POLE-ATHLETE INTERACTION DURING THE POLE VAULT APPROACH PHASE

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The aim of this study was to assess whether pole vaulters interacted differently with the pole during normal and perturbed approach phase conditions. Six national and international level athletes performed nine jumps, which were recorded and analysed. Pole vaulters were found to produce different coordination patterns when interacting with the pole during normal and perturbed approach phase conditions. The variable nature of the highly skilled athletes enforces the need for degenerate behaviours in achieving consistent performance outcomes. Athletes produced different coordination patterns, and should be considered on an individual basis in order to effectively, efficiently and safely improve performance.

KEY WORDS: Pole Vault, Coordination, Coordination Variability.

INTRODUCTION: During the pole vault approach phase the athlete must satisfy a number of task demands. These include achieving a high horizontal velocity, consistently achieving an accurate take-off location (Needham, Bezodis, Exell, Simpson, & Irwin, 2016) and coordinating the lowering of the pole into the plant box (Frere, L'Hermette, Slawinski, & Tourny-Chollet, 2010). These task demands are coupled in nature and while attempting to satisfy them successfully, the athlete must interact with the pole. High horizontal velocities must be achieved while carrying the pole and an accurate take-off location must be achieved while also regulating the lowering of the pole towards a specific target.

Frere et al. (2010) concluded that pole carriage caused decreases in running velocity (between 4.5% and 11%) as a result of significantly smaller step lengths in novice athletes but, to date, no research has explored the pole-athlete interaction during the approach phase in trained athletes. Furthermore, the athlete must coordinate the lowering of the pole into the plant box from varying horizontal velocities and footfall locations. In both the training and competition environment these sources of approach phase variability can be attributed to external factors (such as weather and track conditions) or by training exercises that change the starting position of the run-up. In either situation, the athlete must be able to adjust the lowering of the pole so that it arrives in the plant box at the correct time while also adjusting the locomotor control pattern to achieve a desired take-off location without decreasing horizontal velocity at take-off.

From a dynamical systems perspective, coordinated movement patterns emerge from the complex relationship between task, organismic and environmental control parameters (Newell, 1986). The selection of coordination patterns is driven by the process of self-organisation in order to solve a movement problem (Wilson et al., 2008) and quantification of coordination between joints has proven insightful for understanding how joints, segments and/or individual systems interact. The aim of this research was to assess whether athletes interacted differently with the pole during normal and perturbed approach phase conditions. Perturbation was achieved by manipulating the starting location of the approach and thus introducing environmental variability. The purpose of this information was to inform coaching practitioners prescribing training exercises that aim to enhance this interaction in order to allow the athlete to effectively and efficiently satisfy the task demands outlined above.

METHODS: Participants & Protocol: National (n = 3, PB = 60-70% of World Record, P1-3) and international (n = 3, PB = 75-80% of World Record, P4-6) level female pole vaulters were recruited. 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 nine jumps (three per condition) over an elastic training bar (90% of personal best). To assess the response pattern of the pole-athlete system, the constraint domain was manipulated. This was achieved by perturbing the starting position conditions of the run-up in a random order between three positions: self-selected, normal starting position (C1); 30 cm closer (C2); or 30 cm further away (C3) from the plant box. These conditions simulated those experienced by the athlete where a greater demand to regulate the footfall locations and pole lowering during the approach phase existed.

3D kinematic data were collected using 15 Vicon Vantage cameras situated around the runway in order to capture the final steps of the approach phase. Camera sampling frequency was set at 250 Hz. Eighteen markers were placed on the athlete and pole to achieve a full body marker-set. Marker trajectories were tracked and gap filled before being filtered with a 4^{th} order zero lag Butterworth filter. Optimal cut-off frequencies were determined for each marker using auto-correlation (Challis, 1999). Athlete centre of mass (CoM) location was determined using de Leva's model (1996) and pole CoM was determined using specific measurements of the pole.

Pole-athlete system interaction was assessed using a modified vector coding procedure (Chang et al., 2008) between the pole-ground and trunk-ground angle. Mean coupling angles ($\bar{\gamma}$) and coordination variability ($\bar{\gamma}_{SD}$) were calculated using directional statistics. $\bar{\gamma}$ were classified into one of four coordination patterns (Chang et al., 2008). These were pole-phase or trunk-phase, where a single segment was moving, in-phase, where segments moved in the same direction, or anti-phase, where segments moved in opposite directions. Time-series waveforms were normalised for the penultimate and final step with each step consisting of a stance and flight phase. Outcome measures including standard deviation of the take-off footfall location, which represents take-off accuracy (TO_{Acc}) and percentage change in step velocity (SV) between penultimate and final step (Δ_{SV}). Success rate represented the number of attempts taken to perform the required nine jumps during testing.

