Run-up strategies in competitive long jumping: How an ecological dynamics rationale can support coaches to design individualised practice tasks

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Abstract

Understanding how individuals navigate challenging accuracy demands required to register a legal jump is important in furthering knowledge of competitive long jumping. Identification of co-ordination tendencies unique to each individual emphasises the need to examine the presence of unique movement solutions and presents important information for individualisation of training environments. In this study, key measures of gait were recorded during the long jump run-ups of 8 athletes at 8 national level competitions in the 2015 and 2016 Australian track and field seasons. These gait measures were examined to identify whether different visual regulation strategies emerged for legal and foul jumps for each competitor. Emergence of different footfall variability data curves, illustrating how step adjustments were distributed across the run-up for each athlete, suggests that athletes interacted differently with features of the competition environment. This observation highlights the importance of movement adaptability as constraints change and emerge across each performance trial. Results provided further support in conceptualising the run-up as a continuous interceptive action task consisting of a series of interconnected events (i.e., individual step lengths) influencing the regulation of gait towards the take-off board. This information can be used by coaches and practitioners in designing training environments that promote athlete adaptation of more functional movement solutions closely matched to the dynamics of competition environments. Results suggest that training designs that help athletes to search, explore and exploit key sources of information from the competition environment will enhance the fit between the individual and the environment and the development of rich, adaptable movement solutions for competitive performance.

Keywords: Ecological dynamics, gait regulation, locomotor pointing, dynamic interceptive actions, long jump, run-ups

1. Introduction

Regulation of gait to accurately intercept a target on the ground with the foot is a task encountered in everyday life and forms part of many critical movements in sport. Termed locomotor pointing in the scientific literature (i.e., De Rugy, Montagne, Buekers, & Laurent, 2001; de Rugy, Montagne, Buekers, & Laurent, 2002; Renshaw & Davids, 2006), over decades, a prominent movement model in sport, used to understand gait regulation, is the long jump run-up (i.e., Berg, Wade, & Greer, 1994; Lee, Lishman, & Thomson, 1982; McCosker,et al., 2020). In the approach phase long jumpers must balance competing speed and accuracy demands (Maraj, Allard, & Elliot, 1998) whilst aiming to satisfy performance goals. All movements interacting with an environment are regulated under ecological laws of control (van der Kamp & Renshaw, 2015). Importantly, individual strategies to achieve the intended outcome goals in a specific task may vary due to differences in existing co-ordination tendencies (based on variations in intrinsic dynamics) and the context in which the task is performed (Button, Seifert, Chow, Araújo, & Davids, 2020).

Understanding of how run-ups are regulated during the long jump has evolved from observations of athlete footfall variability across the run-up where ‘marked and systematic’ decreases in variability values were observed at the initiation point of visual control (Berg et al., 1994; Lee et al., 1982). Early research proposed a two-phase approach control strategy, where an accelerative phase, (increases in footfall variability) was followed by a ‘zeroing-in’ phase (decreases in footfall variability) where athletes visually regulated stride length, coupled to time to contact information from the board (Lee et al., 1982). Theoretically, this explanation is somewhat contradictory in implying movement control in early phases could be initiated by a ‘motor program’ (open loop control mode). In the latter stages of action, movements may be regulated by a stable coupling of perception and action (a closed loop control mode). This problematic need to switch between control modes to explain action regulation was criticised and addressed by Renshaw and Davids (2006). Their work on cricket bowlers' run-ups exemplified how, rather than gait control only becoming visually regulated at some standardised point in the run-up for all athletes, *continuous* perception-action couplings regulated adaptive behaviours throughout the entirety of the run-up, with adjustments emerging in each individual, as and when needed.

More recent investigations of long jump run-ups have identified the influence of key task demands on the visual regulation strategies of athletes in competition. These task demands are associated with a critical rule of long jump being the need to place the take-off foot behind the take-off line for a jump to be measured and classified as 'legal' (*Competition Rules 2014-2015*, 2013). This investigation found different patterns of footfall variability emerging during performance of legal and foul jumps, impacted by athlete level of expertise (McCosker, 2020; McCosker et al., 2020). Importantly, a "funnel-like type of control", where initial high levels of variability led to reductions in variability on approach to the take-off board, was observed in coordination tendencies of athletes with higher expertise levels (McCosker et al., 2020). Periods of footfall variability stability during the run-up of legal jumps were also found to be of importance for the effective 'spread' of gait adjustments approaching the take-off board, supporting the notion that the run-up should be examined as a whole and not broken down into 'critical' phases (McCosker et al., 2020). This form of control was associated with an enhanced ability to calibrate and scale actions to the emergent dynamics of competitive performance landscapes (Jacobs & Michaels, 2007; McCosker et al., 2020; van der Kamp & Renshaw, 2015). The observation, that different gait regulation strategies may exist between legal and foul jumps is important, considering that all previous research on long jump run-ups have only reported performance data from successful (legal jumps - take-off foot behind take-off line) trials (i.e., Lee et al., 1982; Panteli, Smirniotou, & Theodorou, 2015; Scott, Li, & Davids, 1997). Furthermore, recent investigations on elite long jumping have reported the difficulties athletes have in meeting task accuracy demands with nearly one in three jumps registered as 'fouls' (McCosker, Renshaw, Greenwood, Davids, & Gosden, 2019). Whilst recent research has advanced understanding of how gait is regulated during competitive performance, a limitation is that group data were used for analysis, limiting understanding of individual movement solutions. Furthering knowledge of how individuals regulate actions in dynamic, unpredictable competitive environments to meet challenging accuracy demands is integral to ensuring that practice task designs simulate the perceptual, action and cognitive sub-system demands in competition for each athlete.

