VARIABILITY IN THE STEP CHARACTERISTICS OF INTERNATIONAL-LEVEL SPRINTERS DURING THE ACCELERATION PHASE

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This study investigated within-session and across-season variability in step characteristics during maximal effort sprint accelerations of internationally competitive sprinters (n = 7) during training. Kinematic data were collected across multiple sessions over the training season. Of each adjacent four-step interval, steps 1-4 showed the highest absolute variation for step frequency, contact and flight time across the cohort, within-session. Across the season, the variability in each kinematic measure (relative to season mean) was specific to the individual, and no single technique variable fluctuated consistently with velocity. Athletes may benefit from being exposed to a variety of situational and environmental constraints that reflect the unpredictability of competition, enabling them to develop variable movement strategies whilst maintaining consistent performance levels.

KEY WORDS: kinematics, longitudinal, standard deviation, training, z-scores

INTRODUCTION: From a mechanical perspective, horizontal velocity can be calculated as the product of step length and step frequency, with the latter determined from ground contact and flight times. An increase in either step length or frequency will increase velocity, providing the other does not undergo a proportionally similar or greater decrease (Hunter, Marshall, & McNair, 2004). Understanding the interaction between these variables is useful for coaches attempting to identify the aspects of technique associated with higher performance levels in different race phases, including the start and acceleration. Recent investigation into these spatio-temporal patterns have provided mechanical insight into the determinants of acceleration performance (Rabita et al., 2015), and how their rate of change on a step-to-step basis are associated with acceleration capability (Nagahara, Naito, Morin, & Zushi, 2014). Understanding the variability with which these movement patterns are executed is important for informing coaches of the typical extent of the variability within these key step characteristic variables, and how variability in each of these measures may relate to performance.
Few studies have adopted longitudinal approaches to monitoring sprint performance, thus drawing conclusions from single training sessions. Recent insight into how performance and technique outcomes are associated with periodised training programmes revealed step frequency to be more sensitive to short-term training induced changes than step length (Bezodis, Kerwin, Cooper, & Salo, 2018). Routine measurement of the step characteristics of international-level sprinters across an athletics season would allow coaches to better understand training programme design, and consequently plan and adapt training more effectively in an attempt to enhance the effect of their interventions on performance and its underpinning technique. The purpose of this study was to quantify the variability in step characteristics and performance during maximal sprint accelerations, both within-session and across-season, providing novel insight into the kinematic patterns of elite athletes.

METHODS: Seven highly trained, internationally-competitive male sprinters (24 ± 4 years, 83.3 ± 7.1 kg, 1.84 + 0.06 m, 100 m PB: 10.04 ± 0.07 s) provided written informed consent, and ethical approval was granted by the Swansea University Research Ethics Committee. Data were collected unobtrusively during acceleration-focused sessions from starting blocks, without any interference to the coach's scheduled programme. Data for seven athletes was collected from a minimum of three 30 m efforts at a single session that occurred within a three-week period in December. The same data were collected from two of seven sprinters at 13 sessions between October and July (41 and 51 total sprints, respectively). Spatio-temporal step characteristics were collected using an optical measurement system with infra-red light barriers (Optojump, Microgate, Italy). Contact time (T_C) and flight time (T_F) were measured to the nearest ms, with step length (L_S) calculated to a resolution of 1.04 cm. Step frequency (F_S) was calculated as the inverse of the sum of T_C and T_F. A laser distance measurement device (LDM; 300C, Jenoptik, Germany; 100 Hz) was positioned centrally in the lane on a tripod at a height of 1.20 m, and approximate distance of 10 m behind the start line (calibrated so all measured distances were relative to the start line as 0.00 m). The Optojump system was activated prior to standard 'on your marks' and 'set' commands being issued by a coach. The LDM device was manually initiated once the athlete had risen into the 'set' position, before a verbal starting signal of "Go" was provided. Raw displacement data from the LDM device were processed in Matlab™ (v. 9.3.0, MathWorks™, USA) using a fifth-order polynomial function, analytically differentiated with respect to time to yield a fourth-order representation of the velocity-time profile (Bezodis, Salo, & Trewartha, 2012). Instantaneous velocity at 10, 20 and 30 m were determined for each sprint. Step characteristics up to the 17th step touchdown were exported from Optojump for further analysis alongside the velocity data. Mean ± standard deviation (SD) values for each variable (T_C, T_F, L_S, F_S) were calculated in each step for each of the seven athletes within their respective session. The SDs for each step characteristic were then averaged across consecutive four-step sections (i.e. steps 1-4, 5-8, 9-12 & 13-16) to provide measures of absolute variability for each athlete. A repeated measures ANOVA was used to identify main effects ($P < 0.05$) of the four-step intervals for each variable, before post-hoc Tukey LSD tests were used to identify specific intervals the differences existed between. For the two athletes that were monitored on multiple occasions, mean values for each variable across steps 1-4 at each session (n=13) were converted to z-scores (based on the whole-season mean calculated from 13 values) to enable comparison of relative fluctuations in step characteristics and velocity across the season.

