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Step regulation in Paralympic long jumpers with intellectual impairment

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Abstract: Long jump has been extensively used in the investigation of perception-action coupling. The restraints imposed by the tasks nested at the take-off board compel skilled long jumpers to adjust the length of the final 4-5 steps of the run-up based on visual input informing about time-to-arrival. This exploratory study examined the visual regulation parameters in athletes with intellectual impairment (II) during the approach of the long jump. The approach run of 10 elite level T20 Class long jumpers (IIJ) and 10 international level long jumpers without II (NIJ) was recorded during competition. An initial ascending variability of foot placement was observed for both groups, followed by a descending one in the late phase of the approach. The parameters associated with the onset of visual control for IIJ were found to be not statistically significantly different to those of NIJ. The mean maximum toe-board distance variability was 0.38 m and 0.27 m for IIJ and NIJ, respectively. The onset of regulation commenced at the fifth- and third-to-last step for IIJ and NIJ, respectively. The finding that IIJ adjust the last steps of the run-up with sufficient accuracy suggests the presence of visual control. This information can be used to optimize long jump approach run training for athletes with II.

Keywords: visual perception; motor skills; perception-action coupling; visual control; kinematical analysis; spatio-temporal parameters; intellectual disability

Introduction

The very nature of the long jump approach, which requires a near maximum speed and take-off accuracy on the board, characterizes this jumping event as a self-pacing, closed motor skill (Woods, 1998). Cognitive training, in the form of observational (Panteli et al., 2013) or blended learning (Kyriakidis et al., 2021), is shown to be beneficial for improvements in long jump performance. For individuals with intellectual impairment (II), the sensory, perceptive, cognitive, and learning deficits are linked with deficiencies at the perceptual, planning, and execution stages of motor performance. These result in delays in motor development (Eichstaedt & Lavay, 1992; Sherrill, 2004) and, in the case of long jump, decreased jumping distance (Potthast et al., 2011).

Long jump is a task that has been extensively used in the investigation of perception-action coupling due to the restraints imposed on the athlete (Bradshaw & Aisbett, 2006; Hay & Koh, 1988; Lee et al., 1982). Thus, the long jump is a task considered suitable to explore the perceptual and movement behavior of athletes to test the views of Gibson (1979) and ecological psychology for the association between perception and action. The effective execution of the approach phase is considered to be a major determinant of performance in the long jump and approach velocity is its single best predictor (Hay, 1993). In addition, the

constraint of the take-off board requires jumpers to regulate their step length during the approach run (Hay, 1988). As a result, long jump performance is vastly dependent on step length, the number of steps made, and speed progression during the run-up (Hay, 1986).

The time-to-contact estimation when approaching the take-off board can be determined using the tau hypothesis. It is suggested that a quantity (tau) is present in the visual stimulus (Tresilian, 1991) and that it is coupled with a single type of locomotor control (Lee et al., 1982). Studies have indicated two distinct segments during the approach phase (Berg et al., 1994; Hay, 1988; Lee et al., 1982). At first, the approach towards the take-off board commences with an initial accelerative phase, where the athletes acquire the necessary speed for the task. This is the global visual control phase, where the position, in respect to the target, is controlled in a time-based manner (“*global tau*”; Tresilian, 1991). During this phase, athletes perform the run-up with the stereotyped running rhythm mastered in their training. As a result, the variability of the toe-to-board distance in this phase is constantly increased and reaches its maximum value. After this peak, a second segment is evident, where variability is notably decreasing as the take-off board is reached. The local visual control phase (“*local tau*”; Tresilian, 1991) it getting into, effect. In this phase, the jumpers regulate the placement of their foot to negotiate the target (Bradshaw & Sparrow, 2001). The descent in the variability of foot placement marks the perception of the board primarily through visual cues (Bradshaw & Aisbett, 2006; Hay, 1988; Lee et al., 1982), which provide the crucial information to estimate time-to-contact. Another factor that was found to affect the onset of visual control is the magnitude of the approach velocity. This is because approaches conducted with decreased speed resulted in an earlier occurrence of tau-margin (Bradshaw & Sparrow, 2002).

Most skilled long jumpers adjust their step length at the last four to five steps of the approach based on visual input that informs them about time-to-arrival (Hay, 1988; Hay & Koh, 1988). It is proposed that the adjustment of step length is triggered by a multisensory tau, with visual input that assists the athlete to localize the target (namely the take-off board) while their position is localized kinesthetically (Berg & Mark, 2005). Even though “acute sense of limb position and movement (relative to the body and to the proximal support surface) during locomotion is a standard feature of humans” (Berg & Mark, 2005, pp. 523–524), the ability to control the point of foot strike when dealing with a target based on time-to-contact information depends also on the individual’s ability to perceive velocity (Laurent & Thomson, 1991). However, the process of how individuals with II explore and interact with the environment using visual perception, which is linked with deficient visual and motor coordination, has not been fully investigated (Giuliani & Schenk, 2015). It is suggested that adults with II perform poorly in motor tasks with combined speed and accuracy constraints (Carmeli et al., 2008), suggesting that integrating perceptual information into motor action will not result in optimum motor performance in II. In addition, it has been found that individuals with II present a decreased performance in visual-spatial skills (Van Biesen et al., 2010). Furthermore, evidence was provided for the relationship between the severity of II and performance in motor tasks (Vuijk et al., 2010). Thus, athletes with II exhibit delays in the learning process, besides huge variance and inconsistencies concerning performance (Burns, 2015; Vivaracho et al., 2018).