An individualised approach to studying athlete performance in competition is aligned with theoretical concepts from ecological dynamics which emphasise the importance of investigating the performer-environment system to conceptualise how human behaviour emerges (Araújo, Davids, & Hristovski, 2006; Araújo, Davids, & Passos, 2007; Gibson, 1979). Ecological dynamics rationalises that each individual seek their own functional movement solutions (i.e., those that may lead to successful outcomes) during task performance, as they satisfy multiple, interacting constraints in the competitive environment (Button et al., 2020). Here, constraints have been defined as boundaries or features that channel self-organisation tendencies in dynamical movement systems (Button et al., 2020; Newell, 1986). Three classes of constraints shape emergent behaviours related to the: (1) task (e.g., rules of the sport, current competition structure and status, elimination threat; position on leader board); (2) individual (e.g., anthropometrics, leg power, fatigue levels or mental states such as anxiety or self-efficacy) and (3) environmental (e.g., wind velocity, presence and involvement of crowd, altitude). Recent research into long jump performance has identified key interacting task (influence of legal/foul jump), individual (strategic intentions) and environmental (wind strength and direction) constraints that influence performance during elite level long jump competitions (McCosker, Renshaw, Greenwood, et al., 2019).

Additionally, elite long jump coaches experiential knowledge has helped identify key performance contexts that an athlete must navigate during competition (McCosker, et al., 2019) whilst still seeking to maintain key biomechanical efficiencies (i.e., runway velocity and take-off board positions)(see Hay, 1993; Hay & Nohara, 1990). Managing behaviours in these contexts has been captured by a strategy of 'perform, respond and manage', where athletes must adapt to changing task constraints under varying psychological, physical and emotional states, needed in their continuous interactions 'navigating' the '*ebb and flow'* of the competition structure (Jones, 2003; Lewis, 2004; McCosker, Renshaw, Russell, et al., 2019). To exemplify, an athlete may register a foul jump in the first round of a competition. They must '*respond'* to this jump by performing a submaximal jump (or 'safe' jump) in the 2nd round in order to register a legal jump and increase the likelihood of receiving 3 further jumps in the competition after the re-order in 3rd round (*Competition Rules 2014-2015*, 2013). Importantly, these contexts that frame individual performances are unique to each athlete, continually shaped by their own capabilities and available resources, supporting individual adaptations to changing informational constraints that regulate behaviour in competition (Araújo et al., 2006; McCosker, Renshaw, Russell, et al., 2019).

Key ideas in an ecological dynamics framework draw attention to how mere technical repetition and rehearsal of a specific movement pattern in practice may not fully prepare an athlete for satisfying the many interacting performance constraints, exemplified earlier (Button et al., 2020; Renshaw, Davids, Newcombe, & Roberts, 2019). Rather, in performance preparation, athletes need to find adaptable, *functional solutions* exploiting the degeneracy of the movement system. Degeneracy is a movement system property supporting how the same outcomes can be achieved through use of different system components (Edelman & Gally, 2001). Recording and interpreting the nature of continuous interactions between each performer and the competition environment is needed in research. Performance analysis capturing these interactions with key constraints in the sport competition environment may help in the effective design of more individualised training environments (Araújo, et al., 2021).

To assist in designing more contextual training environments, coaches and practitioners can adopt ideas originating from the notion of "sampling" physical and task information from Brunswik (1956), including from competition environments. Brunswik's (1956) original ideas have supported the importance of representative learning designs (Pinder, Davids, Renshaw, & Araújo, 2011), including affective learning designs (Headrick, Renshaw, Davids, Pinder, & Araújo, 2015), that can be used to guide the preparation of athletes for competition. These design frameworks advocate that actions, emotions and decisions observed in competitive environments could be strategically integrated into practice designs, enhancing the potential for their transfer to competition settings. Adoption of these methods to enrich practice specificity could assist movement scientists and sport practitioners in moving away from the 'one-size-fits-all' approach which has been integral to more traditional pedagogical strategies in the past (Button et al., 2020; Chow, Davids, Button, & Renshaw, 2016; Renshaw et al., 2019). Practising preconceived 'ideal' run-ups, without reference to influence of key informational constraints, such as the location of the take-off board and the jump at the end of the run-up (Brown, 2013; Fischer, 2015), may potentially limit the positive transfer of these movement patterns to competition environments (Pinder et al., 2011). Additionally, practising in 'splendid isolation', without encountering some of the similar emotions and intentions, close to those experienced in competition, could inhibit how an athlete perceives and moves (e.g., Maloney, Renshaw, Headrick, Martin, & Farrow, 2018; Oudejans & Pijpers, 2009; Renshaw et al., 2019).

Adopting an idiographic approach is also important in enhancing the design of practice environments ensuring awareness and presence of key informational constraints unique to each individual and the resources available to them (McCosker et al., 2020). Using data on gait variables (e.g., footfall variability and step length adjustments) collected during performance of the run-up in competitive long jumping, and analysed using inter-trial and trial-by-trial methods conducted in field-based locomotor pointing tasks (e.g., Greenwood, Davids, & Renshaw, 2016; Lee et al., 1982; Renshaw & Davids, 2004), the aim of this study was to investigate whether different visual regulation strategies emerged for individuals during legal and foul jumps. It was expected that, based on the sampling of individual results from previous research (McCosker, 2020), different footfall variability data curves would emerge for legal and foul jumps for each participant. We also expected, based on understanding of the unique individual-environment interactions advocated by ecological dynamics (Araújo et al., 2006; Araújo et al., 2007; Gibson, 1979), individual run-up strategies would emerge to shape performance behaviours of athletes in relatively unique ways during competition.

2. Methods

2.1 Athletes

Performance data from eight, highly skilled athletes competing during national level competitive long jumping were selected for analysis. Characteristics of these athletes can be seen in Table 1. Personal best jump distance was deemed to be the best jump distance achieved under competition regulations before the commencement of data collection in 2015. Expertise levels were determined by criteria outlined in previous research in elite long jumping (McCosker et al., 2020): ‘INT’ were those athletes who had competed for their respective nation in Olympic Games, World Championship, World Indoors or Commonwealth Games and ‘NAT’ were those athletes who qualified to compete at national level long jump competitions. All athletes provided consent for use of their performance data through servicing agreements as part of the National Athlete Support Structure or upon entry to the competition. Athletes were free to withdraw from the analysis at any point in time and ethics approval was provided by the relevant university committee.