RESULTS: Group-wide mean ± SD instantantaneous velocities of 8.46 ± 0.07 m/s, 9.81 ± 0.08 m/s, and 10.33 ± 0.12 m/s were achieved at 10, 20 and 30 m, respectively. With each step, contact time progressively decreased, whilst flight time increased (Figure 1a). This inverse relationship led to a relatively consistent step frequency across the 16 steps, enabling velocity to rise as a result of progressive increases in step length (Figure 1b).

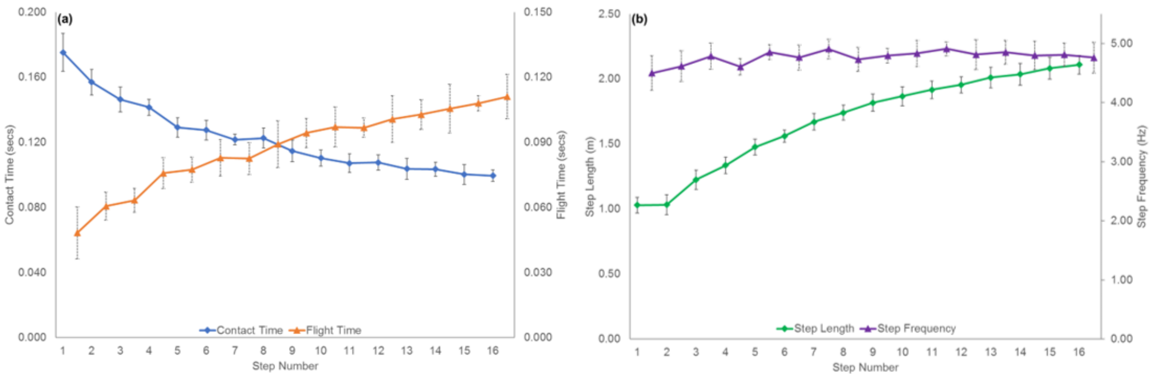

Figure 1. Mean ± SD step characteristics for (a) contact time and flight time, and (b) step length and step frequency for the seven sprinters across the first 16 steps.

* T_F and F_S are presented between x-axis markers as they include temporal information that occurred between consecutive steps.
**The first presented value for L_S is inclusive of the distance between the front block pedal and the start line

Mean standard deviations across the seven sprinters were highest during the first four-step interval for T_C, T_F and F_S, but not for L_S (Table 1), and absolute variability for the group decreased for T_C, T_F and F_S as distance increased. However, these trends were not consistent for every athlete. Significant main effects were observed within the T_C, T_F and L_S variables, with steps 1 to 4 significantly different ($P < 0.05$) from at least one of the subsequent four-step intervals, albeit never the adjacent step 5 to 8 interval (Table 1).

Table 1. Standard deviations calculated within individual steps and averaged across four-step intervals for all step characteristics.

	Contact Time (ms)*				Flight Time (ms)*				Step Length (m)*				Step Frequency (Hz)			
Steps	1-4	5-8	9-12	13-16	1-4	5-8	9-12	13-16	1-4	5-8	9-12	13-16	1-4	5-8	9-12	13-16
Athlete A	2	3	3	2	3	5	4	3	0.03	0.03	0.02	0.03	0.08	0.12	0.14	0.12
Athlete B	7	5	4	3	11	6	5	5	0.03	0.03	0.03	0.04	0.22	0.15	0.14	0.11
Athlete C	6	6	4	2	7	5	6	4	0.04	0.04	0.03	0.05	0.19	0.22	0.10	0.10
Athlete D	6	5	3	2	7	6	5	4	0.03	0.04	0.04	0.05	0.11	0.18	0.17	0.11
Athlete E	8	3	3	3	6	4	4	4	0.03	0.05	0.03	0.05	0.22	0.13	0.07	0.11
Athlete F	5	3	3	2	5	3	3	2	0.03	0.03	0.03	0.03	0.08	0.08	0.08	0.08
Athlete G	7	4	5	2	8	4	4	7	0.02	0.02	0.03	0.05	0.21	0.11	0.14	0.18
Mean	**6** [c,d]	**4** [d]	**4** [a,d]	**2** [a,b,c]	**7** [d]	**5**	**4**	**4** [a]	**0.03** [d]	**0.03**	**0.03** [d]	**0.04** [a,c]	**0.17**	**0.14**	**0.12**	**0.12**

* = significant main effect of four-step interval. [a] = significantly different from steps 1 to 4 interval, [b] = significantly different from steps 5 to 8 interval, [c] = significantly different from steps 9 to 12 interval, [d] = significantly different from steps 13 to 16 interval.