The long jump approach is a motor task that requires a combination of exteroceptive and proprioceptive capabilities. This combination could be the basis for the fact that individuals with II perform poorly in the long jump (Potthast et al., 2011). Nevertheless, the International Paralympic Committee (IPC) has designated in Athletics a sports class named F/T20 for athletes with activity limitations resulting from II (IPC, 2018, p. 144). In detail, it is stated that:

“Athletes with an intellectual impairment have a restriction in intellectual functioning and adaptive behaviour in which affects conceptual, social and practical adaptive skills required for everyday life. This impairment must be present before the age of 18” (IPC, 2016a, p. 6).

These athletes are referred to as athletes with II and have to pass a sport cognition test battery that

“consists of a series of tests on four different components of sport cognition, which are memory and learning, executive functioning, visual perception and fluid intelligence, and processing speed and attention concentration skill” (IPC, 2016b, p. 112).

Health conditions likely to cause the above-mentioned impairments are intellectual retardation and learning deficiency (IPC, 2013, p. 7). As a result, an F/T20 class athlete might present deficits in the ability to learn adequately, execute proficiently, and efficiently adjust their sport technical and tactical skills due to altering environmental conditions (van Biesen et al., 2021). It is generally acknowledged that athletes with II face difficulties in processing information, have reduced visio-spatial awareness, and perform with impaired motor coordination (NASPE, 2012; van Biesen et al., 2018; 2021). Despite these deficits, T20 Class long jumpers demonstrate noteworthy performances, comparable to those of medium-level athletes without II competing at national level championships. To achieve these performances, T20 Class long jumpers undergo rigorous training and execute routine tasks in a similar fashion to their non-impaired counterparts. As mentioned earlier, the long jump is a self-pacing, closed motor skill. Mastering the ability to hit the board accurately at high velocity is typically taught with explicit instruction concerning this specific procedure, followed by repetitive practice.

Bouffard (1990) claimed that teaching of exact skills and sufficient practice may lead individuals with II to mastery and ease of replication. Mastery, in turn, is accomplished mainly in closed motor skills, within a predictable environment, without sudden and rapid motor adjustments (Sherrill, 2004). Thus, making the information processing more automatic in the approach phase through practice may assist jumpers in becoming more aware of the adjustments required in the approach phase. This may reduce the resources required for that task and allows jumpers to allocate more resources on movement accuracy (Van Biesen et al., 2010). Based on the above, it is of interest to examine whether T20 Class athletes' disability restricts the execution of an efficient, in terms of perceptual ability, approach run compared to long jumpers without II.

The purpose of the study was to examine selected parameters that indicate the presence of step regulation and time-to-contact perception during the approach run of T20 class long jumpers compared to those athletes with no II of comparable performance. It was hypothesized that T20 class long jumpers will present differences at the parameters interpreting effectiveness in the locomotor pointing task of accurate foot placement at the long jump take-off board compared to athletes without II. In specific, it was hypothesized that the onset of step regulation will commence later and that the toe-board distance variability will be larger in T20 class compared to athletes without II. The outcome of this study will enrich expert coaches' experiential knowledge about the type of cognitive control used by T20 class athletes to be used in training designs.

Materials and Methods

Participants

The research was conducted following the recommendations of the Declaration of Helsinki. Approval was obtained from the University's ethics committee (IRB00003099). Ten male elite level T20 class long jumpers (IIJ; age $M = 24.9$ yrs, $SD = 5.3$; body height $M = 1.84$ m, $SD = 0.06$; body mass $M = 74.4$ kg, $SD = 6.6$; personal best performance at the competition $M = 6.45$ m, $SD = 0.54$) were recorded during the 2012 London Paralympics and an International IPC athletics event. IJJ were studied due to their classification as T20 class athletes by the IPC medical boards and being among a group of elite long jumpers with II.

The regulation parameters of IIJ were compared with those of ten high level female long jumpers without II (NIJ) and of a similar long jump performance level (age: $M = 25.6$ yrs, $SD = 3.4$; body height: $M = 1.72$ m, $SD = 0.06$, body mass: $M = 56.8$ kg, $SD = 5.0$, personal best performance at the competition: $M = 6.24$ m, $SD = 0.22$). NIJ were recorded during a national championship and a European Athletics Team Championship.

