Expertise and the regulation of gait in the approach phase of the long jump

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In the approach phase of the long jump, athletes attempt to strike the take-off board accurately with minimum loss of speed, and in an optimum body position for take-off. Previous research has shown that skilled long jumpers demonstrate an ascending-descending trend of variability rather than a consistent pattern of foot placement over trials. The present study examined whether non-long jumpers showed a similar pattern of variability in footfall placement between trials to skilled long jumpers. Consistency of foot placement over trials for non-long jumpers (n = 11) was determined using a panned video camera. Digitization of the foot position provided toe-board distances during the run-up phase. Our results showed that non-long jumpers have a similar pattern of descending variability near to the take-off board to expert long jumpers, suggesting the use of visual regulation. However, in comparison to more skilled subjects, non-long jumpers accumulated a considerably larger maximum mean standard deviation in footfall placement between trials (58 cm). Since non-long jumpers had no previous task-specific training, these data extend our current understanding of the regulation of goal-directed gait.

Keywords: constraints, long jump, skill level, variability, visual regulation.

Introduction

The long jump is an athletic event which can be separated into four distinct sections: the approach phase, take-off, flight phase and landing (Hay, 1986). A successful jump has been shown to be heavily dependent on the performance of the approach phase. The aim of the approach phase is to ensure that the athlete strikes the take-off board accurately with minimum loss of speed, and in an optimum body position for take-off (Hay, 1988). The goal of striking the take-off board with precision and speed is a major task constraint on the performer. Successful performance during the approach phase ensures that the effective distance jumped (i.e. the distance from the toe of the take-off foot to the nearest mark in the sand made by the athlete) is as close as possible to the official measured distance (i.e. the distance from the front edge of the board to the nearest mark in the sand made by the athlete). Because long jumpers have to jump six times in competition, a reliable action is needed and the approach phase of the long jump is typically coached to be a stereotypical action. If athletes were able to stereotype their gait in the approach phase, then a low level of footfall variability would be predicted. In this instance, a useful measure of footfall variability is evident in the standard deviation of the mean distance from the toe to the take-off board (toe-to-board distance) for each step over trials.

However, research by Lee et al. (1982) showed that the approach phase of three international long jumpers was actually much more variable with regard to footfall placement over trials than was previously believed (see Fig. 1). They showed that the athletes’ standard error of footfall placement (later identified as the standard deviation by Hay, 1988) gradually increased (up to 37 cm for one athlete) until they were five steps from the take-off board. The variability was then reduced over the final five steps.
On the basis of the slope of the variability curve in Fig. 1, Lee et al. (1982) argued that the approach phase of the long jump actually consisted of two sub-phases: an accelerative phase and a zeroing-in phase. It was proposed that skilled athletes maintained a constant stride pattern while progressively increasing their stride lengths as they accelerated down the track. However, small inconsistencies in stride length had an unavoidable, cumulative effect which resulted in the build-up of footfall variability until the fifth-from-last step. The zeroing-in phase was considered to start after the highest value of the standard deviation of the footfall placement was recorded, when the variability switched from an ascending trend to a descending trend. Lee et al. (1982) suggested that the zeroing-in phase was achieved by visual regulation of stride length. More specifically, they suggested that the optic variable ‘tau’ was coupled to the vertical impulse imparted by the athlete during the thrusting phase of the step. This theory of control has been a contentious issue within the literature (for further discussion, see Warren et al., 1986; Patla et al., 1989; Warren and Yaffe, 1989).

**Expert-novice comparisons**

The findings of Lee et al. (1982), for the pattern of variability in footfall placement during the approach phase, have since been replicated with larger samples of elite subjects. For example, Hay (1988) found evidence to support the views of Lee et al. (1982) with world-class jumpers (n = 19), the results showing a similar pattern of ascending and descending variability in foot placement across trials. Hay (1988) also found that the required stride adjustments were not spread evenly over the final five steps. More than 67% of the total adjustment was made during the final two steps. Interestingly, Hay and Koh (1988) demonstrated that not all elite athletes showed a similar pattern of variability, as in the studies of Lee et al. (1982) and Hay (1988). That is, intra-subject analyses showed that not all subjects exhibited the ascending trend for the first part of the approach followed by a descending trend for the final part. Of 49 subjects in the study by Hay and Koh (1988), 32 displayed a clear ascending-descending trend, 4 subjects had a consistently low level of variability for the whole of the approach phase, and 7 athletes showed an ascending trend of variability up to take-off.

