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Influence of Expertise on the Visual Control Strategies of Athletes During Competitive Long Jumping

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Abstract

Understanding performance of athletes in competition is required for enhancing the quality of how athletes co-adapt to the specific, changing constraints of those environments. In long jumping, for example, an athlete must co-adapt with these constraints while also meeting the challenging accuracy demands of the sport. Examining then how long jumpers with different levels of expertise navigate the competition environment is important. This analysis is necessary, given evidence from motor learning research showing that individuals with higher levels of expertise use different sources of information to guide their performance behaviors. In this study, key gait variables during the long jump run-up were recorded during performance at 8 competitions in the 2015 and 2016 Australian track and field seasons to examine the visual control strategies of athletes differing in expertise levels, when performing legal and foul jumps. No statistically significant differences were observed between jumpers differing in levels of expertise when comparing gait patterns in foul and legal jumps. However, different footfall variability curves did emerge that can advance current understanding of long jump run-ups. International-level athletes exhibited higher levels of functional variability during the initial phases of the run-up of legal jumps, with step adjustments spread across the whole of the run-up, compared to National-level athletes. Since athletes of lower levels of expertise exhibited a more stereotyped run-up profile, it is suggested that coaches and practitioners encourage more exploration in training of this group by incorporating increased levels of representative variability during practice. From a practical perspective, increasing variability in practice contexts could encourage National-level athletes to explore different movement solutions and (re)calibrate actions to changing environmental demands, providing more representative simulations of the competition environment.

Keywords

Ecological dynamics, long jump, visual control, run-ups, gait regulation, expertise

Introduction

Expert performance in sport is predicated on an athlete's ability to continuously adapt to the constraints of the competition environment while successfully calibrating actions to ensure they achieve desired performance goals (Davids et al., 2015; Seifert et al., 2013). Capturing an athlete's performance behaviors in their competition environment is, therefore, important in better understanding the continuous interactions that emerge between the performer and the extensive array of sensory information that surrounds them (Pluijms et al., 2013). In a sport such as long jump, the run-up has proven to be a popular paradigm for researchers interested in enhancing understanding of motor control theory, resulting in studies of performance in controlled settings away from the competitive environment (e.g., Berg et al., 1994; Hay, 1988; Lee et al., 1982). An important issue for applied scientists and sport practitioners is whether these findings from controlled practice environments reflect the adaptive performance behaviors that need to emerge under competitive performance constraints (McCosker, Renshaw, Greenwood, et al., 2019). Recent research has advanced understanding of how athletes coordinate gait during competitive long jumping to meet the challenging task demand of achieving the take-off behind the foul line in order for a jump to be registered (McCosker, Renshaw, Polman, et al., 2020). Despite this understanding, consideration of the effects of different expertise levels in meeting these accuracy demands remains neglected and presents as an important question for researchers, given evidence that experts have the ability to use difference sources of information to guide their actions (Renshaw et al., 2007). Capturing any effects of expertise differences is important given the large gap between qualification requirements for a national championship (Australia: Male – 7.30m; Female – 5.85m) and to the Olympic Games (Tokyo 2021: Male – 8.22m; Female – 6.82m). Identifying functional action solutions adopted by experts in meeting the accuracy demands of long jump in competition may, therefore, play an important role in guiding the skill acquisition of athletes on the pathway and serves as an important challenge for practitioners working in development programs.

Recent research has emphasized the need for long jump performers to continually adapt to the changing constraints of the performance environment under varying emotional states in order to produce requisite performance levels for progression (McCosker, Renshaw, Russell, et al., 2019). These performance demands highlight the importance of understanding how interactions between task, environmental, and individual constraints impact expert performance in long jump run-ups. For example, in round 1 of a competition, an athlete's strategic intention of jumping for maximum horizontal distance serves as a major informational constraint that facilitates manipulation of run-up velocity and foot placement error on the take-off board (Maraj et al., 1998). Athletes also must manage their own expectations, and those of others, around performance, especially the emotional responses that may arise as a consequence. An expectation to qualify for an Olympic final, for example, may provide a source of anxiety hindering performance and potential over- or under-estimation of running velocity resulting in changes in foot placement error on the take-off board and subsequent performance outcomes (McCosker, Renshaw, Russell, et al., 2019). Importantly, these constraints on behavior are constantly changing over different timescales (Button et al., 2020), placing increased emphasis on an athlete's ability to produce functional patterns of behavior that meet desired performance outcomes (Davids et al., 2012). How an athlete regulates the coupling of information and movement during the approach to the take-off board, to meet the emerging constraints of competitive long jumping, has yet to be fully investigated.