The rationale for not selecting male long jumpers without II was because male athletes achieving similar jumping distances (approximately 6.50 m) are considered to be of low-performance level. On the other hand, female long jumpers performing over 6 m are classified as high-level athletes that are considered to master the technical requirements of the event and attain approach velocities comparable to those of elite male T20 long jumpers (see Panoutsakopoulos et al., 2017). Furthermore, to the best of our knowledge, there is no evidence in the literature to suggest differences in visual control and perception ability between males and females in the long jump.

Instrumentation and data acquisition

The custom biomechanical experimental set up which has previously been used to investigate the visual regulation in the long jump was utilized (Theodorou & Skordilis, 2012). Custom 5 x 5 cm reference markers were attached on the ground, parallel to the runway lines, at 1 m intervals.

The approach of each long jump was captured using a high-speed video camera (Exilim-Pro-EX-F1, Casio Computer Co. Ltd, Shibuya, Japan) at a sampling frequency of 300 fps and a resolution of 512 x 384 pixels. The camera was zoomed in on the athletes and was manually panned to record the last 20 m of each athlete's run-up. The camera was set at the spectators' seats, located 15 m from the midline of the runway and approximately 3 m higher from the ground (Figure 1). This same procedure was applied in all competitions for both groups.

In total, 53 run-ups ($M = 5.72$ trials, $SD = 0.78$ for each athlete examined) were recorded for IIJ and 50 run-ups ($M = 5.00$ trials, $SD = 0.94$ for each athlete examined) for NIJ. Each examined athlete performed at least four jumps during the competition for further analysis. Most visual regulation studies use all of the athlete's attempts for the calculation of visual regulation. Recent research evidence (McCosker et al., 2020; 2021) suggests that both legal and foul (stepping over the line) jumps are visually regulated. Therefore, all legal and foul attempts were included in the present analysis, provided that the take-off error was less than 10 cm (that equals the length of the take-off plasticine indicator board) and the approach run preceded a complete long jump was accurately recorded.

Data analysis

The videos were analyzed using the APAS Wizard 13.3.0.3 software (Ariel Dynamics Inc., Trabuco Canyon, CA). The analysis was conducted on the fields depicting the foot contact on the ground in each step. Toe-board distance (TBD), namely the horizontal distance between the take-off line and the athlete's toe, was calculated according to the five-point model (foot contact point plus the four markers surrounding it) that was used by Hay and Koh (1988).

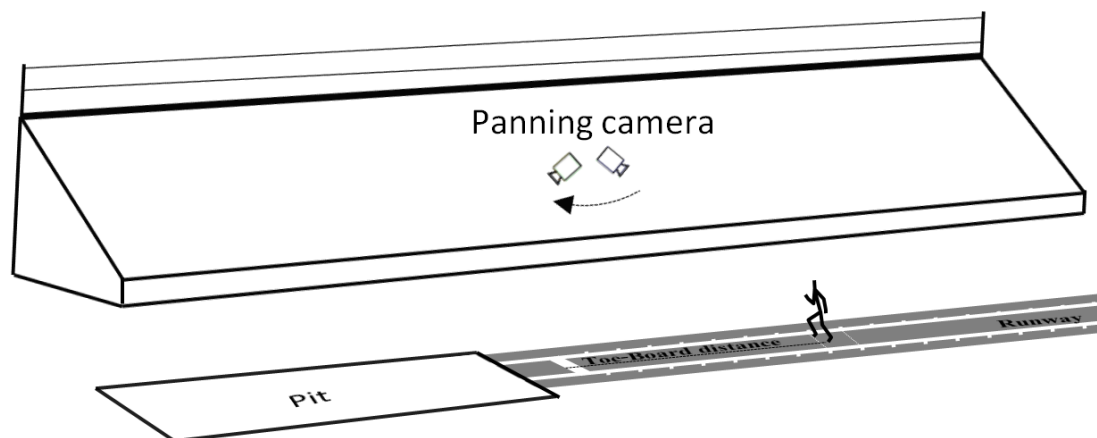


Figure 1. Schematic illustration of the experimental setup.

The inter-trial analysis was used to extrapolate the presence or not of a regulatory pattern. The standard deviation (SD) of TBD for each support phase across trials for each athlete signified the variability of foot placement for a specific step (Berg & Greer, 1995; Berg et al., 1994; Bradshaw & Aisbett, 2006; Lee et al., 1982). A step demarcated the time and distance between two successive foot contacts (Bradshaw & Aisbett, 2006), and its length was calculated by deducting two consecutive TBD (Berg & Greer, 1995). The support phase at which the SD of TBD reached its peak value (TBD_{SDmax}), followed by a systematic reduction thereafter, was identified as the onset of visual regulation (Berg et al., 1994; Bradshaw & Sparrow, 2001).