RESULTS & DISCUSSION: The aim of this research was to assess whether the athlete interacted differently with the pole during normal and perturbed approach phase conditions. Overall, outcome measure results (Table 1) showed perturbing the approach phase did not greatly alter approach phase outcomes. All athletes were able to successfully complete jumps from both unperturbed (C1) and perturbed conditions (C2 & C3). For all but P3, there was no decrease in SV between penultimate and final step. In fact, most athletes were accelerating in both unperturbed and perturbed conditions. P3 demonstrated a deceleration under all conditions suggesting that this performance decrease was independent of experimental conditions. Deceleration reduced by 7-8% when the approach was perturbed (C2 & C3). Interestingly, it appears that C2 & C3 increased the velocity of P3.

Table 1
Approach phase outcome measures.

	C1		C2		C3		
	TO Accuracy (m)	**Δ_{SV}**	**TO Accuracy (m)**	**Δ_{SV}**	**TO Accuracy (m)**	**Δ_{SV}**	**Success Rate**
P1	0.09	1%	0.09	1%	0.01	1%	90%
P2	0.07	2%	0.03	2%	0.06	2%	75%
P3	0.09	-10%	0.06	-2%	0.09	-3%	64%
P4	0.22	5%	0.11	2%	0.33	5%	100%
P5	0.07	3%	0.08	0%	0.08	0%	100%
P6	0.09	1%	0.09	1%	0.05	1%	100%

With the exception of P4, TO_{Acc} was not affected by the perturbations. While it may have been expected that end-point variability would increase if approach phase starting positions were manipulated, this was not the case for most participants. Participants were able to regulate or adapt their locomotor patterns in order to achieve their desired take-off location (Needham et al., 2016) and achieve successful performance outcomes. It is unclear if P4's lower TO_{Acc} was product of experimental conditions and/or a reduced ability to regulate locomotor patterns as TO_{Acc} was highest in C2 and lowest in C3. However, as a 100% success rate was achieved this increased end-point variability does not appear detrimental to the performance outcome. A key distinction between national (P1-3) and international level athletes (P4-6) in this sample was be highlighted by success rate. P4-6 were able to complete nine successful jump in nine attempts, hence a 100% success rate. However, P1-3 had success rates ranging between 64-90%. This highlights the need for athletes to increase degeneracy in movement patterns in order to provide robustness against perturbations (Barris, Farrow, & Davids, 2014) and facilitate consistent performance outcomes. From a performance perspective, the ability to complete successful jumps at every attempt is key in championship finals where medal-winning positions are determined not just by heights cleared but by the number of failed attempts.

Dynamical systems techniques were employed to quantify $\bar{\gamma}$ and $\bar{\gamma}_{SD}$ between the athlete and pole. During the penultimate and final steps, the athlete transitions the pole, moving the hands to an overhead position, coordinating the pole in preparation for take-off. National level athletes utilised a similar coordination pattern for all conditions. An example is provided in fig. 1. Classification of coordination pattern revealed that fluctuation between in-phase and pole-phase, i.e. both the pole and trunk were moving together or only the pole was moving. Frequency between these patterns was approximately 50/50 for both steps under all conditions. The response pattern that was observed here suggests that P1-3 adopted the same motor response regardless of how the initial conditions were perturbed. A major influence of motor task strategy selection has been linked to perceptions and pervious experiences of the performer (James et al., 2003). P1-3 possessed limited experience and so selected a single inflexible strategy. In contrast, the international level athletes demonstrated the selection of differing coordination patterns during the penultimate step (fig. 1) for perturbed conditions.