Table 1

Athlete characteristics

Athlete	Gender	Expertise	Age (yrs)	Personal Best Jump (m)
1	F	INT	27	6.54
2	F	INT	30	6.63
3	F	NAT	19	6.27
4	F	NAT	26	6.20
5	M	INT	27	8.12
6	M	INT	24	8.27
7	M	NAT	21	7.76
8	M	NAT	17	7.52

2.2 Data Collection

Data were collected from observations made during 8, six-round competitions held at 5 venues across Australia during the 2015 and 2016 Australian domestic athletics season. A total of 132 jumps (legal – 74; foul – 58) was used for the analysis. Athletes competed in events according to their own competition scheduling and, therefore, did not always compete in the same events. Trials available for each athlete can be seen in Table 2. All observed competitions were governed by International Association of Athletics Federation rules and regulations (*Competition Rules 2014-2015*, 2013). Therefore, ‘legality’ of trials and distance jumped was formally overseen by accredited officials adjacent to the take-off board and pit.

Table 2

Details of data collection during competition.

Athlete	No. of competitions competed in	Total competition jumps performed	Jump Classification		Total trials analysed	Jump Classification	
			Legal Jumps (%)	Foul Jumps (%)		Total legal jumps analysed	Total foul jumps analysed
1	2	12	7 (58.33%)	5 (41.67%)	10	5	5
2	4	23	17 (73.91%)	6 (26.09%)	21	16	5
3	4	21	16 (76.19%)	5 (23.81%)	21	16	5
4	2	9	4 (44.44%)	5 (55.56%)	9	4	5
5	4	21	10 (47.62%)	11 (52.38%)	21	10	11
6	4	15	6 (40.00%)	9 (60.00%)	14	5	9
7	3	18	6 (33.33%)	12 (66.67%)	18	6	12

8	3	17	12 (70.59%)	5 (29.41%)	17	12	5

Data were collected using methodologies previously used in field-based locomotor pointing research (e.g., Berg et al., 1994; Bradshaw & Aisbett, 2006; Glize & Laurent, 1997; Scott et al., 1997). Using a manually-panned, high-speed, digital camera (Sony Exilim EX-FH20; 210fps; Shutter speed 1/2000) located at an elevated height and perpendicular to the direction of the run-up, the run-up and jump phase of each performance was recorded. Alternating 50cm black and white strips were placed either side of the runway for calculating two-dimensional co-ordinate data for each foot placement of the run-up. Dartfish video analysis software (Dartfish Pro, Version 10) was used to extract 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 was verified by placing running shoes at known distances along the run-up and calculating toe-to-board distances (Greenwood et al., 2016; Renshaw & Davids, 2004). 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).

2.3 Data Analysis

To investigate movement regulation strategies utilised by athletes in competition, trials were separated into 'legal' and 'foul' jumps, as formally determined by the accredited official at each event.

2.3.1 Inter-trial analysis

In line with previous research exploring gait during performance of approach runs in sport (Greenwood et al., 2016; Renshaw & Davids, 2004), variability in toe-board distance for each footfall, defined as the standard deviation of toe-board distance, was analysed for each footfall of the run-up for each athlete (Hay, 1988). Mean standard deviation values for each athlete were then plotted to display foot placement (in)consistency across the run-up and to identify the onset of visual regulation which signified the initiation of gait adjustment (Berg et al., 1994; Glize & Laurent, 1997; Scott et al., 1997). The onset of visual regulation was identified as the point where there was a 'marked and systematic' decrease in the standard deviation of footfall variability (Berg et al., 1994). These procedures constitute the 'inter-trial analysis' methodology observed in previous literature (i.e., Hay, 1988; Lee et al., 1982). Due to no standardised length of the run-up existing, the number of footfalls analysed for each athlete varied between athletes but represented the first initial step towards the take-off board and all subsequent footfalls until take-off.

2.3.2 Step Adjustments

In line with the methodology outlined above, distribution of step adjustment was reported from the first point of visual regulation until the take-off board, as first suggested by Hay (1988). This analysis method explored how changes to gait regulation are spread across the run-up (Greenwood et al., 2016) calculating the corrective adjustment that each participant made after the initial onset of visual control (Hay, 1988). The spread of adjustments was calculated using the following equation used in run-up research (Berg et al., 1994; Hay, 1988; Scott et al., 1997): 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. The total absolute adjustment from the initial onset of visual regulation to the take-off board was then summated and step adjustment for each step expressed as a percentage of total adjustment.

2.3.3 Trial-by-trial Analysis

To examine the relationship between step adjustment needed and the amount of adjustment produced at each step of the run-up, a trial-by-trial analysis following the protocols of Montagne, Glize, Cornus, Quaine, and Laurent (2000) was adopted for each athlete. Importantly, this form of analysis provided an understanding of whether gait adjustments produced were functional and associated with gait adjustments required (Greenwood et al., 2016). This analysis required the calculation of the mean distance of a given footfall from the take-off line and subtracting this from the actual distance of the same footfall from the take-off line (i.e. footfall $_n$ – mean footfall $_n$) to find the adjustment that was needed for each step of the run-up. The amount of adjustment produced by each athlete was then plotted by subtracting the mean step length for a given step from the actual step length (n + 1) of that step. Step n +1 indicates the step that immediately follows footfall n. To exemplify, for a given athlete, if on the 5th footfall from the take-off board, the footfall was 0.20m further from the take-off line than the mean distance for that footfall, the length of the next step would have to be regulated 0.20m more than the mean length for that step in order for that step to remain 'on target'. Linear regression analysis calculated the extent to which the athlete was capable of producing the required adjustment for each step of the run-up (see also Renshaw & Davids, 2004). For each athlete, the coefficient of determination (R^2) for each step of the run-up was plotted to indicate the percentage of the variance in step adjustment produced, explained by step adjustment needed.