The existence of the ascending-descending trend of the variability of foot placement was verified by plotting the SD of TBD for each step (Hay, 1988; Lee et al., 1982; McCosker et al., 2020). The distance of the athlete from the take-off board at the onset of regulation was identified as visual control distance (VC_{Dist}) and the support phase that this occurred as visual control support (VC_s). The time remaining from the onset of regulation till contacting the take-off board was defined as visual control time (VC_{Time}). Tau (τ) at the onset of regulation, which corresponds to the current time-to-contact, was calculated as proposed by Bradshaw and Sparrow (2001) using equation 1:

$$\tau = -\frac{VC_{Dist}}{VC_{Vel}} \quad (1)$$

To perform the inter-trial analysis, the attempts of each athlete were analyzed provided that they had completed at least four attempts. The inter-trial analysis was performed on a group basis. The mean SD was calculated for each athlete to depict the trend of the onset of visual regulation. However, as reliance on group averages could possibly provide misleading information about individual behaviors (Speelman & McGann, 2013) and may mask inter-

subject differences, the onset of visual regulation was evaluated both at a group and at an individual basis (Dallas & Theodorou, 2018).

The step length adjustment (SLA%) that each athlete made at each of the final strides was calculated as a percentage of the total adjustment and was calculated according to equation 2 (Hay, 1988):

$$SLA\% = \frac{(TBD_{SD} - TBD_{SDi-1})}{(TBD_{SDtoSDmax}())} \quad (2)$$

where TBD_{SD} is the standard deviation of TBD, i is the i^{th} last support phase, i.e., the current step examined. For example, if the step examined is the penultimate step, the TBD_{SDi-1} refers to the SD of the 3rd support phase from the take-off board; TBD_{SDto} is the jump take-off (last step take-off); TBD_{SDmax} is the maximum SD at the onset of regulation.

The sum of the SLA% of the last two steps ($SLA\%_{Sum2L}$), the average step length (ASL_{last6}), and average step velocity (ASV_{last6}) of the last six steps of the approach were also calculated to determine the parity of the groups in terms of step kinematics. The average step velocity (ASV) was estimated as (equation 3):

$$ASV = \frac{SL}{t} \quad (3)$$

where SL is the step length and t is the duration from the last foot toe-off contact to the opposite foot last toe-off contact on the ground, as derived from the video recordings.

Statistical analysis

VC_s was considered as a categorical variable. Thus, the possible between-group difference in VC_s was checked with crosstabulation and the chi-square (χ^2) statistic. Cramer's V was used to evaluate the strength of the relationships observed after the χ^2 -test.

Descriptive statistics (mean and SD) were calculated for the rest of the dependent variables (VC_{Dist} , VC_{Time} , VC_{Vel} , τ , TBD_{SDmax} , TBD_{SDto} , $SLA\%_{Sum2L}$, ASV_{last6} , ASL_{last6}) across the jumps for each athlete. Data were examined with the Levene's test and the Kolmogorov-Smirnov normality test. For all variables, the former revealed that the assumption of homogeneity of variances was satisfied ($F_{18} \leq 3.083$, $p = .096$) and the latter that the scores were normally distributed ($D_{20} \geq .104$, $p = .053$).

The differences in the dependent variables, except for VC_s , between IIJ and NIJ, as group was the independent variable, were examined using the parametric independent samples t -test. An alpha (α) level of .05 was used and Cohen's d was calculated for the estimation of the effect size (Cohen, 1988). The effect size with d higher than 0.2 was interpreted as 'small', higher than 0.5 as 'medium', and higher than 0.8 as 'large'. All statistical analyses were conducted using the IBM SPSS Statistics v.25.

Results

As a group response, both groups exhibited a typical initial ascending-descending variability of foot placement pattern as they approached the take-off board (Figure 2). A maximum value of 0.363 m for the mean TBD_{SDmax} was observed at the 6th support phase (5th step from the board) for the IIJ athletes. NIJ athletes demonstrated as well a similar trend of ascending-descending variability, with mean TBD_{SDmax} peaking at a maximum value of 0.245 m at the 3rd to last step from the take-off board (Figure 3).

