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CHANGES IN STEP CHARACTERISTICS DURING SPRINT PERFORMANCE DEVELOPMENT

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Horizontal sprint velocity is the product of step length (SL) and step frequency (SF), but the relative importance of these step characteristics (SC) to step velocity (SV) remains uncertain. This study monitored changes in SC for three developing athletes over a 5 week training period. SV, SL and SF were calculated from manually digitized, reconstructed (2D-DLT) 50 Hz video co-ordinates of foot contacts in 60 m sprints. Performance (60 m time) and SV improved where each athlete increased the SC that had correlated significantly (p < 0.05) with SV at the start of training. This suggested that developing athletes initially favoured the SC upon which they relied at the start of training. These findings inform sprint coaching and direct further research into biomechanical variables determining SC and their inter-relationships.

KEYWORDS: athletics, step velocity, step length, step frequency, speed, run.

INTRODUCTION: Average horizontal velocity of the centre of mass (CM) determines sprint performance. Step velocity (SV), the average horizontal velocity from one foot contact to the next contra-lateral contact, is the product of step length (SL) and step frequency (SF). As velocity reaches its maximum, an increase in one step characteristic (SC) is often accompanied by a decrease in the other due to a negative interaction between SL and SF (Hunter et al., 2004). Consequently, an optimum balance between SL and SF is desirable to maximise sprint velocity. Often influenced by the analyses used, sprint research has found conflicting outcomes on whether greater SF or SL is more beneficial to sprint performance. Consequently, it is undecided whether developing SL or SF is more important in achieving an optimal SC relationship. Cross-sectional studies of SC have identified that SL increases more with SV at lower velocities (Mero & Komi, 1985), while SF appears to be more important for achieving maximum velocities (Kuitunen et al., 2002). It has also been suggested that between individuals longer SL produces greater SV, but within individuals, increases in SF are more effective in enhancing SV (Hunter et al., 2004). A recent study adopting a within-subject, longitudinal approach identifies that athletes can reach an elite level with SL or SF being the reliant SC (Salo et al., 2011). A study monitoring SC changes in developing athletes over a training period would provide knowledge of how the SC relationship evolves as performance improves. Such insights will aid sprint training, particularly in developing athletes, by allowing coaches to focus on either increasing SF or SL. Studying SC over an entire 60 m run will provide additional insights into how steps vary in a way that has not been readily available in previously reported research based on single-phases of sprint runs.

METHOD: **Collection:** Three male, developing athletes (Athlete 1, (A1): height = 1.86 m, mass = 87.7 kg, age = 20 yrs, 60 m PB = 8.24 s; A2: 1.75 m, 75.6 kg, 20 yrs, 8.34 s; A3: 1.70 m, 71.1 kg, 19 yrs, 8.65 s) gave written informed consent to participate in the study. The athletes had no history of serious or recent injuries and were fit for the duration of data collection. They trained at an indoor athletics centre twice a week for five weeks, completing five 60 m sprints per session against fellow developing athletes. During each session, separated by at least three days, the athletes performed a similar warm up. A ceiling mounted light gate timing system (PLG, Cheng et al., 2010) was used to record 60 m sprint times during every trial. A block start was initiated by an audible signal (hooter). Rest between each trial was never less than 5 minutes, minimising the effects of fatigue. During each of the 10 training sessions, seven 50 Hz digital video cameras (Sony DCR-TRV 900E) were positioned on an adjacent balcony to capture the entire 60 m sprint. The cameras were set with a shutter speed of 1/300 s, manually focused, with a field of view of at least 9 m in the lane of interest. The images overlapped between one and two metres and each camera was individually calibrated (Bezodis et al., 2008). For calculating step positions, a 9.000 x 1.170 m horizontal plane comprising six marks on the track surface was created. For identifying CM positions, a virtual six point, 9.000 x 2.053 m sagittal plane was created at the centre of the lane using a vertical calibration pole holding a 0.100 m diameter sphere centred 2.053 m above the track surface marks.