The understanding of visual control in the long jump run-up has been developed through observation of athlete footfall variability curves expressed across the run-up. Decreases in variability, observed to be "marked and systematic," are considered to signify the visual regulation of stride length, coupled with time to contact information from the board (Lee et al., 1982). Current understanding of run-ups in long jump has demonstrated that an "online" type of visual control exists, influenced by key information sources near the take-off board, and an athletes' need to make adjustments "as and when needed" throughout the run-up (Greenwood et al., 2016; Renshaw & Davids, 2006). Recent work has built on these findings, showing the emergence of different visual control strategies during National-level competitive long jumping when comparing legal and foul jumps. This body of work found that a critical period of stability in footfall variability in the middle phase of the run-up facilitates a more functional regulation of gait (legal jump) towards the locomotor pointing target (McCosker, Renshaw, Polman, et al. under review). Significantly, this most recent study did not consider differing expertise levels as a potential contributing factor to gait regulation.

Given the importance of this period of stable footfall variability in gait during legal jumps, it is important to identify whether this strategy is adopted by elite level athletes during competition. This issue is of particular importance given that recent evidence has shown that the interaction of individual, environmental, and task constraints results in a change in the actions of experts (e.g., Araújo et al., 2010; Renshaw et al., 2009). Previous research into expertise has revealed that experts are more likely to attune to, and (re)calibrate actions to, specifying information in the performance environment in different ways, compared to athletes of lesser expertise (van der Kamp & Renshaw, 2015) thus facilitating skilled movement regulation. In contrast, non-experts may still complete a task through the use of non-specifying variables (Withagen, 2004), but the organization of movement may not be sufficient to demonstrate expertise (van der Kamp & Renshaw, 2015). This is important because previous research has identified the presence of key information sources near the take-off board in long jump (i.e., a standing official) which serve as specifying variables during the run-up (Greenwood, 2014). In competition, however, athletes may have to rely on non-specifying variables as they are faced with uncertain and changing environments of competition (van der Kamp & Renshaw, 2015). An athlete, therefore, needs to continuously (re)calibrate actions in accordance to changes in the information that is available in a particular performance environment for effective goal achievement (Araújo & Davids, 2018; Cabe & Wagman, 2010; Fajen, 2008; Withagen & Michaels, 2002). Accordingly, we would expect expert performers in long jump to demonstrate the ability to exhibit and adapt to both periods of stability and variability (Davids et al., 2015; Seifert et al., 2013), showing a more functional relationship with the performance environment.

The ability of expert performers to produce more adaptive movement behaviors may be better understood through the idea of degeneracy within the movement system (Seifert et al., 2013). Degeneracy refers to the same outcomes being achieved through use of different system components (Edelman & Gally, 2001), providing a theoretical rationale for performance outcome consistency to be a product of a skilled athlete’s ability to continuously adapt movements to enhance performance functionality, rather than simply repeating “ideal” movement patterns practiced in isolation (Barris et al., 2014; Seifert et al., 2013). Research has observed that high levels of variability at the initiation of movement can lead to functional movement adaptions with a reduction in variability observed as the act unfolds. This is termed “funnel like” control (Bootsma & Wieringen, 1990; Davids et al., 1994; Scholz et al., 2000). This progressive emphasis on movement accuracy as performance unfolds can be seen in long jump run-ups, where footfall variability decreases as the take-off board is approached (eg., Glize & Laurent, 1997; Lee et al., 1982). Since athletes in long jump are faced with variable performance environments, the role that practice plays in promoting more adaptive movement patterns has increasing significance. In training, coaches are faced with the need to promote key biomechanical efficiencies associated with maximizing horizontal distance jumped (Hay, 1993; Hay & Nohara, 1990) while still preparing athletes for the flexible and adaptive demands of the performance environment (McCosker, Renshaw, Greenwood, et al., 2019; McCosker, Renshaw, Russell, et al., 2019). Sampling of current coach education resources highlights a tendency to focus more on ensuring consistent and rhythmical approaches in training if an athlete continually overs steps the take-off board by removing the take-off board completely from run-up training (e.g., Brown, 2013) or by removing the take-off component of the long jump (e.g., Fischer, 2015). This coaching practice ignores the known role that the take-off board and the jump itself plays in constraining gait regulation in the athlete (e.g., Glize & Laurent, 1997; Hay, 1988; Lee et al., 1982; Renshaw & Davids, 2004). This approach in training seemingly places more emphasis on gait consistency rather than on meeting the key demands of the sport (i.e., differentiating legal/foul jumps). Understanding, then, how performers during competition contend with the inherent variability of performance environments is critical to future practice design recommendations where actions and decisions should simulate those found in competition (Pinder et al., 2011).