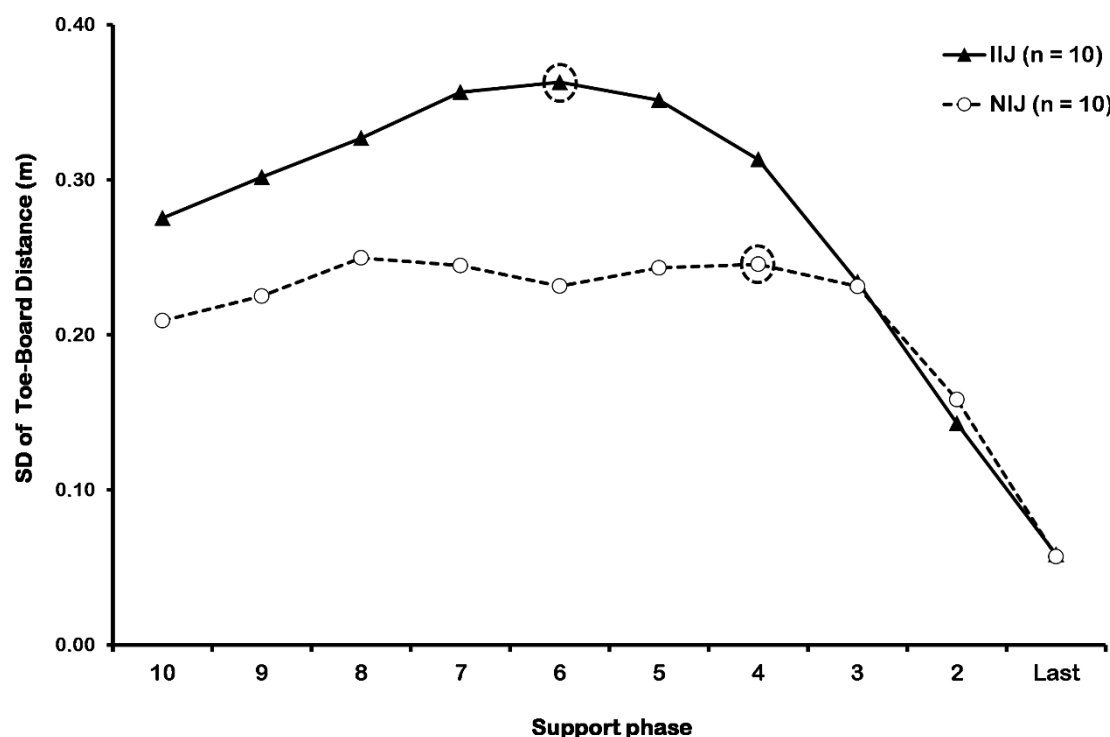


Figure 2. Mean values of the SD of the toe-board distance at each support phase extracted from the inter-trial analysis. The dotted circle denotes TBD_{SDmax} and the onset of visual control (IIJ: T20 class long jumpers; NIJ: high level female long jumpers with no intellectual impairment).

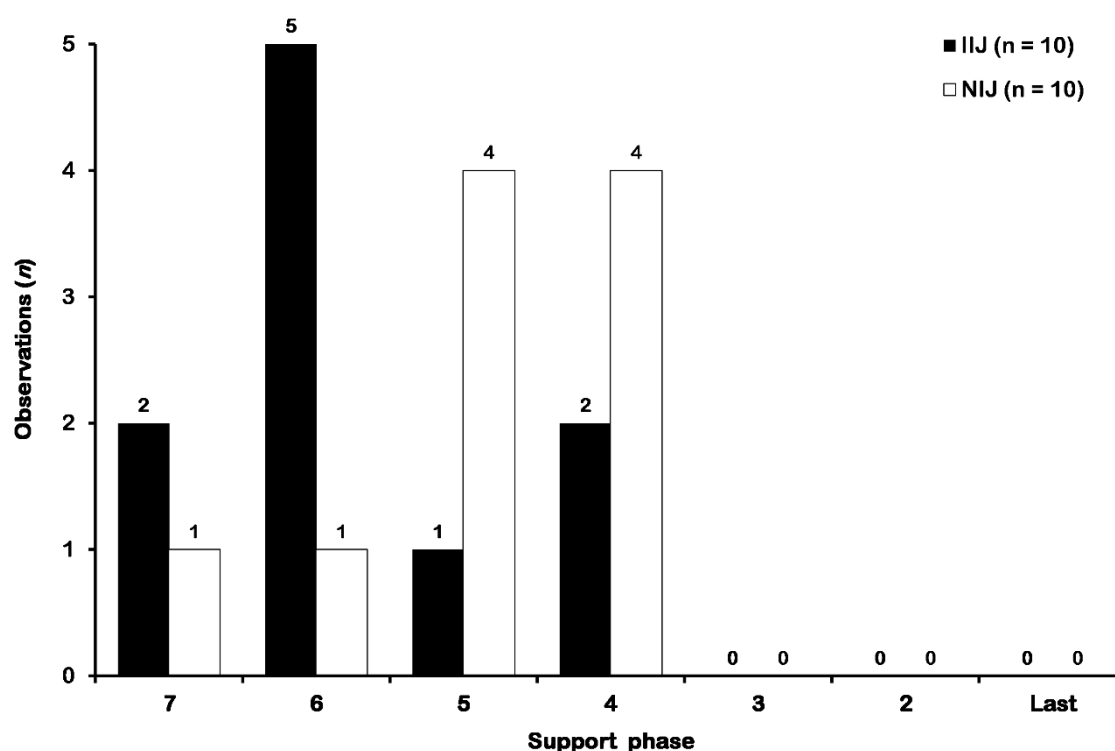


Figure 3. The number of observations where TBD_{SDmax} (onset of regulation) was recorded on each of the last support phases of the approach for the examined groups (IIJ: T20 class long jumpers; NIJ: high level female long jumpers with no intellectual impairment).