Processing & Analysis: The PLG system provided 60 m sprint times. Video images were digitised using Peak Motus (v5.1, Peak Performance Technologies Inc.) and the coordinates reconstructed using 2D-Direct Linear Transformation (Walton, 1981) with lens correction included. SL was calculated as the anteroposterior displacement of the 5th metatarsal head from the first field after touchdown of one foot to the corresponding image for the opposite foot. Due to the constraints of a 50 Hz frame rate, SF was calculated as the quotient of SV and SL. CM position was based on a full body, 20-point model; anthropometric data were taken from de Leva et al. (1996), with the exception of the foot segment (Winter, 2005) to which the mass of a typical running shoe (0.2 kg) was added. The anatomical landmarks were digitised in the fields pre and post touchdown to determine the mean position of CM for each contact (Bezodis et al., 2008). SV was calculated as the horizontal displacement of the CM from one foot contact to the contra-lateral foot contact, divided by the corresponding time interval. An error analysis against a 'reference' motion analysis system (CODA, Charnwood Dynamics Ltd, UK) found reconstructed ground contact locations were within 0.01 m of the CODA values. Each athlete's fastest sprint per week in weeks one (WK1), three (WK3) and five (WK5) are presented. This approach focused analysis on the athletes' best sprints and gave a clear representation of SC change as performance developed. Each sprint comprised approximately 32 steps, with a total of 283 steps analysed. The results were analysed on an individual basis to ensure no trends were masked by the grouping of data (Dufek et al., 1995). To stabilise variances and normalise distributions, SC were natural log-transformed (Bland, 2000) and Shapiro-Wilks tests ($p > 0.05$) confirmed normality. Variation inflation factor values < 4 indicated no multicollinearity problems between SC. Relationships between SC were analysed by Pearson correlations. The steps falling in each 10 m split were identified and mean SV, SL and SF values calculated. SC differences between WK1-3 and WK3-5 for each of the six splits were analysed to assess changes in SC during the training period. Significant differences in sprint times and SC across weeks were identified using Repeated Measures ANOVA with a post hoc Bonferroni correction for repeated measures. The level of significance (α) was set *a priori* to 0.05.

RESULTS: The individual athletes best times in WK1, WK3 and WK5 were as follows: A1 = 8.00, 7.94, 7.76 s; A2 = 8.16, 8.00, 7.86 s and A3 = 8.74, 8.42, 8.66 s. As a group, performance (60 m time) improved significantly ($p < 0.05$) between WK1 and WK 5. As the athletes accelerated during a sprint, SL and SF increased as SV increased for all athletes, in all sprints. During the maximum velocity phase (splits 4-6), SV correlated positively with 60 m time (r = 0.95), underlining the importance of the maximum velocity phase. A negative interaction between SF and SL was found across all athletes (r = -0.53) during this phase. Table 1 provides the correlation values (r) for SC relationships during the maximum velocity phase for individual athletes. SF correlated more strongly than SL with SV in A2 (r = 0.64) and A3 (r = 0.45), whereas SL correlated more strongly in A1 (r = 0.38). This individualised correlation was apparent for each week and was strongest in the sprint which was the best performance. Significant ($p < 0.05$) changes in mean SC for each 10 m split between WK1-3 and WK3-5 are identified in Figure 1.

Table 1.
Pearson Correlation values (r) for step characteristic relationships in all steps during the entire 60 m sprint (splits 1-6) and the maximum velocity phase (splits 4-6). Correlations are for individual athlete's (A1, A2 & A3) fastest sprints from WK1,3,5 and across the three analysed weeks