A consideration of the dynamic nature of competition environments and their influence on performance of long jump run-ups is important, given that elite level long jumpers commit foul jumps for a significant proportion of attempts, and that these fouls impact intentionality of performance in future jumps in the competition (McCosker, Renshaw, Greenwood, et al., 2019). In understanding how experts organize their functional movement behaviors during competition, training tasks can also be better designed to facilitate maintenance of coupled perception and action processes (Davids et al., 2012). Using gait variables recorded during the run-ups in competitive long jumping, this study aimed to investigate whether differences in expertise ("International" vs "National") underpin differences in visual control strategies, reflected in functional (i.e., legal jump) or dysfunctional (i.e., foul jump) run-ups. Based on previous motor performance research (Davids et al., 2015; Seifert et al., 2013), we expected that International (INT) level athletes would show higher levels of functional variability, combined with periods of stability throughout the run-up, compared to National (NAT) level athletes.

Methods

Participants

Athletes were categorized into one of two groups to distinguish between different levels of expertise: (1) 8 International-level athletes (Male – 4; Female – 4) who had competed for their respective nation in Olympic Games, World Championship, World Indoors or Commonwealth Games (INT mean (*SD*): age 26.1 (±4.1) yrs, personal best – male 8.21 (±0.12) m; female 6.63 (±0.08) m and (2) 18 National-level athletes (Male – 9; Female – 9) who qualified to compete at National-level long jump competitions (NAT mean (*SD*): age 20.8 (±3.40) yrs, personal best – male 7.66 (±0.17) m; female 6.09 (±0.26) m. All athletes provided consent through servicing agreements as part of the National Athlete Support Structure or upon entry to the competition. They were free to withdraw from the analysis at any time, and ethics approval was provided by the relevant university committee.

Data Collection

Performance data were collected during 8, six-round competitions during the 2015 and 2016 Australian domestic athletics seasons. These 8 competitions were held at 5 venues across Australia. A total of 94 jumps (legal – 57; foul – 37) for INT athletes and 170 jumps (legal – 119; foul – 51) for NAT athletes were used for analysis. All competitions were governed by *Competition Rules 2014-2015* (International Association of Athletics Federations, 2013). The "legality" of trials and distance jumped was formally overseen by officials standing adjacent to the take-off board and pit.

Data for each footfall were collected aligned with previous methodology utilized in locomotor pointing research in long jump (Bradshaw & Aisbett, 2006; Lee et al., 1982). A manually panned high-speed digital camera (Sony Exilim EX-FH20; 210fps; Shutter speed 1/2000) was located perpendicular to the direction of the run-up at an elevated height to capture the run-up and jump phase of each performance. To allow for the calculation of two-dimensional co-ordinate data for each foot placement of the run-up, alternating black and white stripes of 50cm in length were placed on either side of the runway. Using Dartfish video analysis software (Dartfish Pro, Version 10), this procedure enabled the extraction of the horizontal distance values between the toe and take-off board (toe-board distance) for each foot placement of the run-up. Validity of the procedure for calculating foot placement data was assessed by recording running shoes placed at known distances along the runway. Calculated error levels of toe-to-board distance accuracy (±0.01 m) were within accepted norms for locomotor pointing research (Glize & Laurent, 1997; Greenwood et al., 2016; Renshaw & Davids, 2004).

Data Analysis

In line with previous research methods for exploring gait during performance of sporting run-ups (Greenwood et al., 2016; Renshaw & Davids, 2004), variability in toe-board distance for each footfall and the distribution of adjustments across the run-up was measured and reported. Standard deviation of the toe-board distance for each step of each participant was calculated to interpret foot placement variability across the entire run-up (Hay, 1988). These values were then plotted allowing for the identification of the onset of visual regulation and consequent initiation of gait adjustment defined by a "marked and systematic" decrease in the standard deviation of footfall variability (Berg et al., 1994). A total of 18 footfalls was included in the analysis for both groups, reflecting the point where all participants were represented (Renshaw & Davids, 2004).

From the point of visual regulation, distribution of step adjustment was calculated up until the take-off board as first suggested by Hay (1988) using the following equation: Adjustment (%) = $(S_i - S_{i-1}) / (S_{max} - S_J) \times 100$, where S is the standard deviation of the toe-board distance, i is the i^{th}-last step, and j is the take-off. Total absolute adjustment from the visual regulation point to the take-off board was then summated and step adjustment for each step expressed as a percentage of total adjustment.

