and competition. Adapted from Bezodis et al. (2008b).

Analysis revealed that changes in SF mirrored those in SV throughout the training period in a much closer fashion than did changes in SL. This response was consistent across the training group. When analysed in the context of the type of training being undertaken throughout the study an interesting pattern emerged. The increases in both SV and SF occurred subsequent to the phases in which there was a high volume of weight training, but during those periods where low volume, high intensity sprint training was predominant. The high volume weight training phases would have increased the athletes' ability to develop force, and then when the focus of training was shifted to high intensity sprint work on the track the increase in force that could be generated would facilitate a reduced ground contact time whilst generating an equivalent impulse (Weyand et al., 2000), and therefore an increased SF. Whilst the response to training was shown to be consistent across the training group, the athlete presented here was shown to be SF reliant in the analysis conducted in Bezodis (2006) and Salo, Bezodis et al. (2011). It is thought that there may be an influence of the coach and his philosophy and training style on the step characteristic reliance of individual athletes. Further study with a different group of athletes would be required in order to confirm or refute this hypothesis.

THE INFLUENCE OF RACE PHASE ON STEP LENGTH AND STEP FREQUENCY:

Further to the analyses of SL and SF as mean values in competition and on a step-by-step basis throughout a training season, additional insight into the relationship between SL and SF can be developed by investigating changes to those variables within a sprint run. To the knowledge of the author, there was little or no published research that has investigated the step-by-step differences in velocity, SL and SF between the maximum velocity and deceleration phases of a 100 m sprint in well-trained senior sprinters. Therefore, a study was designed with the aim of developing an understanding of the contributions of SL and SF to changes in velocity as an athlete decelerates in a 100 m sprint (Bezodis et al., 2011).

Nine experienced university- to national-level track and field athletes each performed between three and five maximal 100 m sprints, with SV, SL and SF measured from 30-40 and 70-80 m of each trial. As a group, step velocity significantly decreased from 9.42 to 9.17 m/s from the maximum velocity to the deceleration phase of the sprint (Table 1). Mean step frequency also significantly decreased from 4.40 to 4.25 Hz between the two phases, whilst there was no change in step length (2.15 to 2.17 m). However, the relative contributions of SL and SF varied depending upon whether the data were analysed on a group or individual athlete level. At the group level, the decrease found in this study in SV and SF between the maximum velocity and deceleration phases and relative maintenance of SL were similar to those reported by Korhonen et al. (2003) in a group of Masters athletes and Gajer et al. (1999) in a group of national level sprinters.

Table 1: Step frequency, step length and step velocity in the maximum velocity and deceleration phases of the 100 m sprint, and percentage change from the maximum velocity to the deceleration phase.

Athlete	Step Frequency [Hz]			Step Length [m]			Step Velocity [m/s]		
	30-40 m	70-80 m	% Diff.	30-40 m	70-80 m	% Diff.	30-40 m	70-80 m	% Diff.
1	4.86	4.72	-2.8	1.91	1.84	-3.7*	9.28	8.68	-6.4*
2	4.06	3.81	-6.1*	2.44	2.56	4.6*	9.91	9.74	-1.7
3	4.19	4.09	-2.3*	2.18	2.19	0.6	9.13	8.97	-1.7*
4	4.21	4.13	-2.0*	2.13	2.14	0.6	8.96	8.83	-1.4*
5	4.28	4.25	-0.6	2.14	2.13	-0.5	9.16	9.06	-1.1*
6	4.43	4.28	-3.5*	2.25	2.31	3.0*	9.96	9.89	-0.7
7	4.57	4.41	-3.4*	1.98	1.98	0.0	9.04	8.73	-3.4*
8	4.80	4.48	-6.5*	2.01	2.05	2.4*	9.63	9.21	-4.3
9	4.24	4.12	-2.9*	2.29	2.28	-0.6	9.72	9.38	-3.5*
Mean	4.40	4.25	-3.4*	2.15	2.17	0.8	9.42	9.17	-2.7*

(* = p <0.05)

When analysed on an individual-athlete basis to reveal trends that may have been masked by the grouping of data (Dufek et al., 1995), new patterns became apparent. Six of the nine athletes tested showed a significant decrease in velocity between the maximum velocity and deceleration phases of the sprint. The three athletes who did not show a reduction in velocity in this study were the only three who showed an increase in SL between the maximum velocity and deceleration phases of the sprint. Furthermore, when defined by mean maximum running velocity across all steps, the three athletes whose SV did not decrease were three of the four fastest sprinters in this study. It is possible, therefore, that better sprinters are able to mitigate the causative factors of deceleration in a 100 m sprint by adapting their SL to overcome the potential loss of velocity. These three athletes were, however, those that showed the largest percentage decrease in SF from within the sample. If velocity is to remain constant, it is to be expected that an increase in one step characteristic would lead to the concomitant decrease in the other step characteristic, due to their negative interaction (Hunter et al., 2004). It is possible that there is an underlying mechanism within a 100 m sprint whereby the trade-off of a reduction in SF combined with an increase in SL is the most effective method of maintaining velocity at near maximum levels. It is clear, however, that further investigation of the changes joint kinematics and kinetics between the phases of a sprint run would be necessary in order to provide additional supporting evidence for this proposed mechanism.