3. Results

Table 3 provides descriptive statistics for each athlete for trials analysed. For wind recordings, higher average velocity was measured during foul jumps for six of the eight athletes. All athletes recorded similar accuracy levels at the take-off board during legal jumps, with six of eight athletes recording lower performance averages during foul jumps when compared to legal jumps.

Table 3

Descriptive statistics for all athletes

Athlete	Avg. Jump Distance Legal (m)	Avg. Jump Distance Foul (m)	Take-off Board Accuracy Legal (m)	Take-off Board Accuracy Foul (m)
1	6.39 (± 0.14)	-	0.09 (± 0.05)	-0.08 (± 0.12)
2	6.46 (± 0.13)	-	0.12 (± 0.05)	-0.06 (± 0.05)
3	6.02 (± 0.42)	-	0.12 (± 0.07)	-0.04 (± 0.04)
4	6.01 (± 0.23)	-	0.11 (± 0.13)	-0.09 (± 0.05)
5	7.69 (± 0.24)	-	0.09 (± 0.04)	-0.11 (± 0.04)
6	7.87 (± 0.19)	-	0.11 (± 0.10)	-0.10 (± 0.12)
7	7.61 (± 0.16)	-	0.10 (± 0.05)	-0.12 (± 0.11)
8	7.61 (± 0.24)	-	0.12 (± 0.06)	-0.08 (± 0.05)

3.1 Inter-trial analysis

Figure 1 displays athlete footfall variability curves across the run-up separated by jump condition (legal, foul). High levels of inconsistency were observed in the starting position of each athletes' run-up with variability ranging from 1.33m to 0.02m during legal jumps and 1.18m and 0.08m during foul jumps with a mean variability of 0.68m and 0.65m respectively. The initial onset of visual regulation in legal jump conditions varied between athletes, with five of the eight athletes showing marked and systematic reductions in toe-board standard deviation in the first five footfalls from the start of the run-up. During performance of foul jumps, this initial point of visual regulation onset was evident in the first five footfalls for six of the eight athletes. All athletes displayed multiple periods of visual regulation during both legal and foul jump conditions. Maximum values of toe-board footfall variability measures were highest in foul jump conditions for five of the eight athletes.

Insert Figure 1.0 near here

3.2 Step Adjustments

The amount of adjustment made per step, reported as an absolute percentage of total adjustment, is presented for the first four steps after the initial onset of visual regulation and for the last four steps of the run-up in Table 3. Greater adjustments were observed in the first four steps during legal jumps when compared to foul jumps for four of the eight athletes. When comparing adjustments made in the last four steps of the run-up, one athlete did not start visually regulating until the last six steps and hence no comparison could be made. Of the remaining seven athletes, five showed fewer adjustments in the last four steps of the run-ups during legal jumps, when compared to foul jumps, with the remaining two athletes making greater adjustments.

Table 4

Absolute percentage of step-length adjustments for the first four steps after the initial onset of visual regulation and the last four steps of the run-up for each athlete.

Athlete	Legal Jumps – Step Adjustments (%)		Foul Jumps – Step Adjustments (%)	
	First 4 Steps	Last 4 Steps	First 4 Steps	Last 4 Steps
1	45.23	13.47	18.93	14.46
2	24.71	25.36	29.83	16.54
3	29.91	39.43	35.26	41.48
4	n/a*	n/a*	43.26	56.74
5	46.28	32.51	40.66	43.21
6	48.15	22.55	40.46	26.49
7	25.84	24.19	42.94	18.27
8	33.53	35.75	30.91	37.34

*Did not initiate visual regulation onset until after the sixth footfall to the take-off board, therefore, all step adjustments were made during this period.

Note: Adjustments are separated by jump outcome (legal, foul).

3.3 Trial-by-trial analysis

Correlations between the amount of adjustment needed and produced for each step of the run-up are displayed in Figure 2 for each athlete. For legal jumps, significant correlations were observed for every athlete, with the exception of athlete 4, indicating athletes' ability to make adjustments based on need during the run-up. The number of steps across the run-up in which a significant correlation was observed varied between athletes ranging from 0 to 13.

The highest correlation between adjustment needed and produced emerged during the last four steps of the run-up for 4 of the 8 athletes. For foul jumps, significant correlations were found between the amount of step adjustment needed and produced for every athlete. The number of steps across the run-up in which a significant correlation was found ranged from 3 to 8. The highest correlation between adjustment needed and produced emerged during the last four steps of the run-up for 2 of the 8 athletes.

Insert Figure 2.0 near here

4. Discussion

Understanding how individual athletes meet the challenging accuracy demands of competitive long jumping is important for advancing knowledge of how gait is individually regulated under exacting performance conditions. In this study, we investigated whether different visual regulation strategies emerged for individuals during legal and foul jumps in competitive long jumping. Analysis of run-ups of eight highly trained athletes revealed the emergence of different visual regulation characterised by gait regulation during both legal and foul jumps for each athlete. Despite some structural similarities, results revealed different footfall variability profiles and differences in how step adjustments were distributed across the run-up for each athlete. These findings indicate that athletes interacted differently with the performance environment as they sought to meet the highly challenging accuracy demands of the sport. This observation suggests existence of highly skilled, relatively unique adaptations by each athlete to the constraints of the competitive environment, commensurate with the national and international level of the participants in the study. These findings highlight the significance of seeking to understand the nature of visual regulation strategies at the individual level scale, impacting how training tasks may be strategically designed for each athlete.