Descriptive statistics were calculated on jump classification (legal and foul jumps) with the effect of expertise determined using the chi-square test for association and using phi as the effect sizes. Descriptive statistics on jump distance were also calculated with differences between expertise determined using a Mann Whitney Test. To examine the effect of expertise levels (INT and NAT) across step number (1-17) on footfall variability for legal and foul jumps, a generalized estimating equation (GEE) procedure with identity link function was used. A separate GEE was used to determine any differences across step number on footfall variability for legal and foul jumps within each expertise level. A curve estimation procedure was also conducted for each level of expertise for both legal and foul jumps. Analysis was completed in SPSS version 25.0 (SPSS Inc., Chicago, IL). Statistical significance levels were set at $p < .05$.

Results

Between group comparison

Table 1 provides descriptive statistics for jump distance and jump classification across all competitions. No statistical significance was found between groups for number of foul jumps made ($\chi^2 = 2.39$, $p = .12$, phi = -.10), however, jump distance was found to be significantly different (U = 2776.5, $p = .05$).

Table 1. Jump distance and classification

	Total jumps analyzed	Jump Distance	Jump Classification	
		Mean (±SD)	Legal (%)	Foul (%)
International	94	6.93 (±0.73)	57 (60.64%)	37 (39.36%)
National	170	6.78 (±0.80)	119 (70.00%)	51 (30.00%)

The GEE did not reveal any significant differences between groups (INT and NAT) across step number (1-17) for footfall variability during legal and foul jumps. In understanding the formation of the footfall variability curves for each group, for the INT group, mean group footfall variability values showed a marked and systematic decrease from footfall 17 in the legal jump conditions, identifying this point as when athletes began to visually regulate gait (see Figure 1). The decrease in variability stopped at footfall 14 and remained consistent up until the ninth footfall before the take-off board, before showing further marked and systematic decreases up to the take-off step. For the NAT group, a short period of footfall variability stability was evident at the start of the run-up after which mean group variability showed a marked and systematic decrease from footfall 17, identifying this point as when athletes began to visually regulate gait. The decrease in variability stopped at footfall 14 and remained consistent up until the fifth footfall before the take-off board, before showing further marked decreases to the take-off step. Curve estimation procedure showed that for legal jumps for the INT group a linear model provided the best fit ($F(1,149) = 64.29$; $p < .001$; $R^2 = .301$) whereas for the NAT group this was a logarithmic model ($F(1,322) = 29.06$; $p < .001$; $R^2 = .08$).

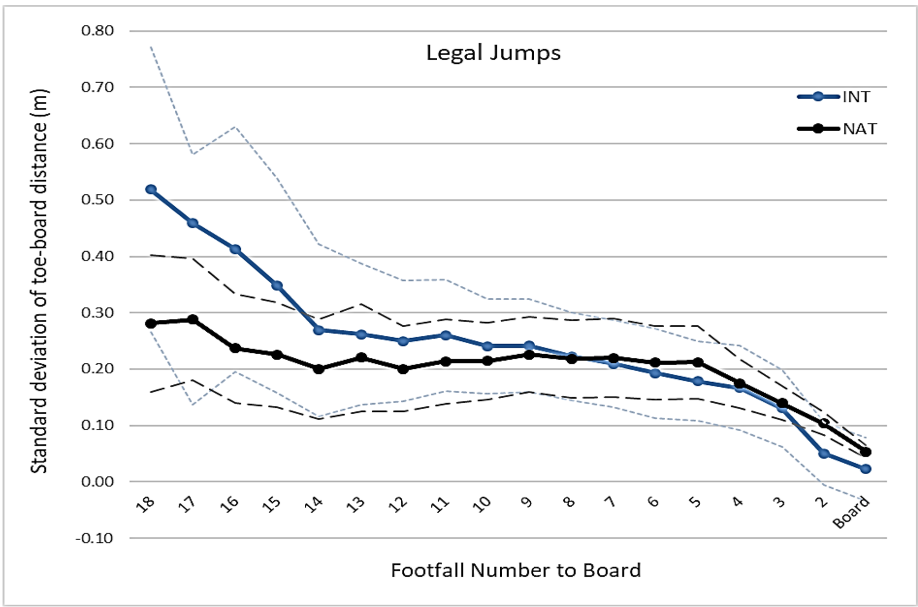

Figure 1. Mean standard deviation for each footfall of the entire run-up (m), separated according to expertise (INT, NAT) for legal jumps. Upper and lower confidence intervals for each level of expertise are depicted by the respective dashed lines. Visual regulation was initiated at the seventeenth footfall from the take-off board for both the INT and NAT group. No significant differences were found between levels of expertise.