There has been very little research examining whether novice jumpers use visual regulation, as do their more expert counterparts. One very recent and relevant programme of work on non-expert long jumpers has been conducted by Berg and colleagues (e.g. Berg et al., 1993, 1994; Berg and Greer, 1995). They provided some support for the argument that the strategy of visual regulation of action in locomotion towards a target in space is not a function of extensive task-specific expertise. Their analysis was conducted on a sample of ‘novice male long jumpers’, filmed during two high-school track and field competitions (grades 9-12; age range = 15-18 years). The results of the

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**Figure 1** A reconstruction of the mean standard deviation of toe-board distance in the run-up for novices and elite long jumpers. Data adapted from Lee et al. (1982), Hay (1988) and Berg et al. (1994). L = last; J = jump.
study by Berg et al. (1994) showed that the high-school long jumpers displayed an ascending-descending trend similar to that found in the data of Lee et al. (1982; see also Fig. 1). The curves of Fig. 1 infer that the novice long jumpers also used a visual control strategy. Berg et al. (1994) interpreted these findings as suggesting that visual control emerged at about the fourth step from take-off, a point in the run-up that was also integral to the visual regulation strategy of both elite males and females. The values for the subjects of Hay (1988) were 4.4 and 4.1 steps respectively (when corrected by Berg et al., 1994). Berg et al. (1994, p. 862) concluded that, ‘the manner in which gait is visually regulated in the LJA [long jump approach] is less a specially trained skill than a natural means of controlling gait in this task’.

Despite these similarities, there is still some ambiguity regarding the use of the term ‘novices’ to describe the subject sample in the study by Berg et al. (1994). An important issue concerns whether the group may be appropriately classified as novices, in the sense of having had no experience with the task of long jumping. In fact, the data from the same subject sample was used in a further analysis by Berg and Greer (1995), who indicated that, although classified as novices, their subjects had undergone an unspecified amount of practice and coaching in the task of long jumping. This clarification may go some way towards explaining the surprisingly similar levels of variability in the patterns of footfall placement for the elite and novice jumpers depicted in Fig. 1.

Further support for the notion that the subjects used by Berg et al. (1994) were practised in the task of long jumping emerges when one compares the data from the elite and novice jumpers for mean distance jumped in the previous analyses. Berg and Greer (1995) reported a mean best performance of 5.42 m (range 4.92-6.22 m) for the high-school male jumpers in their study. Note that the elite adult female jumpers in the study by Lee et al. (1982) had recorded best jumps between 5.78 and 6.54 m. Therefore, there is some evidence that, although the sample of Berg et al. (1994) may have been considered to be novices relative to the elite athletes in the study by Lee et al. (1982) and Hay (1988), by virtue of the amount of experience they had at the event, they had, nevertheless, demonstrated a considerable amount of skill in long jumping as indexed by the mean distances jumped.

From a theoretical perspective, the ecological framework, preferred by Lee et al. (1982) to explain their findings with long jumpers, argues that interceptive timing is an integral part of the basic repertoire of animals evolved to locomote around a cluttered environment. The ability to time interceptive actions is not just the preserve of elite athletes. For example, McLeod et al. (1986) reported that timing variability within the range 5-10 ms was reached very quickly for subjects labelled ‘ordinary people’ (the term used by McLeod and Jenkins, 1991, p. 286) engaged in a novel batting task. Furthermore, von Hofsten (1983) found that, when spatial variability of flight was held constant, infants aged 9 months could reach to grasp moving objects with considerable timing accuracy (mean variable timing error was only around 50 ms). These data may provide an explanation for the surprising amount of similarity found in the studies of Hay (1988) and Berg et al. (1994). The implicit indication is that the relative novices of Berg et al. (1994) had benefited from the small amount of task-specific training they had experienced. Therefore, because of the previous training of the novice long jumpers, it is unclear whether the similarities in the data between the samples of Hay (1988) and those of Berg et al. (1994) were a result of the task-specific training or the result of a fundamental mechanism for regulating gait in approach tasks. As yet, there has been no empirical research into the control of the approach phase of the long jump in non-long jumpers (i.e. with no specific training at the task). Accordingly, a major aim of this study was to determine the pattern of footfall variability for subjects who had received no specific instructions or practice in the long jump.