Findings of the inter-trial analysis revealed the formation of individually unique footfall variability curves for each athlete when comparing legal jumps (see Figure 1). Foundational understanding of gait regulation in long jumping indicated a two-phase strategy consisting of a 'acceleration' and 'zeroing-in' phase (e.g., Lee et al., 1982). In contrast, results of the present study support previous research in cricket run-ups suggesting that step regulation is made by each athlete *when* needed and *at multiple times* throughout the run-up (see Figures 1 and 2) (Greenwood et al., 2016; Renshaw & Davids, 2004). More recent research has also associated a specific profile of foot variability with different levels of expertise based on group data analyses (McCosker et al., 2020). However, the results of the current study highlighted *individual profiles* that emerged in competition. These individual profiles provide evidence suggesting that athletes utilised different visual regulation strategies in order to meet task accuracy demands, whilst co-adapting to the emerging constraints during competitive long jumping. For example, athlete 1 exhibited a descending-stable-descending profile of footfall variability during legal jumps whilst athlete 5 exhibited a more ascending-descending-stable-descending profile. Regardless of the nature of the footfall variability profile emerging during legal jumps, it is evident that athletes were able to use key informational constraints in the competition performance environment to guide the successful interception of the take-off board from behind the take-off line.

Inter-trial analysis also revealed the structurally similar presence of stable levels of footfall variability during legal jumps in all athlete profiles. This finding supports previous research advocating the importance of periods of footfall variability stability for functional gait regulation towards the take-off board (McCosker et al., 2020; Renshaw & Davids, 2006). Interestingly, however, the duration of this period of stability could not be associated with a specific level of expertise as has been suggested (McCosker et al., 2020). Rather, results showed how each athlete exhibited periods of stability that appear to facilitate the functional regulation of gait towards the take-off board, based upon personal needs (see Figures 1 and 2). For example, athlete 7 and 8, both NAT level athletes, exhibited very different periods of stability across the run-up (see Figure 1), yet registered similar average jump distances (see Table 3). When comparing legal and foul jumps, it is evident that these periods of stability need to be viewed in terms of their contribution to satisfying the accuracy demands of the sport (i.e., lead foot behind the take-off line at take-off). Five of the eight athletes, for example, made greater adjustments in the last four steps of the run-up during foul jumps, compared to the last four steps of legal jumps (see Table 4). These larger adjustments, closer to the take-off board during foul jumps, appear to be too great for functional adjustments to be made and agree with data reported in previous research associating poor jump performance with large step adjustments close to target interception (Bradshaw & Aisbett, 2006; McCosker et al., 2020). .

The ability of athletes to spread adjustments across the whole of the run-up during legal jumps appears to be aided by a *funnel like* control strategy, observed in previous research and exhibited by 6 of the 8 athletes in the current study (see Figure 1). To exemplify, this organisation of movement patterns has been associated with task expertise in long jumping (Glize & Laurent, 1997; Lee et al., 1982; McCosker et al., 2020; Scott et al., 1997), as well as performance of other interceptive tasks, such as hitting and catching (see Bootsma & Wieringen, 1990; Davids, Handford, & Williams, 1994; Savelsbergh, Whiting, & Bootsma, 1991). Our results, however, imply a more complex explanation. Since a funnel-like type of control was evident across both legal and fouls jumps for the skilled athletes, understanding what levels of variability are functional, and how these levels may vary between individuals, is important to advance understanding of how skilled athletes manage long jump run-ups under constraints of competition. Theoretically, our understanding of functional movement variability is based on the premise that the level of variability exhibited affords flexibility to each athlete to adapt actions to satisfy the dynamical constraints emerging in the competitive performance landscape (Barris, Farrow, & Davids, 2013). Adopting an individualised perspective allowed us to view these levels of variability in terms of how they actually contributed to performance functionality in individual athletes (i.e., achieving a legal jump). Careful interpretation of performance variability is, thus, important and will depend on the individual and the resources and capacities (known as effectivities, Gibson, 1979) available to them (e.g., *knowledge of* the environment, perception-action skills and physical and psychological capabilities). As an example, consider performances of athlete 2, an international level athlete and athlete 3, a national level performer. Both athletes displayed similar funnel like control and levels of accuracy at the take-off board (see Figure 1 and Table 3). However, athlete 2 initiated visual regulation earlier in the run-up, compared to athlete 3 (footfall 20 vs footfall 17) and displayed a more even distribution of step adjustments for legal jumps, when comparing the first and last 4 steps (see Table 4). These comparative results imply that task expertise is more associated with knowing when and how to use key informational constraints in the performance environment to calibrate and scale actions to satisfy task demands. More specifically in long jumping, knowing how hard to kick off the surface for each step of the run-up is important (McCosker et al., 2020; van der Kamp & Renshaw, 2015). This example suggests that undertaking ideographic analyses could help practitioners to enhance the design of training environments through the strategic integration of key informational constraints to meet the specific needs of each individual.

Results from the trial-by-trial analysis also revealed a large amount of between-individual variability across the whole of the run-up for legal and foul jumps, that enhance our understanding of gait regulation in competitive long jumping (see Figure 2). Significant correlations between adjustments needed and produced at different steps of the run-up during legal jumps for each athlete demonstrated the capacity of athletes to satisfy the accuracy demands of long jump in a variety of ways. However, it is clear that the adjustments made during foul jumps were insufficient in satisfying the run-up task constraints (i.e., resulting in the front foot remaining behind the take-off line). These adaptations emerged in spite of the presence of significant correlations between adjustments needed and produced for individual steps during foul jumps. It is important to note, that whilst adjustments were made in an attempt to match what was needed to bring the run-up back online into ‘safety’ threshold margins that would result in a legal jump, it is clear that very few adjustments had 1:1 mapping (i.e., a correlation value of 1.0). This, observation suggests that the gap between what (performance) was needed and what (performance) is actually possible had been exceeded resulting in a foul jump. In contrast, in a legal jump, adjustments were able to bring the run-up back ‘on-track’ sufficiently. This finding further emphasises the conceptualisation of the run-up as a continuous interceptive action action consisting of a series of interconnected events (McCosker et al., 2020). In this respect, the run-up should be considered as a whole (complex system) and as part of an overall contribution to the successful (or unsuccessful) attainment of performance goals (i.e., legal jumping) and not examined by decomposition into its individual components (i.e., individual step length adjustments) (Clarke & Crossland, 1985).