A difference between IIJ and NIJ for VC_s (6th and 5th step from the board for IIJ and NIJ, respectively) was not observed ($\chi^2_3 = 5.467$, $p = .141$, $V = .523$). Individually,

participants differed as each one visually regulated the athlete's approach at a distinct instant which ranged from the 7th up to the 4th last support phase of the approach.

The descriptive statistics of the individual responses and the results of the independent samples *t*-test are presented in Table 1. A significant between-group difference was found only for SLA%Sum2L ($p < .001$, $d = 2.51$, large effect), as NIJ made the majority ($\approx 86\%$) of their step-length adjustment at the last two steps opposed to the respective $\approx 54\%$ observed for IIJ.

Table 1. Results (mean and standard deviation) of the individual responses for the examined parameters and of the comparison between groups.

PARAMETER	IIJ ($n = 10$)		NIJ ($n = 10$)		<i>t</i>	<i>p</i>	<i>d</i>	95%CI
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>				
Best jump (m)	6.46	0.54	6.24	0.23	1.171	0.257	0.53	-0.177, 0.597
VC _{Dist} (m)	10.15	2.36	8.39	2.29	1.693	0.108	0.78	-0.425, 3.945
VC _{Time} (s)	1.02	0.26	0.80	0.23	1.942	0.068	0.90	-0.018, 0.448
VC _{Vel} (m/s)	8.92	0.62	8.84	0.27	0.345	0.736	0.17	-0.392, 0.540
τ	1.15	0.30	0.95	0.27	1.568	0.134	0.70	-0.067, 0.463
TBD _{SDmax} (m)	0.38	0.14	0.27	0.10	2.058	0.054	0.90	-0.002, 0.232
TBD _{SDto} (m)	0.06	0.04	0.06	0.03	0.089	0.930	0.03	-0.032, 0.035
SLA%Sum2L (%)	53.6	13.9	85.6	11.5	5.609	<0.001	2.51	20.03, 44.03
ASV _{last6} (m/s)	9.23	0.56	9.02	0.18	1.155	0.263	0.51	-0.176, 0.600
ASL _{last6} (m)	2.16	0.21	2.16	0.11	0.107	0.916	0.00	-0.148, 0.164

NOTE. IIJ: T20 Class long jumpers; NIJ: high level female long jumpers with no intellectual impairment; *d*: Cohen's *d*; 95% CI: 95% confidence interval; VC_{Dist}: visual control distance; VC_{Time}: visual control time; VC_{Vel}: velocity at the onset of regulation; τ : tau at the onset of regulation; TBD_{SDmax}: maximum standard deviation of toe-to-board distance at the onset of regulation; TBD_{SDto}: standard deviation of toe-to-board distance at the jump take-off; SLA%Sum2L: step length adjustment of the last two steps; ASV_{last6}: average step velocity of the last 6 steps; ASL_{last6}: average step length of the last six steps.

Discussion

The results of the present study did not confirm the hypothesis that IIJ would be less effective in the locomotor pointing task of accurate foot placement at the take-off board compared to NIJ. No statistically significant differences were found between the two groups for the parameters that depict the onset of step regulation and the toe-board distance variability except the SLA%Sum2L.

According to the findings for VC_s, VC_{Time}, VC_{Dist}, and τ , a trend was observed for IIJ to execute the approach with an earlier onset of regulation compared to NIJ. The observed onset of regulation for IIJ was earlier to those reported in the literature for long jumpers of similar performance level (3.59 steps, Bradshaw & Aisbett, 2006; 3.5 steps, Hay 1988; 2–5 steps, Lee et al., 1982; 3 steps, Starzak & Makaruk, 2015). The value of TBD_{SDmax} (approximately 0.38 m), which is considered to be a measure of the consistency in the stereotyped segment of the approach run, was higher (in absolute terms, but not significantly different) in IIJ compared to NIJ (0.27 m) and those reported in other studies (0.27 m, Hay & Koh, 1988; 0.24 m, Hay 1988; 0.34 m, Theodorou, Skordilis, et al., 2013). Nevertheless, values of approximately 0.38 m have also been reported as 0.37 m (Lee et al., 1982), as well as ≈ 0.40 m (Starzak & Makaruk, 2015) for female athletes of a similar level of performance. However, the comparison of the maximum amount of variability of foot placement with those reported for international-level athletes (>0.50 m; McCosker et al., 2020) and untrained adults with no II (0.58 m; Scott et al., 1997) or even for adolescent female long jumpers (0.44 m; Panteli et al., 2014) suggests a higher level of consistency in IIJ.