**Methods**

**Subjects**

Eleven male undergraduate students participated in the investigation (age 20-25 years). None of the subjects had practised or received any training in any of the jump events of athletics and so could be considered to be non-long jumpers.

**Procedure**

Testing took place at an athletic stadium where the long jump runway conformed to International Amateur Athletics Federation guidelines. Subjects were required to attempt their maximum long jump distance but were not informed about the purpose of the investigation. No restrictions were placed on subjects with regard to maintaining a consistent starting position over trials or the number of strides they were required to perform. Subjects were required to indicate their intended take-off leg. No restrictions were placed by the experimenters on whether subjects jumped off their leading foot. The jumps were performed in rounds and the distance jumped was recorded after each trial. All subjects
completed consent forms after being advised of the requirements of the study.

Data collection

Spherical markers (6.5 cm in diameter) were placed at 2 m intervals along either side of the runway, lying parallel to the runway’s long axis. This was to enable calculation of the horizontal distance between the toe and take-off board (toe-board distance). The approach phase of each long jump was recorded using a video camera (Panasonic F-15) operating at 25 Hz. The camera was manually panned to allow the whole of each subject’s run-up to be recorded. The panned camera was elevated at a height of 3.5 m and from a distance of 15 m so that the markers on both sides of the runway were visible (see Fig. 2). In total, 47 run-ups were analysed, yielding a minimum of three jumps per individual subject. Trials in which the subjects’ actual take-off leg did not correspond with their intended take-off leg were removed from the analysis.

Data reduction

To determine the toe-board distances for each foot placement of the approach, the film of each subject’s run-up was digitized using an Arvis digitizer and an Archimedes 440 microcomputer. A five-point model was used and included the toe during the support phase and the four markers which surrounded the foot at ground contact. Toe-board distance was calculated using a method developed initially by Chow (1987) and expanded for use in the long jump by Hay and Koh (1988). This procedure required the toe-marker distance to be determined initially (see Fig. 3). Toe-marker distance was calculated by projecting lines from the two near-side markers through their corresponding far-side markers until the projected lines intersected. A third line was then projected from the point of intersection along the front edge of the toe and through parallel lines on which the markers lay. The result was a ratio value for the horizontal distance of the toe between the markers. As the distance between the markers was known (2 m), the ratio was used to provide the distance between the toe and the markers. The toe-board distance was calculated by the addition of the toe-marker distance and the marker-take-off board distance (see Fig. 3). The standard deviation of the toe-board distances for each step across trials for each subject was taken as a measure of variability of foot placement for a particular step. Step length was also determined by the subtraction of toe-board distances.

The validity of the procedure for calculating the toe-board distance was determined by filming running shoes placed at known distances along the runway. The toe of the running shoe was then digitized using the algorithm developed. The level of accuracy achieved was considered to be sufficient for this investigation, as a comparison of the shoe distance with the digitized distance showed the error to be ~1 cm.

Results and discussion

Distance jumped

The best performance of the adult male subjects in this investigation was 4.56 ± 0.41 m (mean ± s; range = 3.95-5.41 m). The best performance value in this investigation was 86 cm below that recorded for the mean of the best jumps in the high-school novice sample studied by Berg and Greer (1995). The jump distance data add to the construct validity for the
subject sampling techniques, used in this and other studies, of the regulation of gait during the approach phase of the long jump.

**Overall pattern and amount of footfall variability**

A major aim of this investigation was to determine the pattern of footfall variability for non-long jumpers in the approach phase of the long jump, and to compare the results with existing data for relative novices and elite athletes. Previous research has shown that both relative novices (i.e. beginners who have received some coaching and practice) and elite athletes display an ascending-descending trend of variability for foot placement over trials. Figure 4 provides a comparison of previous research (i.e. data from Lee *et al*., 1982; Hay, 1988, Berg *et al*., 1994) with the findings of the current investigation.