Understanding of legal versus foul jumps, as described above, can be strengthened when considering recent research conceptualising how athletes have to navigate different performance contexts during competition (*perform, respond* and *manage*) to achieve one of two common performance intentions (jump for maximum distance or more conservatively for submaximal distance) (McCosker, Renshaw, Russell, et al., 2019). Considering the inability of some athletes to calibrate and scale actions to these changing performance contexts may help us understand how they were unable to make the required step adjustments necessary to register a legal jump. For example, consider the context where an athlete competing in a

National championship final, has fouled the first two rounds of the competition and must record a legal jump in round 3 that is long enough to be ranked in the top 8 athletes to receive a further 3 jumps in the competition (*Competition Rules 2014-2015*, 2013). For a well-credentialled athlete with pressures to make Olympic team selection, this situation may be too difficult to *manage*. They may be unable to calibrate and adapt actions effectively across the run-up, resulting in an overestimation of running velocity and large foot placement error at the take-board i.e., foul or ineffective jump position (Maraj et al., 1998; McCosker, Renshaw, Russell, et al., 2019). In contrast, a developing athlete who has just reached their first National final, may think they have nothing to lose in this situation and can *perform* resulting in the effective calibration of actions to meet task requirements.

4.1 Implications for motor learning and coaching science

Gaining an understanding of how athletes develop their own movement solutions to successfully (or unsuccessfully) meet the accuracy demands of long jump is a useful tool in enhancing the fit between the individual and the performance environment during practice. This investigation revealed the emergence of different visual regulation strategies during legal and foul jumps in competitive long jumping for individual athletes. Rather than using this information to direct 'the reproduction of text-book' techniques in practice, based on putative models of repeatable movement patterns in more traditional theories of skill acquisition (Adams, 1971; Ericsson, Krampe, & Tesch-Romer, 1993; Gentile, 1972), practitioners can use this information to help design training environments that up-skill athletes to find more adaptable solutions to changing competition environments. Helping athletes to search, explore and exploit key informational constraints from the competition environment in training will promote a tighter fit between the individual and environment and enhance the development of a rich array of movement solutions that work (i.e., are functional) (Araújo & Davids, 2011; Chow et al., 2016; Renshaw, Arnott, & McDowall, 2021). Besides gathering data on individual interactions with the performance environment, the effective design of training environments is also built on a foundational knowledge of individual, task and environmental constraints that influence competitive behaviours. This theoretical platform will support integration of appropriate informational sources into training designs, so that athletes gain valuable exposure to representative competition constraints and learn to attune to those that are most useful in producing adaptable movement solutions (Button et al., 2020; Renshaw et al., 2019). Importantly, both empirical data from performance analyses and coaches' experiential knowledge reported in previous research have provided a platform for practitioners to better understand what influences performance in long jump competitions (McCosker, Renshaw, Greenwood, et al., 2019; McCosker, Renshaw, Russell, et al., 2019). The following section will provide practical examples of how coaches and practitioners can better design training environments to enhance the fit between the individual and the environment based on the individual analysis of gait regulation in long jump.

4.2 Designing coaching interventions for individual athletes

First, let us consider athlete 3, a national level athlete who, at the time of data collection, had previously competed at various junior major championships internationally and was part of National pathway programs. The greater percentage of step adjustments made in the last 4 steps of the run-up, for both legal and foul jumps for this athlete (see Table 3), could have negative implications for runway velocity and key take-off variables (Bradshaw & Aisbett, 2006). The higher average wind velocity during foul jumps for this athlete is also important to recognise, given the known influence of wind direction on jump performance (de Mestre, 1991; McCosker, Renshaw, Greenwood, et al., 2019; Ward-Smith, 1985). To assist in helping the athlete make step adjustments during the run-up, small sprint hurdles could be placed down the runway to help facilitate stride length adjustment whilst still maintaining critical runway velocity (Galloway & Connor, 1999). Randomising the number and placement of hurdles positioned on the runway may help the athlete to continually adjust to the environment (Bradshaw & Sparrow, 2001; Lundin & Berg, 1993) whilst, importantly, still being required to meet task intentions (i.e., maximal or submaximal jump). Performing these jumps in variable wind conditions with known specifying information present near the take-off board (i.e., chevrons and official) (Greenwood et al., 2016) may also help the athlete search for the optimal affordance (knowing how hard to kick off the surface for each step) for each repetition.

Furthermore, we can also consider athlete 5, an INT level athlete who, at the time of data collection, had competed at senior major championships internationally. Of the 21 trials collected for this athlete, over half were classified as foul jumps (see Table 1) and similar to athlete 3, more step adjustments were made in the last 4 steps of the run-up for foul jumps when compared to legal jumps (see Table 3). Importantly, previous research has highlighted the potential emotional and psychological impact of foul jumps on future jump performance in a competition (McCosker, Renshaw, Greenwood, et al., 2019; McCosker, Renshaw, Russell, et al., 2019). For example, a foul jump in round 1 of a competition increases the odds of a foul jump in subsequent rounds in elite level competitions (McCosker, Renshaw, Greenwood, et al., 2019). An inability to regulate emotions and changes in cognitive strategy after a foul could then lead to future changes in movement coordination patterns (i.e., step adjustments) (Connor, Farrow, & Renshaw, 2018). The implication is that foul-jumping athletes may need to be afforded more opportunities in training to learn how to self-regulate in responding to foul jumps and to navigate varying performance landscapes (McCosker, Renshaw, Russell, et al., 2019). For example, across a series of three jumps, this athlete could be asked to jump for maximal distance in the first of these jumps. If this jump was registered as a foul, then the athlete could be asked to “respond” to this foul by making a submaximal jump in Round 2. In order to intensify the emotional response to a further foul in Round 2, a virtual scoreboard could be implemented where known competitors and registered jumps are listed. The athlete could then be asked to “manage” the situation by registering a jump sufficient enough to make the Top 8 competitors and be eligible for a further 3 jumps as per normal competition rules (*Competition Rules 2014-2015*, 2013). This strategic intervention for enriching self-regulation skills will provide the athlete opportunities to experience more contextual training scenarios, adapting to changing task constraints as can be expected in the competition performance environment (McCosker, Renshaw, Russell, et al., 2019).