	A1		A2		A3	
	SV vs. SL	SV vs. SF	SV vs. SL	SV vs. SF	SV vs. SL	SV vs. SF
60 m SPRINT (SPLITS 1-6)						
WK1	0.98*	0.85*	0.94*	0.64*	0.93*	0.60*
WK3	0.71*	0.46*	0.97*	0.69*	0.78*	0.62*
WK5	0.97*	0.93*	0.90*	0.62*	0.95*	0.80*
Three weeks	0.87*	0.63*	0.93*	0.63*	0.90*	0.66*
MAXIMUM VELOCITY PHASE (SPLITS 4-6)						
WK1	0.25*	0.06	-0.11	0.67*	-0.28	0.55*
WK3	0.29*	-0.11	0.12	0.64*	-0.29	0.72*
WK5	0.49*	-0.12	0.15	0.93*	0.25	0.41*
Three weeks	0.38*	0.19	0.12	0.64*	0.08	0.45*
	SL vs. SF		SL vs. SF		SL vs. SF	
MAXIMUM VELOCITY PHASE (SPLITS 4-6)						
WK1	-0.92*		-0.91*		-0.94*	
WK3	-0.98*		-0.33		-0.96*	
WK5	-0.90*		-0.60*		-0.60*	
Three weeks	-0.81*		-0.55*		-0.84*	

*** statistically significant relationship between variables (p < 0.05)**

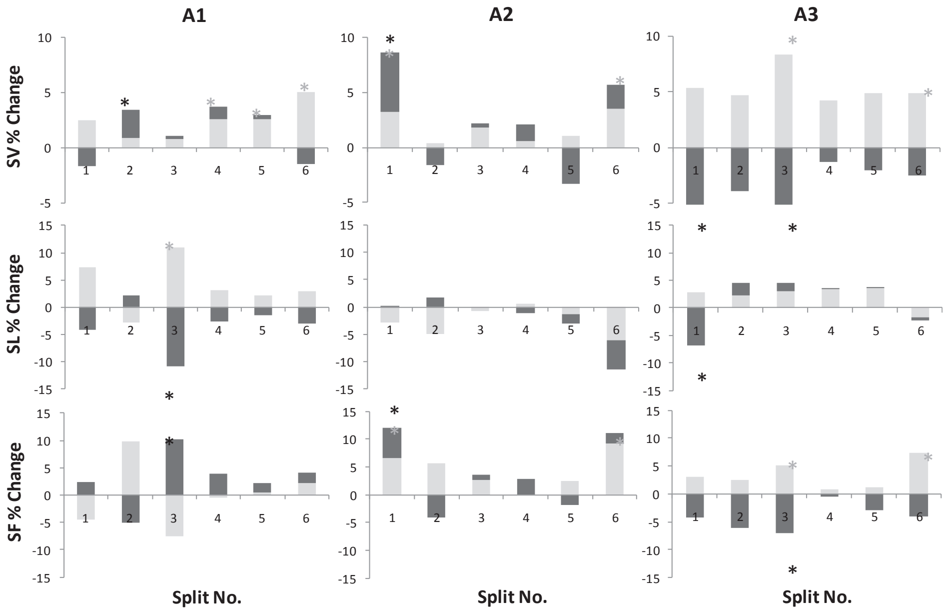

Figure 1: SC analysis for A1, A2 and A3, depicting % change in mean SV, SL and SF for each 10 m split (1-6) over WK1-3 (grey) and WK3-5 (black) of the training period.
* = significant differences between WK1-3 (grey) and WK3-5 (black) P < 0.05.