For foul jumps, mean group footfall variability for the INT group showed a marked and systematic decrease from footfall 17 which indicated the point of initial onset of visual regulation. This variability continued to fall until footfall 11 after which a small increase was evident before a period of stability up until footfall 5. After this point, variability showed further marked decreases to the locomotor pointing target (see Figure 2). For the NAT group, foul jumps were characterized by an initial gradual decline in variability at the start of the run-up followed by a short period of stability in footfall variability up until footfall 10. This observation was followed by an ascending pattern of variability and a marked and systematic decrease in footfall variability from the fifth footfall from the take-off board. Curve estimation procedure showed that for fouls jumps for the INT group ($F(3,147) = 21.41$; $p < .001$; $R^2 = .46$)" and NAT group ($F(3,158) = 5.08$; $p < .001$; $R^2 = .09$) a Cubic model provided the best fit.

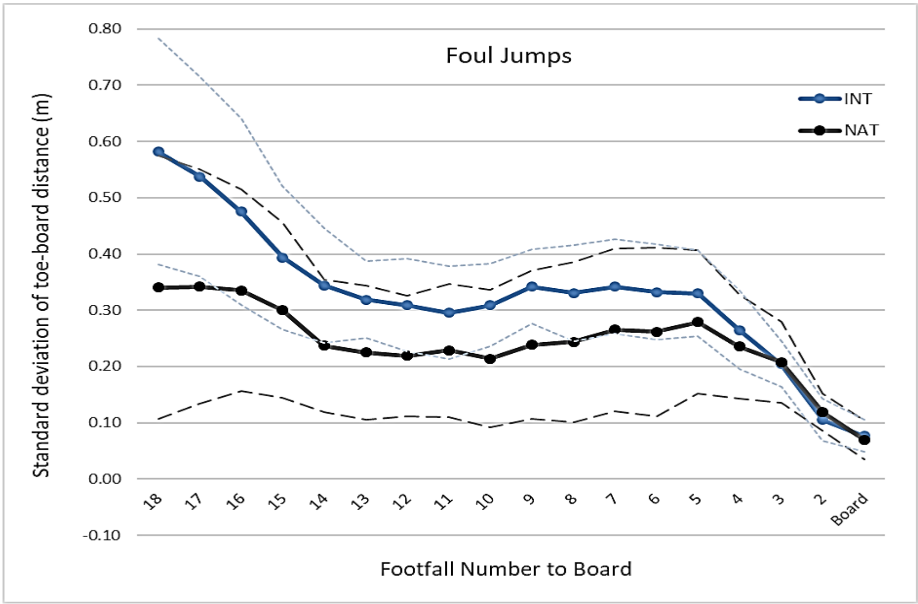

Figure 2. Mean standard deviation for each footfall of the entire run-up (m), separated according to expertise (INT, NAT) for foul jumps. Upper and lower confidence intervals for each level of expertise are depicted by the respective dashed lines. Visual regulation was initiated at the seventeenth footfall from the take-off board for INT group and at footfall 5 for the NAT group. No significant differences were found between levels of expertise.

Within Group Comparison

Results revealed significant differences between gait performances during legal and foul jump conditions for each level of expertise. For the INT group, the GEE found significant differences between legal and foul jump conditions at footfall 5 (B = 0.10; $p = .03$) and for the NAT group at footfall 3 (B = 0.05; $p = .04$). Figures 3 and 4 compares jump outcomes for each level of expertise.

