LOCOMOTOR CONTROL PATTERNS DURING THE POLE VAULT APPROACH PHASE

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The aim of this study was to investigate the visual regulation of locomotion during the pole vault approach phase on athletes of differing skill levels. Seven well-trained athletes performed six jumps which were recorded and analysed. Pole vaulters utilised three locomotor control patterns. However, these were not associated with skill level. The non-stable nature of footfall variability in athletes enforces the need for degeneracy in approach phase movement patterns. Coaches should include training exercises that require intentional use of visual regulation to aid athletes in achieving the flexibility to adapt to changing constraints during the approach phase. Athletes should be considered on an individual basis in order to effectively, efficiently and safely improve performance. Practical solutions are offered which provide examples of how individual locomotor patterns can be interpreted to inform the prescription of training interventions.

KEY WORDS: Visual Regulation, Footfall Variability, Degeneracy.

INTRODUCTION: The production of a high horizontal velocity during the pole vault approach phase is considered to be fundamental in achieving a high performance outcome (Adamczewski & Perlt, 1997). Additionally, the need for the athlete to achieve low end-point variability in the form of a precise take-off location is considered to be a key performance factor within pole vault coaching literature (Richardson, 2013), as well as the wider gait-regulated athletics disciplines (Hay & Koh, 1988). Consistent performance outcomes can be achieved by different patterns of coordination (Bernstein, 1967) and as such, movement pattern variability can be considered functional if it allows the performer the flexibility to adapt to changing constraints during goal-directed actions (Barris, Farrow, & Davids, 2014). Degeneracy provides the theoretical framework to explain functional movement variability and provides athletes with robustness against perturbations. In events such as the pole vault it has been proposed that performers make adjustments through visual control mechanisms (Lee et al., 1982) where by the athlete uses perceptual reference points close to the target to control locomotion. Visual control mechanisms have been explored extensively within long jumping and appear to be present across populations, regardless of the athlete's level of skill (Bradshaw & Aisbett, 2006), age (Panteli et al., 2014), or familiarity with the task (Scott et al., 1997). Little is known about the pole vault approach phase which is more complex in nature due to additional factors such as pole carriage. The aim of this study was to investigate the visual regulation of locomotion during the pole vault approach phase on athletes of differing skill levels. The overall purpose is to inform coaching practitioners when prescribing visually regulated training exercises.

METHODS: Participants & Protocol: National (n=5) and international (n=2) level male pole vaulters were recruited and ranked according to their personal best (PB) (table 1). Ethical approval was granted by the University's Research Ethics Committee and all participants provided written informed consent. A multiple single-subject design was adopted.

Data Collection & Processing: Each participant performed six jumps over an elastic training bar, set at 90% of their personal best, from a self-selected length of approach. Data collections were conducted during a single session at the National Indoor Athletics Centre at Cardiff Metropolitan University. Motion data was collected using four HDV cameras (Sony, Japan) placed 10 m apart at perpendicular angle 25 m from the runway. A 40 m x 3 m plane was calibrated by placing a calibration pole of known distances at sequential points 2 m apart along the centre of the pole vault runway. Video data was digitised and reconstructed using a custom nine-parameter 2D-DLT with lens correction. Reconstruction accuracy was assessed and was found to be <1% of the horizontal field of view. 18 body landmarks were digitised for the purposes of mass centre location (CoM). Two points on the pole were also digitised and location of the pole's CoM recorded using a simple balance test.

Table 1. Participant Information

Participant ID	P1	P2	P3	P4	P5	P6	P7	Mean	± SD
Age (years)	22	19	22	19	20	21	29	21	3.7
Mass (kg)	84.7	69.6	99.1	69.1	66.1	69.2	90.0	76.7	12.7
Stature (m)	1.91	1.75	1.93	1.81	1.80	1.81	1.92	1.85	0.07
PB (m)	5.53	4.40	4.30	4.40	4.40	4.52	5.45	4.64	0.53
PB % of WR	89.8	71.4	69.8	71.4	71.4	73.4	88.5	75.3	8.66
Athlete Ranking	1^{st}	= 4^{th}	7^{th}	= 4^{th}	= 4^{th}	3^{rd}	2^{nd}		

The following variables were calculated: step velocity, defined as average velocity of the CoM across each step; pole angle, defined as the relative angle of the pole to the ground; step length, defined as horizontal displacement between consecutive ground contacts of the distal end of the shoe. Visual regulation was assessed indirectly using standard deviation (SD) of footfall locations during the approach phase, this was defined as the SD of the distal end of the shoe during each ground contact phase across all trials per participant. This onset of visual control was defined as the step at which a marked and systematic reduction in footfall SD was observed. Means and SDs of each variable were produced for each participant. Footfall SD patterns were defined according to Hay & Koh (1988). There were; an 'ascending/descending' where an overall increase in the footfall SD proceeded a systematic decrease in footfall SD, an 'ascending only' pattern where only a systematic increase in footfall SD was observed and a random fluctuation pattern where irregular rising and falling of footfall SD was observed.