4.3 Limitations and future directions

While the sample size of the current study was predicated on competition scheduling of elite long jumpers, future research could look to examine larger data samples and use inferential statistics within further investigations. Indeed, capturing data within competition presents many challenges including restrictions on accessibility of the performance arena, the unpredictability of each athlete performance and the general lack of experimental control (Pluijms, Canal-Bruland, Kats, & Savelsbergh, 2013). Also, in an event such as long jumping, athletes may only perform 3 jumps within a single competition in some instances. In light of this, the dataset used within this investigation is a reflection of what is possible in terms of gaining valuable information on high level long jumping during competition. Researchers will need to devise strategies oh how best to approach these challenges for future investigations, with strategically planned training competitions a possible option, ensuring that experimental designs replicate comparable decision making, perception and actions as observed in competiti . Future research can also be directed towards better understanding the contextual challenges and self-regulatory demands in long jump competition and how this influences the emergent visual regulation strategies of athletes as a competition unfolds. This investigative approach can consider interpreting and understanding the roles of footfall variability stability in facilitating the successful (or unsuccessful) attainment of tactically-defined, performance intentions (i.e., maximal or sub-maximal jump). It would also be of interest to better understand the impact of a foul jump on the emergent run-up strategies in subsequent jumps. This approach is of importance, given previous research has reported that nearly one third of jumps in elite level long jumping are classified as foul jumps (McCosker, Renshaw, Greenwood, et al., 2019).

5. Conclusion

Understanding how individuals meet critical accuracy demands during competitive long jumping is important in preparing athletes for long jump performance and assisting with the individualisation of training design. Using data on gait variables collected during performance of the run-up in competitive long jumping, the current study investigated whether different visual regulation strategies emerged for individuals during legal and foul jumps. Analysis of individual data revealed the emergence of different visual regulation strategies characterising gait regulation during both legal and foul jumps for each athlete during competitive long jumping. These findings suggest that athletes interacted differently with the competition environment with a high level of adaptability displayed, in order to meet the accuracy demands of the sport. Capturing these unique interactions between individuals and the competitive environment in performance analytics can provide information to be used strategically by coaches and practitioners in practice to up-skill athletes in finding more adaptable solutions to changing competition environments.

Declaration of Competing Interest

None.