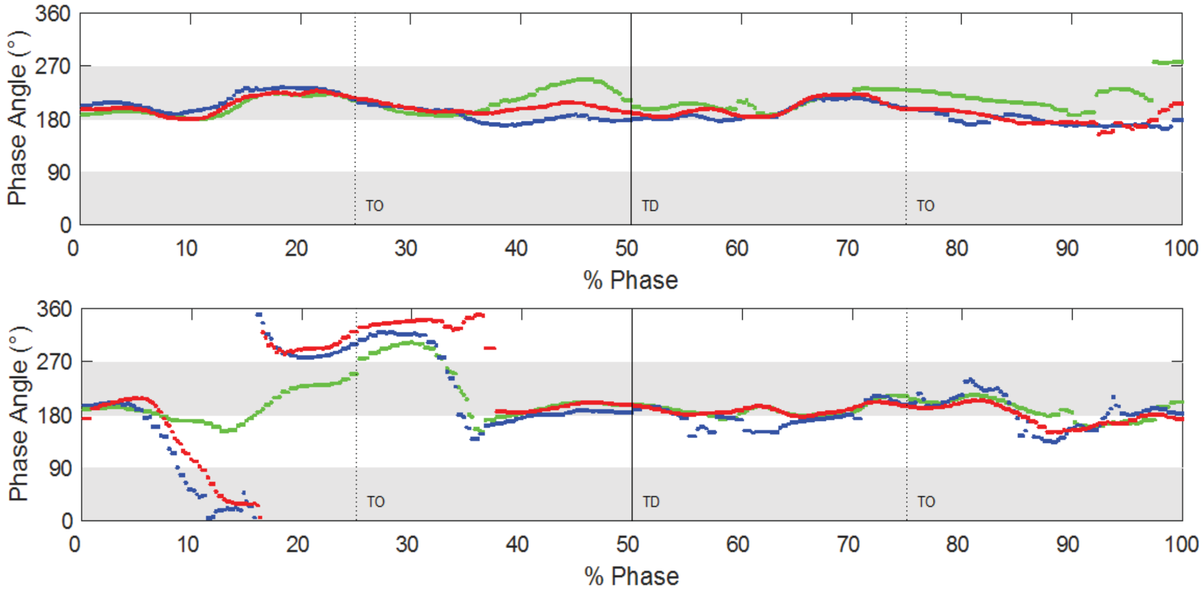

Figure 1. P3 (upper) & P5 (lower) coupling angle for all conditions (Green = C1, Blue = C2, Red = C3). TD = Touch Down (0, 50 & 100%), TO = Toe-off (25 & 75%). 0-50% = Penultimate Step, 50-100% = Final Step. Grey background = In-Phase, white background = Anti-Phase.

For participant's P4-6, coordination classification revealed a pole-phase dominant pattern for C1. Under C2 and C3, frequency between classifications is evenly divided between all four patterns, demonstrating the emergence of a more complex coordination pattern. If previous perceptions and experiences are indeed an influencing factor in strategy selection then it seems plausible that participants of a higher skill level with greater experience would possess a greater number of motor solutions which suit the requirements of the system during a particular repetition (Lees & Bouracier, 1994). Hence, they can solve the movement problem and respond to perturbations in a more flexible manner.

For P1-3, $\bar{\gamma}_{SD}$ ranged between 0° - 30° with the highest levels of $\bar{\gamma}_{SD}$ occurring in the final 10% of phase just prior to take-off. In contrast, $\bar{\gamma}_{SD}$ for P4-6 ranged between 20° and 65° with peaks in variability evident between 10-40% and 90-100% of phase. These time points coincide with the athletes' planting action and results support the concept that high $\bar{\gamma}_{SD}$ can be associated with the transition between coordination patterns (Haken et al., 1985). Variability has been shown to decrease with practice but can also be high in expert performance. In this study, P1-3 presented low levels of $\bar{\gamma}_{SD}$ while their more skilled counterparts, P4-6, presented higher levels. Results match the U-shaped hypothesis of $\bar{\gamma}_{SD}$ (Wilson et al., 2008) although the addition of novice athletes in future research would be beneficial. Implications for training recommendations can be derived from these findings. Athletes who present low levels of $\bar{\gamma}_{SD}$ (e.g. P1-3) should engage in activities that promote functional variability during the approach phase, which contribute to the development of flexible motor patterns and consistent performance outcomes. Coaches should consider skill level and $\bar{\gamma}_{SD}$ when prescribing training drills.

CONCLUSION: Pole vaulters produced different coordination patterns when interacting with the pole during normal and perturbed approach phase conditions. Athletes of a higher skill level exhibited a greater number of motor response patterns under perturbation, higher levels of $\bar{\gamma}_{SD}$ and greater success rates. These differences were linked to skill level and highlight the need for degeneracy in movement patterns to cope with environmental variability. By relating these findings to the application of training theory, coaches can implement athlete specific training drills that effectively and efficiently enhance the ability to achieve consistent performance outcomes.

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