DISCUSSION: Case studies of three developing athletes were used to identify how SC and their inter-relationships changed as sprint performance improved over a five week training period. Maximum SV (Mean ± SD) increased from 8.23 (± 0.41) to 8.49 (± 0.35) m/s, velocities similar to the recreational athletes analysed by Hunter et al. (2004) (7.44-8.80 m/s) but slower than the elite athletes of Bezodis (2007) (9.15-10.45 m/s). Over the entire 60 m sprint, SV correlated significantly with step SL and SF (Table 1). This pattern was expected; SV is the product of SL and SF and as an athlete accelerates both SF and to greater extent SL, increase. Conversely, a negative interaction between SL and SF during the maximum velocity phase means optimising the SL-SF relationship is necessary to produce the highest SV. A significant negative relationship was evident between SF and SL during the maximum velocity phase in this study (r = -0.53, $p < 0.05$), underlining the presence of a negative interaction between the variables (Hunter et al., 2004). The SC analysis of the maximum velocity phase found A2 and A3 exhibited higher SV-SF correlations (3 weeks: r = 0.64, $p < 0.05$; r = 0.45, $p < 0.05$) whereas A1 showed a greater SV-SL correlation (r = 0.38, $p < 0.05$). Although the SV-SF patterns in A2 and A3 are in line with the findings of Hunter et al. (2004) (SV increase being a result of SF increase), the SL reliance of A1 suggests that in developing athletes either SL or SF can have the greater influence on SV. During the training period, the athletes did not change their SF or SL reliance in the maximum velocity phase, supporting the suggestion that successful athletes can be either SF or SL reliant (Salo et al., 2011). Furthermore, the athletes exhibited their strongest SV-SF or SV-SL correlations when they produced their fastest sprint time over the five weeks (Table 1). The greater improvements were evident where the SC that correlated significantly ($p < 0.05$) with SV at the start of the training period increased, for example A2 significantly improved SV in splits 1 and 6 where SF significantly increased ($p < 0.05$; Figure 1). This phase specific, between-week analysis enabled identification of individualised development trends, while exemplifying the SL or SF reliance. Considering the small sample and limited training time, these findings will be investigated through further study.

CONCLUSION: The athletes were able to improve SV, and ultimately sprint performance, by changing SL, SF or both. Greater SV improvements were evident where the SC that correlated significantly ($p < 0.05$) with SV at the start of training increased. Therefore, the present study indicates that for developing athletes, training which initially focuses on improving the reliant variable (SF/SL) may increase training effectiveness. The analysis of SC over the entire 60 m, and within 10 m splits, allowed a more complete view of the sprint than previously published (e.g. Hunter et al., 2004; Salo et al., 2011).

REFERENCES:

Bezodis, I.N., Kerwin, D.G. & Salo, A.T. (2008). Lower-limb mechanics during the support phase of maximum-velocity sprint running. *Medicine and Science in Sports and Exercise*, **40,** 707-715.
Bland M. (2000). *An Introduction to Medical Statistics (3rd edition).* Oxford Medical Publications.
de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics,* ***29***, 1223-1230.
Cheng, L., Tan, H., Kuntze, G., Bezodis, I.N., Hailes, S., Kerwin, D.G. & Wilson, A. (2010). A low-cost, accurate speed tracking system for supporting sprint coaching. *Journal of Sports Engineering and Technology,* ***224,*** 167-179.
Dufek, J.S., Bates, B.T., Stergiou, N. & James, C.R. (1995). Interactive effects between group and single-subject response patterns. *Human Movement Science*, **14,** 301-323.
Hunter, J.P., Marshall, R.N. & McNair, P.J. (2004). Interaction of step length and step rate during sprint running. *Medicine and Science in Sports and Exercise,* ***36,*** 261-271.
Kuitunen, S., Komi, P.V. & Kyröläinen, H. (2002). Knee and ankle joint stiffness in sprint running. *Medicine and Science in Sports and Exercise*, ***34***, 166-173.
Mero, A. & Komi, P.V. (1985). Effects of supramaximal velocity on biomechanical variables in sprinting. *International Journal of Sport Biomechanics*, ***1***, 240-252.
Salo, A., Bezodis, I.N., Batterham, A.M. & Kerwin, D.G. (2011). Elite sprinting: are athletes individually step frequency or step length reliant? *Medicine and Science in Sports and Exercise.* Advance online publication. doi: 10.1249/MSS.0b013e318201f6f8
Walton, J. (1981). *Close-range cine-photogrammetry: A generalised technique for quantifying gross human motion.* Unpublished Doctoral Thesis. The Pennsylvannia State University.
Winter, D.A. (2005). *Biomechanics and Motor Control of Human Movement*. John Wiley and Sons, Inc.