Fluctuations from the mean season value for each step characteristic and velocity were presented as z-scores for the two athletes monitored across 13 training sessions (Figure 2). For both athletes, velocity at 10 m was lowest during the first two monitoring sessions of the season, and reached its highest two values at weeks 16 and 27. Step characteristics for both athletes did not follow a progressive change in one direction from the onset of monitoring. Week 16 provided one example of the highly individualised nature of this data. Whilst both athletes achieved their fastest 10 m velocity, F_S was -1.26 z-scores below, and 1.43 z-scores above, the respective season mean for Athletes F and G. The z-score of each step characteristic appeared highly changeable within each athlete, occasionally fluctuating by over three z-scores from the previous monitoring session.

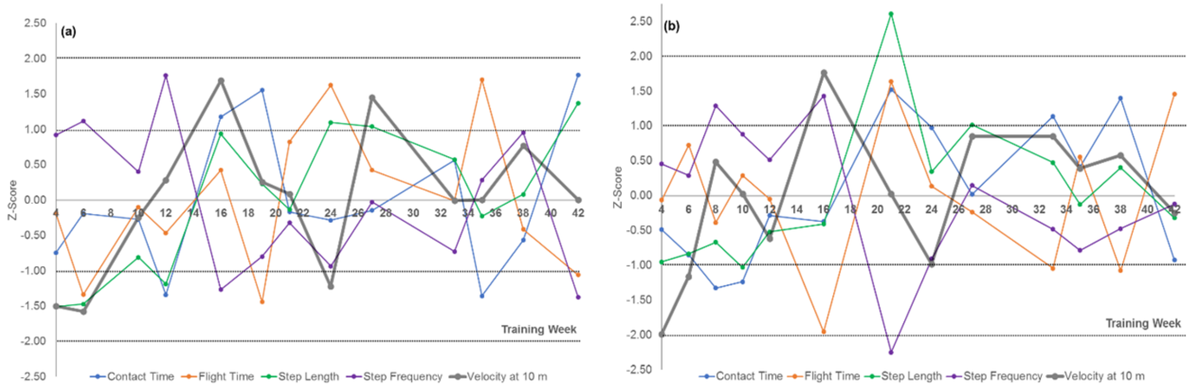

Figure 2. Mean z-scores for each step characteristic across steps 1 to 4 and velocity at 10 m for (a) Athlete F and (b) Athlete G, over a season of 13 training sessions.

DISCUSSION: The study quantified within-session variability for step characteristics during the acceleration phase. Mean SD values revealed the first four-step interval to be significantly more variable than the third and fourth-step intervals for $T_{C,}$ and the fourth-step interval for T_F and $L_{S.}$ Discriminable kinematic changes that have been shown to occur during this early acceleration phase include rapid elevation of centre of mass (CM) height, and initial foot contact moving towards striking the ground in front of the CM (Nagahara, Matsubayashi, Matsuo, & Zushi, 2014). Factors such as these may contribute to the increased variability of $T_{C,}$ and T_F that this study reported. The association between step rhythm (T_F divided by T_C) and velocity would be an interesting extension to this research to establish if more successful starters execute their acceleration strategies with less variability. Whilst the concept of

absolute invariability has previously been viewed as optimal, evidence from sprint start research supports the dynamical systems theory, advocating high movement variability in order to produce a consistently high performance outcome (Bradshaw, Maulder, & Keogh, 2007). The authors encouraged coaches to expose their athletes to a variety of constraints during training so that they are better equipped to adapt joint coordination patterns to any given set of circumstances encountered in competition. The finding that L_S was less variable in the first four-step section may partially be explained by consistent foot placements in the starting pedals and active attempts to bring the point of touchdown back behind the CM.
The study also investigated individual fluctuations in technique variables and performance level across an entire athletics season. This analysis revealed individual-specific responses which showed no clear linear progression or depreciation. No changes in any technique variable (relative to season mean) were consistently associated with performance (velocity at 10 m). The variable step-to-step loading patterns observed in this study may enable the sprinters to reduce the cumulative forces acting on specific tissues whilst still producing a consistently high level of performance. This may offer insight to why specific step characteristics did not closely follow performance level in this study, and supports the need to document longitudinal trends as opposed to potentially unrepresentative data collected from single training sessions. Velocity peaked for both athletes in the 16th and 27th weeks of their training seasons, coinciding with periods of outdoor warm weather training where the training programme emphasised speed work. Athlete F demonstrated greater L_S values during these sessions relative to his season average, whilst it was elevated F_S that was responsible for Athlete G's improved performance in week 16, but this was not the case in other fast weeks (27 and 33). These highly changeable technique outcomes suggest international-level athletes may select and execute from a choice of movement strategies that are situational dependent e.g. external conditions or physical status, to achieve their highest velocities.

CONCLUSION: This study showed that, as distance increased, T_C and T_F became less variable, L_S became more variable, and the variability in F_S did not change. Monitoring the outcome of step characteristics and velocity over an athletics season revealed highly individualised and variable movement strategies employed by international-level sprinters to accelerate maximally. This study has provided novel insight into the season-long kinematic patterns of internationally competitive athletes. Future studies should continue to explore the association between variability and performance over extended time periods, which may inform training programme design and skill acquisition.

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