During the “zeroing in” phase to the board, IIJ opted for a more proportionate distribution (53.5%) of the accumulated error as opposed to the NIJ athletes who preferred

a bulky correction over the last two steps (85.5%), a response which paradoxically is observed among experienced long jumpers (Hay, 1988; Panoutsakopoulos et al., 2021). To optimize the biomechanics of the take-off, it is likely that IJ were more reliant on the event's technical requirements, where the last step must be the shortest and the second-to-last step must be the longest of the final approach (Hay, 1986). As a result, the task of regulating the step length to accurately conduct the foot placement on the board is performed concurrently with the task of adjusting the step length at the last two steps (Panoutsakopoulos et al., 2021). The simultaneous execution of both tasks under the constraint of maximum speed requires a high level of information processing which is acquired by manipulating key perceptual information sources in training. For example, if the athlete places the starting point more proximally or distally, as well as if the task nested at the end of the approach is changed (run through, take-off, complete jump), then, different information - movement couplings emerge. These modifications result in forming functional relationships that work within the specific context of the task (Panteli et al., 2016). Practice should aim to facilitate IJ to be receptive and to capitalize on the specific informational constraints by learning to self-regulate in demanding performance contexts (McCosker et al., 2019). This should be carried out taking into account the cognition limitations and the technical requirements of the event. In the present study, IJ successfully performed the demanding technical constraint of a large penultimate and a short last step (2.17 m, 2.29 m, and 2.01 m for 3rd, 2nd, and last step, respectively). This is notable, as it is suggested that IJ athletes execute a short sprint dash with a considerably smaller step length compared to sprinters without IJ (Andrews et al., 2009). Therefore, future research should investigate how different information within the performance environment may affect key technical elements like the “large penultimate - short last step” technique.

Another reason for more proportionate distribution of the accumulated error could be the type of vision (foveal or peripheral) that IJ may use for the perception of body orientation and self-motion. The optical variable tau is an estimate of time-to-contact that is extracted by the observer's velocity and position at a specific time instance and is suggested to occur earlier at lower approach velocities (Bradshaw & Sparrow, 2001). Since the velocities at the onset of regulation were almost identical between the two groups, it is possible that the perceptual systems of IJ were more attuned to the optical information available. In guiding locomotion, to maximize sensitivity available in the fovea, obstacles and paths must be fixated (Owen, 1985). Long jumpers are traditionally instructed to avoid gazing towards the board (i.e., not to use foveal vision), as an erect posture is essential both for optimizing vertical impulse and minimizing forward angular momentum at take-off. Research suggests that poorer jumpers appear to sample information about time-to-arrival foveally, while higher level jumpers acquire information through peripheral vision (Berg et al., 1993). Furthermore, individuals with developmental coordination disability demonstrate a larger dependency on online foveal visual feedback of their path of locomotion (Warlop et al., 2020). Although the direction of gaze was not assessed in this study, the explicit gazing through a head tilt towards the take-off board during the approach run was a common characteristic of IJ observed by the authors of the present study during video processing. A recent study provided evidence that there is a coincidence of the occurrence of regulation onset with the dwell time on the take-off board (Hildebrandt & Cañal-Bruland, 2020). It could be the case that the fixation on the take-off board provided early information about the impending collision, thus allowing an earlier regulation of gait and a more proportionate distribution of adjustments. However, the use of take-off markers or mats of contrasting colors (Theodorou, Ioakimidou, et al., 2013) should be utilized by coaches in the training context. This would facilitate IJ to perceive their target early without detrimental effects on their body posture.

Finally, when at take-off, accuracy on hitting the board was a task where IIJ performed equally successfully with NIJ. The values recorded for the toe-board distance at take-off (mean 0.06 m, SD = 0.04 m) were similar to those reported for Olympic level long jumpers (0.04 - 0.06 m, Hay, 1988). In addition, accuracy on hitting the board in the examined IIJ was superior to that of previously analyzed IIJ (0.20 - 0.30 m, Potthast et al., 2011), experienced long jumpers (0.08 - 0.12 m, Hay & Koh, 1988), young athletes (0.15 m, Berg & Greer, 1995), young novice long jumpers aged 12-13 years old (0.14 m, Panteli et al., 2014), and untrained adults (0.25 m, Scott et al., 1997). The high level of consistency in IIJ regarding the variability of foot placement during the approach can be considered as a contributing factor for the observed accuracy of foot placement on the board (Makaruk et al., 2015).