RESULTS & DISCUSSION: The aim of this study was to investigate the patterns of visual regulation during the pole vault approach phase on athletes of differing skill levels. The current study demonstrates variations in footfall variability in pole vaulters of differing skill levels. This aligns with the findings of previous research which has shown that across skill levels of long jumpers, an ascending/descending pattern of footfall variability is most common (Hay & Koh, 1988). Additionally, 'ascending only' and 'random fluctuation' patterns were observed. Examples of these from the current study are given in figure 1.

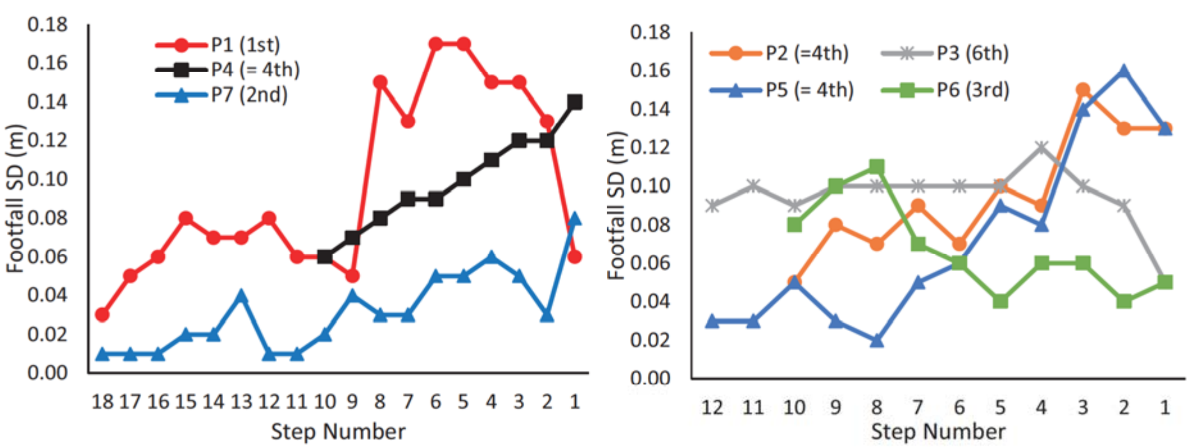

Figure 1. Examples of visual regulation types (Left). Participant no. and rank given in legend. 'Ascending/descending' pattern – circular points. 'Ascending' pattern – square points. 'Random fluctuations' – triangular points. Additional visual regulation data (right). Descending x-axis values represent step number from take-off.

All participants presented ascending/descending patterns (figure 1), except P4 who presented a purely ascending pattern and P7 who presented patterns of random fluctuations. The ascending/descending pattern found in five participants is remarkably similar to that of previous long jump studies (Hay & Koh, 1988) and suggests that the majority of pole vaulters in this sample did use visual regulation to achieve a desired take-off location. P4 did not demonstrate evidence of visual regulation (figure 1). This purely ascending pattern of footfall variability is normally associated with unconstrained locomotion (Bradshaw, 2004). Despite this, variability still remained low, perhaps due to the reduced number of steps in P4's approach phase (10 steps compared to 18 steps used by others). This finding indicates that the participant may experience difficultly with longer approach runs where greater variability in footfall location could accumulate. Visual regulation patterns do not appear to be associated with skill level here given that P4's performance level is equal to that of P2 and P5 who did use visual regulation. Further to this, P7 the second highest ranked performer, presented very low levels of variability (random fluctuations, figure 1) throughout the approach phase (mean ±SD = 0.03 m ± 0.02), demonstrating that high performance levels can be achieved through the use of differing visual regulation strategies. P7's visual regulation strategy is the closest to a stereotyped movement pattern i.e. an approach run with the absence of variability. However this strategy may lack robustness as the participant does not show an ability to make functional adjustments during the approach phase.