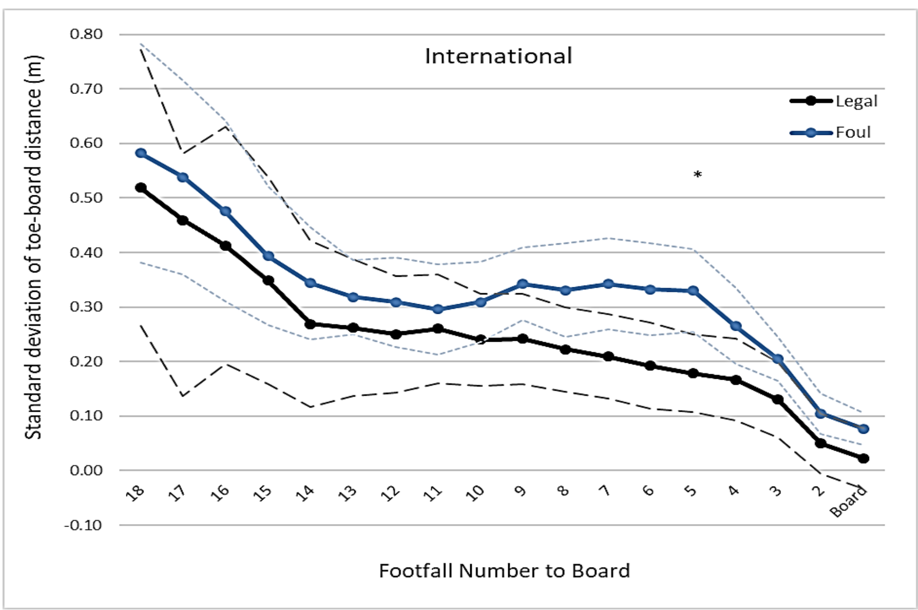

Figure 3. Mean standard deviation for each footfall of the entire run-up (m), separated according to jump outcome (legal, foul) for the INT group. Upper and lower confidence intervals for each jump outcome are depicted by the respective dashed lines. Visual regulation was initiated at the seventeenth footfall from the take-off board in both conditions. *Significant differences observed between conditions: $p < .05$.

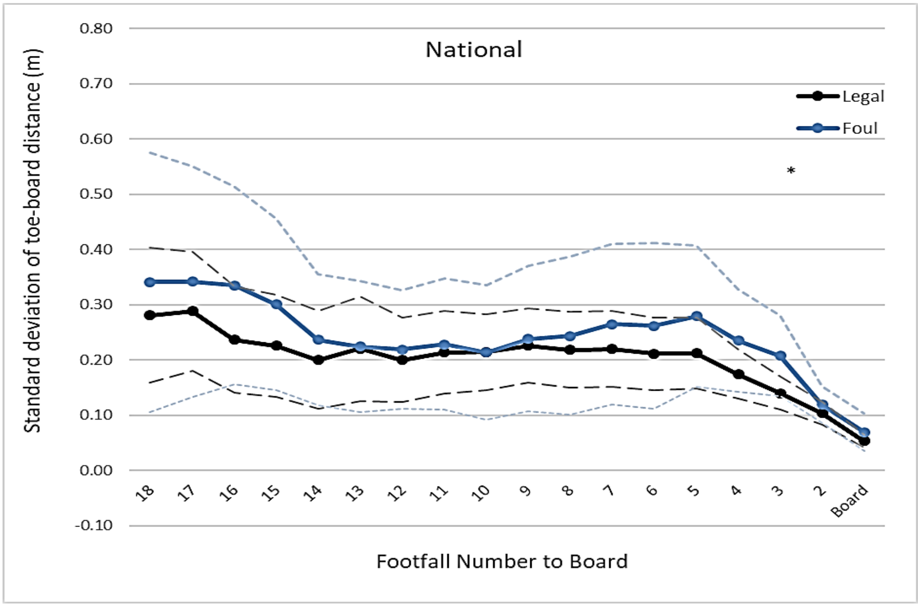

Figure 4. Mean standard deviation for each footfall of the entire run-up (m), separated according to jump outcome (legal, foul) for the NAT group. Upper and lower confidence intervals for each jump outcome are depicted by the respective dashed lines. Visual regulation was initiated at the seventeenth footfall from the take-off board for legal jumps and at the fifth footfall from the take-off board in foul jumps. *Significant differences observed between conditions: $p < .05$.

Step Adjustments

The amount of adjustment made is reported per step as an absolute percentage of total adjustment. Adjustment measures were calculated from the initial onset of visual regulation for each condition until the completion of the run-up (see Hay, 1988). In the first four steps after the initial onset of visual regulation for the INT group, 48.15% of total step adjustments was made in the legal jump condition with 30.05% of adjustments made in the final four steps of the run-up. In comparison, the NAT group made 32.58% of step adjustments in the first four steps after the initial onset of visual control with 47.65% of adjustments made in the final four steps of the run-up. For foul jumps, the INT group made 39.53% of total step adjustment in the first four steps after the initial onset of visual regulation with 38.80% of adjustments being made in the final four steps. In comparison, since the NAT group did not initiate visual control onset until after the fifth footfall to the take-off board, all step adjustments were made in the final four steps to the take-off board.

Discussion

By capturing data in competition, coaches and practitioners will be able to interpret the richness of the constraints of typical performance environments (Renshaw & Gorman, 2015), enhancing the capacity to use these findings to design better practice environments. In this study, we sought to investigate whether level of expertise influenced visual control strategies associated with legal and foul jumps during long jump competitions. Examining the influence of expertise level in competitive performances was considered to be an important step in research, given that athletes of higher levels of expertise would be expected to use different sources of information to regulate performance behaviors (Renshaw et al., 2007). Analysis of competitive long jump run-ups of INT and NAT groups revealed the emergence of different control strategies for functional (i.e., legal jump) organization of gait regulation towards the take-off board. The INT group exhibited higher levels of functional variability during the initial phases of the run-up, with step adjustments spread over the whole of the run-up, which appears to be critical for enhancing the functional regulation of gait towards the locomotor pointing target. In contrast, the NAT group exhibited more consistent footfall variability curves during legal jumps which appear to contribute to a greater need for gait adjustments closer to the take-off board. These findings reveal critical differences in how experts (re)organize functional movement patterns during competitive performance and provide insights on how practice task designs should promote the search for more useful information to guide and re-calibrate actions to changing competition demands.