The findings of our study suggest that T20 class long jumpers, although they belong to classification with difficulties to understand new or complex information, along with deficits in learning and applying new skills, seem to perform the demanding locomotor pointing task quite successfully as athletes with no II. The emerging ascending-descending trend of the variability of foot placement during the approach run of IIJ may be related to the perceptual-motor learning model of Sherrill (2004), who described the skilled movement as a process held within the central nervous system. Learning is complex and perceptual-motor training focuses on certain foundations (physical, mental, and emotional) that underlie the mastery of movement skills. These skills are developed and modified with practice and are always subject to certain processes (e.g., perception, attention, memory, etc.) which, in turn, may either facilitate or limit their development (Sherrill, 2004). One could assume that this probably happens due to their involvement in specific long jump training. It is suggested that, if individuals with II are properly instructed, they can perform qualitatively like their chronological-age counterparts (Eichstaedt & Lavay 1992). With some extra time and proper training (appropriate feedback, adequate trials, and sufficient practice time), individuals with II may store information in the long-term memory, improve their movement accuracy equally to counterparts without II (Horgan, 1983), and eventually reach and maintain mastery. Van Biesen et al. (2010) suggested that, through repetitions, II athletes are becoming aware of information processing. In addition, individuals with II respond automatically and attention is focused upon movement accuracy. It is probable that through training, IIJ obtained meaning from relevant input, blocked non-respective information from entering their short-term memory, and managed to get a consistent and predetermined motor outcome restored eventually in their long-term memory.

The only feature that IIJ differentiated from NIJ was the percentage distribution of adjustments. Although performance in visuomotor tasks demanding input from the periphery, including bipedal locomotion, may be elevated through appropriate training, it could be that the percentage distribution of adjustment in IIJ was not affected by the intentional or incidental learning process. Instead, it could be subjected to the constraints imposed on the actor by the task (Berg et al., 1994), thus reflecting a functional constraint on the system (Laurent & Thompson, 1991). An insuperable constrain for IIJ athletes seems to be the attainment of high velocity while negotiating the target. Although there is evidence that suggests that the physical qualities of II athletes are similar to those of active individuals without II (Van de Vliet et al., 2006), the examined IIJ failed to achieve velocities similar to those of elite male jumpers without II during the approach run (Panoutsakopoulos et al., 2017).

Although results support the theory claiming that teaching of exact skills and sufficient practice may lead individuals with II to mastery and ease of replication if provided with proper instruction (Bouffard, 1990; Sherrill, 2004), certain limitations do not allow the generalization of the present findings without caution. One limitation is the small sample

size of the examined elite IIJ athletes. However, this was inevitable due to the scarcity of the population. The athletes examined in the present study represented the best male IIJs at that particular period. Furthermore, although the participants were exclusively elite IIJ, co-morbid conditions (e.g., epilepsy, syndromes) and respective medication used were not feasible to record. Therefore, we can only assume that our sample exhibited only athletes with mild II, without co-morbid conditions limiting performance. Also, the present results may not generalize to an extended population of athletes with II and it cannot provide evidence to what extent the reported differences can be attributed solely to II (Potthast et al., 2011).

The model describing the processes (perceptual, attention, memory, etc.) underlying the development of a specialized motor skill such as the run-up in long jumping, is vast. Several interacting areas shaping together the development of specialized motor skills, with elements such as cognition, motivation, environment, acuity (visual, hearing, kinesthetic), were not even discussed in the present study as its aim was not an in-depth explanation as to why this phenomenon occurs. Paralympic sport classes' aim is to downgrade the impact of impairment on the outcome of competition (Tweedy & Vanlandewijck, 2011) and to consider this impact on performance (Mann & Ravensbergen, 2018). Since a sport-specific examination is required to evaluate the association between II and performance, additional research should be conducted to further examine the interaction of step length and step frequency and their contribution to approach speed development during the final segment of the approach. Furthermore, future research should investigate the effect of step characteristics' asymmetry, as well as the biomechanics of the take-off in athletes with II.

Perspectives

From the results of this study, the Paralympic T20 class long jumpers regulated their approach run similarly to elite female long jumpers without intellectual impairment, who have comparable performance levels, but with the onset of regulation was initiated a step earlier. This earlier onset of regulation might cause difficulties to maintain the acquired approach speed which is a crucial determinant of long jump performance. This adds to the difficulty that jumpers with intellectual impairment have to manage, as they exhibit an enhanced variability of step length during a sprint run (Andrews et al., 2009). Despite the detrimental effect of the intellectual impairment on elite performance and the slower rate of acquiring experience in the sporting skill (Burns, 2015), coaches should monitor and take action to prevent the earlier regulation that results in a greater loss in velocity on the take-off board. Future research should focus on the mechanisms that control step regulation of elite level long jumpers with intellectual impairment and their interaction with the performance environment, constraints, and nested actions, adding the effect of different training methods (i.e., explicit vs. implicit learning) on mastering visual control strategies.

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