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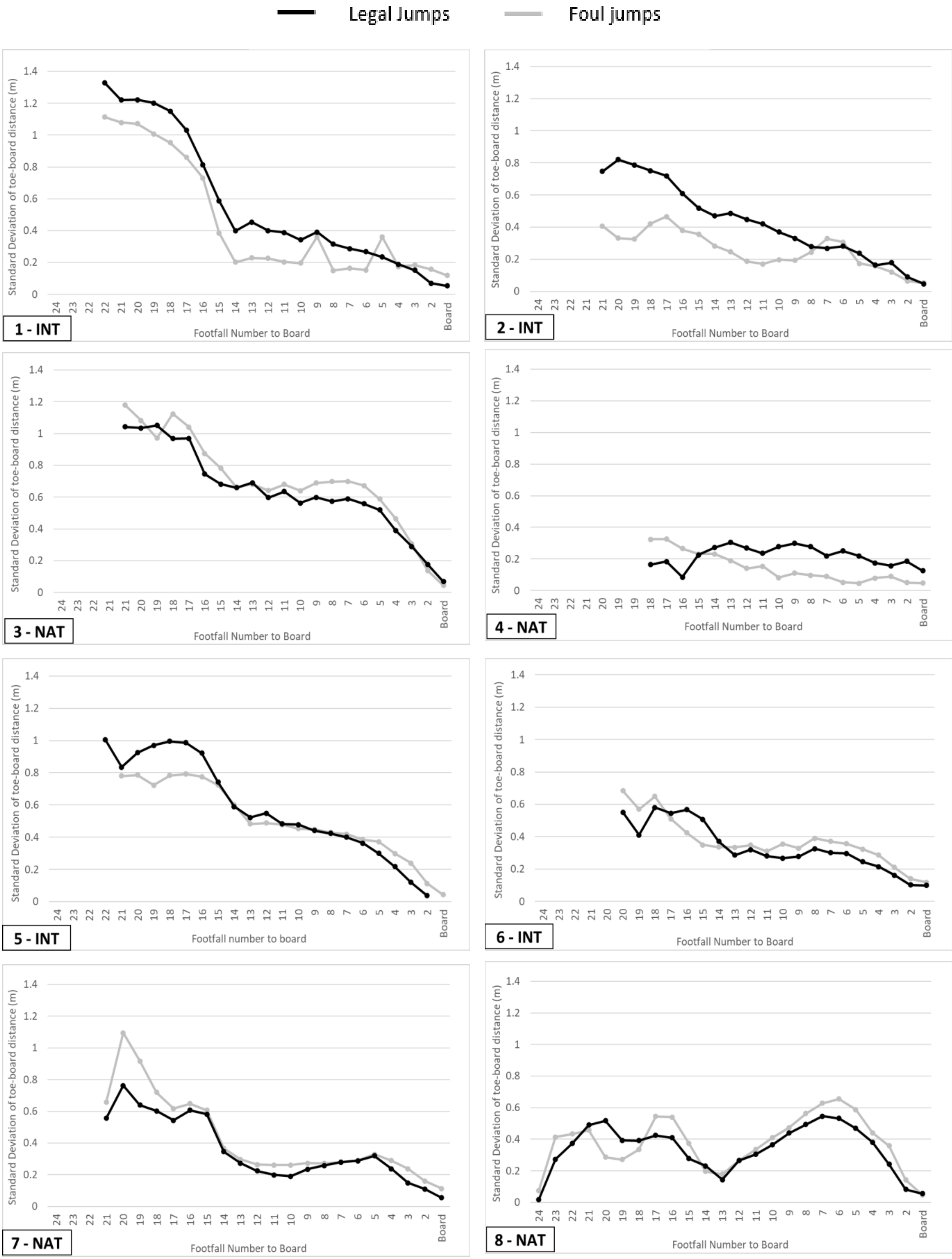
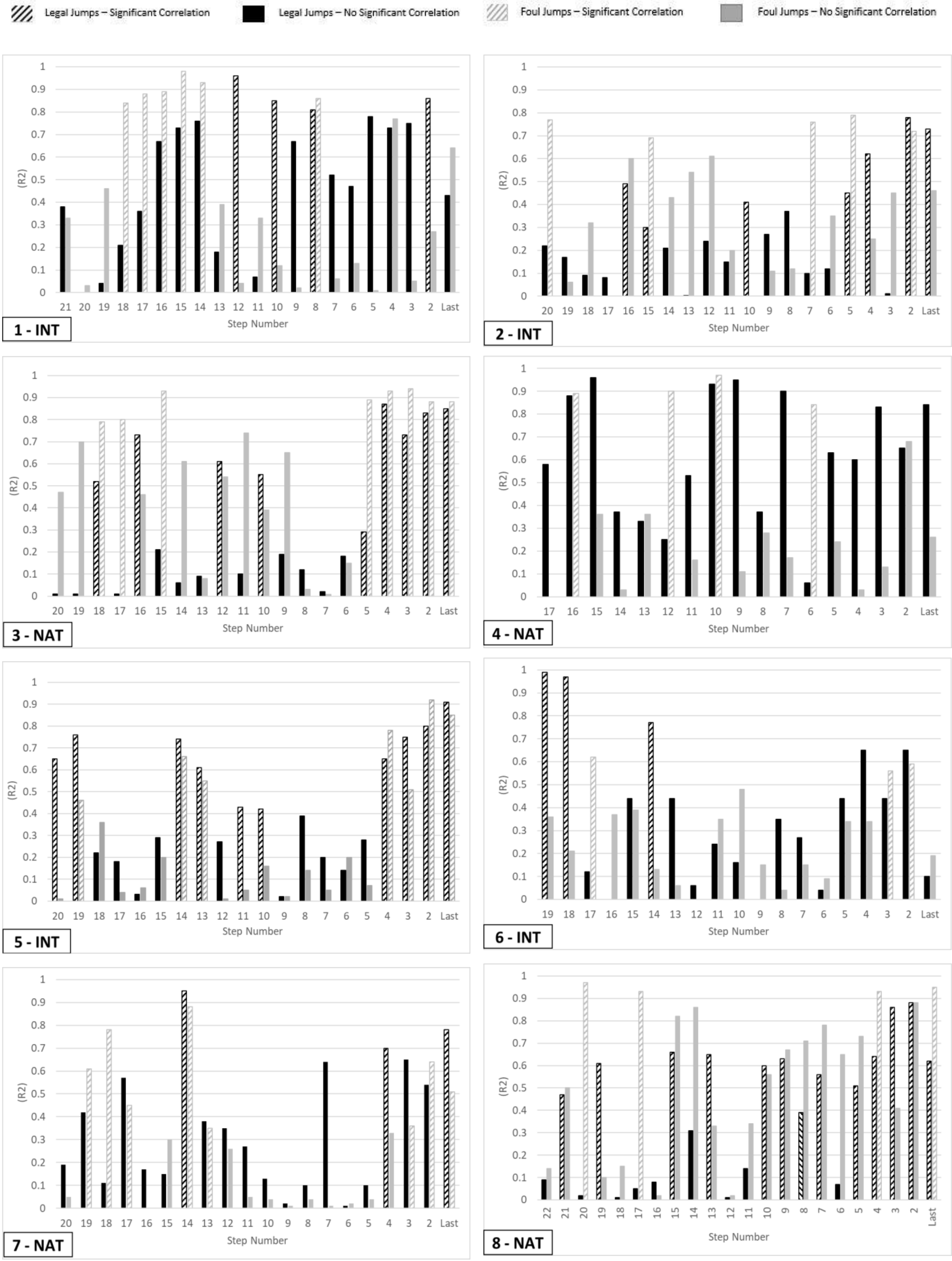
Figure 1



Legal Jumps
Foul jumps
1 - INT
2 - INT
3 - NAT
4 - NAT
5 - INT
6 - INT
7 - NAT
8 - NAT
Standard Deviation of toe-board distance (m)
Footfall Number to Board
Footfall number to board
Board

Figure 2



Legal Jumps – Significant Correlation
Legal Jumps – No Significant Correlation
Foul Jumps – Significant Correlation
Foul Jumps – No Significant Correlation
(R2)
Step Number
1 - INT
2 - INT
3 - NAT
4 - NAT
5 - INT
6 - INT
7 - NAT
8 - NAT

Figure 1. Mean standard deviation for each footfall of the entire run-up (m), separated according to jump outcome (legal, foul) for each athlete. Note the different run-up lengths between athletes and the different curves of footfall variability for legal and foul jumps for each athlete.

Figure 2. Trial by trial analysis. Relationship (R^2) between the amount step-length adjustment needed and the amount of adjustment produced for each athlete separated by jump outcome (legal, foul). *Significant correlations: $p <.05$.