THE INFLUENCE OF JOINT KINETICS ON SPRINT PERFORMANCE:

The series of studies presented above provide clear evidence that the influence of SL and SF on sprint performance can vary from individual to individual. Whilst providing a valuable insight into the higher-level factors that might influence velocity, detailed study of more specific variables is necessary. The study of joint kinetics can improve the understanding of the underlying causes of a movement (Winter, 2005). Biomechanical investigations of sprint running have studied the joint kinetics of the movement, but a comprehensive understanding of its causative mechanisms has not yet been achieved. To date, several studies have presented group-level analyses of the importance of joint kinetic factors to sprint performance (e.g. Mann, 1981; Johnson & Buckley, 2001; Belli et al., 2002). One possible approach to increasing understanding is to investigate the factors that relate to performance on a within-athlete basis: examples from sprinting include Weyand et al. (2000) and Hunter et al. (2004), although these have only reported joint kinematics and ground reaction forces, and have not extended to joint kinetics. A study was designed, therefore, in order to understand and summarise the individual biomechanical factors that contribute to changes in sprint performance between runs in elite sprinters (Bezodis et al., 2007; 2008a; 2009).

Data were gathered from one ground contact per run from four sprinters in the maximum velocity phase of sprint trials. Joint moments, power and work (Figure 3) were calculated by standard inverse dynamics equations, as presented by Winter (2005). When analysed on a within-athlete basis it was possible to highlight joint kinetic variables that appeared linked to SV. The large hip extension moments seen in early and mid stance were linked to SV, and were consistent with the findings of Mann and Sprague (1980), who showed them to be crucial to sprint performance. The magnitude of positive work performed at the ankle joint was shown to be linked to sprint performance (Bezodis et al., 2007), and furthermore, there appeared to be a trade-off between the amount of positive work generated at the ankle and hip joints during the stance phase, on a within-athlete basis.

Whilst, on an individual athlete level, there appeared to be links between either SL or SF, velocity and joint kinetic variables, there was no clear pattern that emerged on a between-athlete basis. Future studies should focus on trying to identify which relationships are most important to performance on both a within- and between- athlete level, since this will help to inform the design of specific training programmes that utilise detailed biomechanical evidence to facilitate improvements in performance.

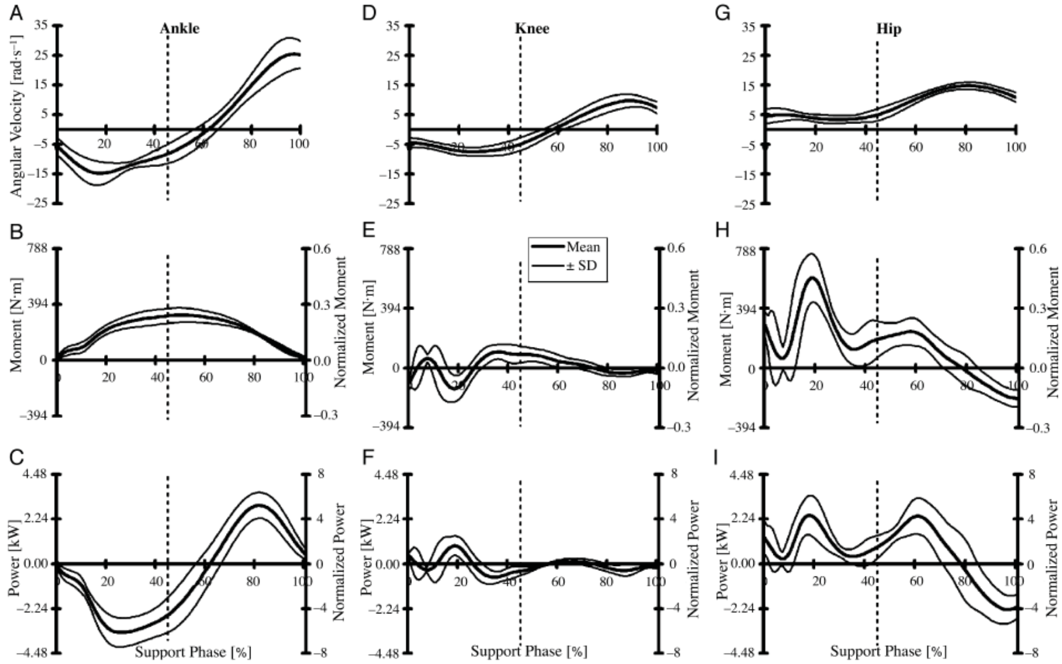

Figure 3: Joint angular velocity, moment, and power at the ankle (A–C), knee (D–F), and hip (G–I) during the support phase in maximum velocity sprinting (mean ± standard deviation). Vertical dashed line corresponds to the transition from the braking to the propulsive phase of support. Adapted from Bezodis et al. (2008a).

FUTURE WORK AND CONCLUSIONS:

It is clear from the data summarised in this paper that athletes respond in differing ways when manipulating SL and SF in order to attempt to maximise velocity. Furthermore, it appears that the way in which a study is designed and the research question is answered might influence the apparent relative importance of SL and SF. Whilst some progress has been made in understanding the SL- SF relationship and the mechanisms that underlie it, there remains much scope for increasing knowledge in this area. Studies that are able to identify the contributions of specific joint kinematic and kinetic factors to SL, SF and velocity throughout the different phases of a sprint run will contribute significantly to the body of biomechanical knowledge in this area. In turn, this will increase the ability of biomechanists to facilitate the improvement in performance in sprinters in an applied setting.

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