Analysis revealed differences in the curves of footfall variability when comparing legal and foul jump performance for INT and NAT groups. While statistical significance was not found for each step number between expertise levels, the observed differences in how each curve is expressed holds importance in advancing current understanding of long jump run-ups, based on the traditional interpretation of gait regulation (i.e., Glize & Laurent, 1997; Hay & Koh, 1988; Lee et al., 1982; Renshaw & Davids, 2004). For the INT group, gait during legal jump performance was characterized by a descending-stable-descending formation of footfall variability into the take-off board. In contrast, the NAT group showed a strategy of stable-descending-stable-descending formation of footfall variability. The observed presence of a period of stability in the middle of the run-up displayed by INT and NAT level athletes supports previous research findings that have revealed its importance in maintaining running velocity for the effective re-orientation of the body near the take-off board (McCosker, Renshaw, Polman, et al., 2020; Renshaw & Davids, 2006). However, our results suggest that athletes of higher expertise have a much shorter period of stability followed by a longer descending phase as they approach the take-off board. The shorter stable phase appears to help facilitate a more functional regulation of gait towards the take-off board during legal jumps and "spreads" the adjustments across the approach phase. This spreading of adjustments means that INT athletes only needed to make 30.05% of step adjustments in the final four steps. In comparison, the longer stable phase of the NAT athletes meant that they needed to make 47.65% of their adjustments in the last four steps. The smaller adjustments needed nearer to the locomotor pointing target for INT athletes has potentially positive implications on minimising runway velocity loss and enhancing overall jump distance (Bradshaw & Aisbett, 2006). Understanding the impact of these periods of stability on runway velocity is a critical task for future research, given the positive relationship between runway velocity and jump distance in long jump (Hay, 1993; Hay & Nohara, 1990).

The need for athletes of higher expertise to spread adjustments across the whole of the run-up for legal jumps appears to be facilitated by higher levels of functional variability exhibited during the initial phases of the run-up when compared to NAT athletes. This strategy supports the notion of a funnel like type of control, where movement initiation is characterized by high levels of variability allowing for adaptation of behavior and, in the long jump approach, the reduction of footfall variability as the take-off board is approached (see Bootsma & Wieringen, 1990; Davids et al., 1994; Glize & Laurent, 1997; Lee et al., 1982). Lower levels of variability at movement initiation and longer periods of stability observed in NAT athletes suggest a possible search for more "consistent" run-ups in-line with previous research emphasizing the need for a consistent stride pattern down the runway (Berg et al., 1994; Hay, 1988; Lee et al., 1982). Given this difference in initial footfall variability, it would appear that athletes of higher expertise levels have an enhanced ability to calibrate and scale actions to the dynamics of competitive performance landscapes. This observed difference also supports previous research advocating that functional variability increases with task expertise (Bernstein, 1967; Davids & Araújo, 2010; Manoel & Connolly, 1995; Seifert et al., 2014). Importantly, this skilled adaptation involves becoming attuned to a wider range of perceptual variables that facilitate more efficient gait adjustments

(Araújo et al., 2010; Savelsbergh & van der Kamp, 2000). For example, previous research has highlighted how a vertical reference point (i.e., a standing official) next to the take-off board presents as an information source used by athletes to more effectively spread adjustments across the whole of the run-up (Greenwood, 2014). It also means gaining greater sensitivity to the consequences of actions (Araújo et al., 2006) and subsequently knowing how hard to kick off the surface of the runway for a given required step time as competition demands change (van der Kamp & Renshaw, 2015). Understanding that expertise involves a higher level of adaptability to changing performance landscapes, while still meeting the unique sport specific task demands, such as placing the take-off foot behind the take-off line in long jumping, is an important advance in better understanding performance in sports like the horizontal jumps.