In this study magnitudes of footfall variability were low across skill levels when compared to long jumpers who demonstrate magnitudes of footfall variability that decrease with greater skill level (Panteli et al., 2014). While the pole vault approach phase shares similar performance characteristics to that of long jumping (Hay & Koh, 1988) it is a considerably more complex skill for two reasons. 1) The absence of a visual target (e.g. a take-off board) to steer towards and 2) the need to lower the pole into a plant box while running at high velocities. Given these complexities, one may be lead to assume that maximum footfall variability (FV_{max}) would be greater for pole vaulters as control of locomotion would be more difficult. However, this was not the case in this sample. The largest FV_{max} was presented by the highest ranked participant, P1 at ±0.17 m. This value was lower than the FV_{max} reported for elite long jumpers (0.23 m) (Hay, 1988). All participants recorded a FV_{max} lower than the value reported by Hay & Koh (1988) with a mean FV_{max} across the sample of 0.13 m. The lower magnitudes of variability may be due to pole vaulters typically using fewer steps in the approach phase than long jumpers, thus reducing the opportunity for variability in step lengths to accumulate and reducing the need for functional adaptations to be made. Indeed, the largest FV_{max} was recorded by P1 who used the longest approach run (18 steps). Additionally, due to the added task constraint associated with pole carriage it may be more demanding for the pole vaulter to successfully and safely take-off if magnitudes of footfall variability were at the levels achieved by long jumpers. The consequences of not achieving a low end-point variability are far greater for the pole vaulter who risks serious injury. The added constraint of pole carriage may in fact limit the athlete's ability to functionally adapt during the approach phase.

The point at which visual control emerges could be identified only in athletes who present an ascending/descending pattern. For example, for P1 this was five steps from take-off (figure 1). The mean step at which visual control emerged was found to be the fourth step from take-off. This finding is comparable to those of novice (Berg et al., 1995) and elite long jumpers (Hay & Koh, 1988). However, this mean may be somewhat misleading and mask the magnitudes of intra-athlete variability. Variability in onset of visual control was found to range between eight steps (P6) and two steps (P5) from take-off with no two athletes initiating onset at the same step despite successful outcomes. An earlier onset in visual control has been associated with greater skill and performance levels (Bradshaw & Aisbett, 2006). However, in the case of this sample this does not appear to be true. The earliest onset point in this sample was observed in P5, eight steps from take-off. However P5's performance level was 16% lower than the top ranked participant P1 whose onset point was five steps from take-off. Furthermore, P2, P3 and P5 presented onset points at steps from take-off, three, four and two respectively despite all achieving the same performance level. This highlights that individual performers are able to achieve specific task goals in different ways, even under similar performance constraints and does not link the point of emergence of visual control with skill level in this sample. There remains no satisfactory explanation as to why visual control emerges where it does however, this characteristic is consistent with features of self-organisation within the non-linear dynamics paradigm. The findings of this study could not link the point of onset with changes in characteristics such as CoM velocity or pole angle or other derived step characteristics.

The mean variability of the take-off location was 0.09 m ±0.04 m. This value is lower than that reported for elite long jumpers (0.11 m) (Hay & Koh, 1988) despite the absence of the visual target. This lower end-point variability may be attributed to lower horizontal CoM velocities achieved by pole vaulters (8.5-9.5 ms^{-1}) when compared to long jumpers (approx. 10+ ms^{-1}).

By linking the application of biomechanics, motor control and training theory, these findings can provide coaches with meaningful information relating to individual approach phase performance. Practical solutions can be derived from individual's approach phase data, whereby specific drills that introduce visual regulation (e.g. P4) and promote functional variability during the approach (e.g. P7) which may ultimately contribute to an environment in which athletes adapt or develop their locomotors pattern in order to achieve the desired take-off location.

CONCLUSION: Pole vaulters were found to utilise three distinct locomotor control patterns. However, these were not associated with skill level. The non-stable nature of footfall variability in most athletes enforces the need for degeneracy in movement patterns. These key findings can be linked to the application of training theory to allow coaching practitioners to prescribe informed interventions in the pursuit of performance enhancement. It is recommended that coaches include training exercises that require intentional use of visual regulation to aid athletes in achieving the flexibility to adapt to changing constraints during the approach phase. Athletes should be considered on an individual basis in order to effectively, efficiently and safely improve performance.

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