Interestingly, participants at both levels of expertise expressed similar footfall variability curves during foul jumps, leading to increased levels of step adjustments made in the final four steps of the run-up when compared to legal jumps. The magnitude of these adjustments required during foul jumps appears to be too great for functional adjustments to be made to satisfy the accuracy constraints. This observation supports previous research findings associating large gait adjustments immediately prior to target interception with poor jump performance (Bradshaw & Aisbett, 2006). Previous research has also conceptualized how long jump performance involves navigating different performance contexts (McCosker, Renshaw, Russell, et al., 2019) and an inability of athletes to calibrate and adapt actions to these varying contexts can be used to help understand why athletes commit fouls in competition. For example, an athlete may enter a competition with expectations to jump a personal best knowing that, if successful, this performance level will likely result in a top 3 placing in the competition. However, a foul jump in the first round of the competition and unexpected "outstanding" competitor performances, could result in perturbations to expectations and an athlete being unable to "manage" the situation. The result may be the emergence of an underestimation of running velocity and changes in foot placement error on the take-off board in subsequent rounds (Maraj et al., 1998; McCosker, Renshaw, Russell, et al., 2019). Capturing such examples in competition is integral to furthering understanding of how athletes adapt visual control strategies across changing performance contexts to successfully (or unsuccessfully) meet accuracy demands, providing a challenge for future research.

Our findings highlight the need for athletes to be afforded the opportunity in training environments to develop adaptable information movement couplings to calibrate their actions to the changing performance landscapes of high-performance competition (Savelsbergh & van der Kamp, 2000). This concept is important for guiding the skill acquisition of emerging athletes on the pathway and can be used by practitioners working in development programs. Rather than promoting a search for consistent run-ups in practice (Brown, 2013; Fischer, 2015), which may only provide opportunities to develop a coupling between information and movement under very specific performance circumstances (Barris, Farrow, & Davids, 2013), training environments should provide high levels of representative performance variability (Sigmundsson, Trana, Polman, & Haga, 2017). This approach would help athletes discover more useful information to continuously guide and adapt their actions (Fajen & Devaney, 2006; van der Kamp & Renshaw, 2015). That is, practice should consist of "repetition without repetition" as noted by Bernstein (1967, p. 234).

What should "repetition without repetition" look like in long jump training? This training approach should involve navigating varying performance contexts (McCosker, Renshaw, Russell, et al., 2019) and avoiding the overemphasis of repeating idealised movement patterns advocated in more traditional theories of skill acquisition (Adams, 1971; Ericsson et al., 1993; Gentile, 1972). Araújo and Davids (2011) termed this approach to practice design "skill adaptation." For example, the known influence of wind direction and strength on performance can be strategically integrated into the design of training by regularly requiring athletes to change the direction of their run-ups. This adaptive approach to practice could be implemented randomly across a series of jumps as athletes are asked to "respond" to the change in wind strength and direction by ensuring a legal jump (McCosker, Renshaw, Russell, et al., 2019). How an athlete responds to this sample scenario would also change according to changes in intrinsic dynamics (i.e., fatigue, speed gains across a training cycle) allowing coaches to manipulate training variability to the needs of each individual athlete and the resources available to them. While broadening the range of variability is likely to incur more "errors" in training (i.e., fouls) initially, coaches and practitioners need to understand that this will provide opportunities for athletes to explore and exploit available information for re-calibrating their actions to the changing dynamics of the environment (van der Kamp & Renshaw, 2015).

Conclusion

Understanding the movement patterns of expert performers during competitive performance is important in advancing understanding of how athletes co-adapt with emerging constraints, while still meeting performance goals. To further understand the regulation of gait across the run-up in competitive long jumping, the current study investigated whether different levels of expertise led to differences in visual control strategies underpinning functional or dysfunctional movement coordination. Analysis of group data revealed contrasting visual control strategies adopted by differing levels of expertise in the execution of legal jumps in long jump competitions. Higher levels of initial functional variability with step adjustments spread over the whole of the run-up appear critical to more functional adjustments towards the locomotor pointing target for athletes of higher expertise. Since the NAT athletes exhibited a footfall variability curve that appeared to provide for a search for a more consistent run-up, coaches and practitioners should be encouraged to integrate more variable practice within training, facilitating athlete adaptations. Increased representative variability in training will promote a search for more useful information to guide and re-calibrate actions to changing demands. This methodology will assist in simulating the dynamic requirements of the competition environment, preparing athletes for more than just a technical performance. It is also important to recognize that, while this study is the first to provide evidence of how athletes of different expertise regulate gait during competition, the nature of the group analysis fails to recognize the importance of strategies of individual athletes (Renshaw & Davids, 2006). Further work is needed to explore individualized, case study approaches to better understanding individual adaptations to gait during long jump run-ups (Renshaw & Davids, 2006).

Author's Declarations

The authors declare that there are no personal or financial conflicts of interest regarding the research in this article.

The authors declare that they conducted the research reported in this article in accordance with the Ethical Principles of the Journal of Expertise.

The authors declare that they do not have permission to make the dataset publicly available.

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