There are two important features to note in Fig. 4. The first is the maximum amount of variability for the non-long jumpers (58 cm). This value is considerably larger than the values found in previous research (e.g. 23 cm for Hay, 1988; 29 cm for Berg *et al*., 1994). Lee *et al.* (1982) suggested that the increase in variability was due to small inconsistencies in stride length accumulating over the approach. A comparison of the data from the present study with those of Berg *et al.* (1994) suggests that, with a small amount of task-specific training, a high level of consistency in the run-up can be attained by beginners. With the non-long jumpers, the high variability in footfall placement over trials may have been a result of variations in the adopted start position for each trial, in addition to the inconsistencies in stride length. On the basis of the comparison of the data from the current investigation with that of Berg *et al.* (1994), it is plausible to assert that, if the non-long jumpers had received some training in using a consistent starting position, their maximum mean standard deviation would have been considerably lower (see Hay and Koh, 1988).

The second, and most important, aspect is that the non-long jumpers displayed a descending trend of variability similar to that demonstrated by the elite and novice athletes. By the fourth-from-last-step, the variability exhibits a descending trend until the take-off. By the take-off board, the standard deviation of footfall placement across trials was reduced to 9 cm. The suggestion is that, to guide the final phase of their run-up, the non-long jumpers also used vision. The most important implication of this finding is that, when related to the standard deviation of the toe-board distance for the take-off stride (see Fig. 4), the non-long jumpers were still able to reduce the larger variability to a value that is consistent with that of the expert athletes.

The descending pattern of variability found in this study is remarkably similar to previous research (e.g. Lee *et al*., 1982; Hay, 1988; Berg *et al*., 1994). The current findings support Berg and co-workers’ (1994) conclusion that the general descending trend of variability (indicative of visual regulation) is robust to task-specific training, since the non-long jumpers in the present investigation had received no practice or coaching in the task. The data from the non-long jumpers can also be taken to show that the strategy used to intercept the 20 cm target is one that has not been specifically learned to regulate gait in the approach phase of the long jump. A likely explanation is that the strategy is an emergent property of the constraints similar to
those found in everyday forms of goal-directed gait (e.g. regulating one's strides to accurately step onto a kerb during walking).

**Inter-subject differences in amount and pattern of variability**

When the average of the standard deviation for toe-board distance is examined in Fig. 4, the descending trend of variability is apparent. However, when the data of the subjects were viewed individually, it became apparent that not all subjects showed the same pattern or amount of variability. For example, one subject displayed a pattern of variability different to that described by Lee et al. (1982) but similar to that shown by four athletes in Hay and Koh's (1988) study, by showing a very low standard deviation for toe-board distance across all strides. Figure 5 compares the data from two

**Figure 4** Mean standard deviation of toe-board distance in the run-up for non-long jumpers, novices and elite long jumpers. Data adapted from Lee et al. (1982), Hay (1988) and Berg et al. (1994). L = last; J = jump.

**Figure 5** Standard deviation of toe-board distance in the run-up for subjects 4 and 7. L = last; J = jump.
subjects (subjects 7 and 4) who displayed clearly differing patterns of variability in footfall placement, which have distinct inferences for the use of vision. An explanation for the pattern of variability in subject 7 is that, as a fairly low level of variability was maintained throughout the approach, the further slight reduction may not have been necessary. This argument is supported by a comparison of this subject's standard deviation of toe-board distance at take-off with the group mean, which showed a difference of only 1 cm. This finding may indicate why the subject did not show a descending trend in footfall variability, but further investigation is required to determine why there is such a large difference in the amount of variability built up in the approach between individuals with no task-specific training.

That our findings are similar to those of Hay and Koh (1988) suggests that a second strategy may exist which is also resilient to training and which also cannot be a strategy developed specifically for the long jump. Subject 11 also demonstrated a low level of variability, but with a descending trend in relation to the take-off board. From the video footage, it was apparent that both subjects 7 and 11 were visually fixating the take-off board. This qualitative analysis seems to contradict the possibility that the low variability of the second identifiable strategy is dissociated from the more typical visual regulation strategy in relation to the take-off board. The present data suggest that the findings of Hay and Koh (1988), of alternative strategies in hitting the take-off board, may not simply be a function of a 'programming strategy' developed through the high level of task experience in the elite population sampled in their study.

The point of emergence of visual guidance

All the subjects reported looking at the take-off board in this study, which provides qualitative support for the pervasiveness of the strategy of visual regulation. Berg et al. (1994) previously suggested that the onset point of visual control should be determined by identifying a 'marked and systematic' reduction in the standard deviation of toe-board distance. It was noted in the Introduction that Berg et al. (1994) found that visual control emerged at approximately the fourth step from take-off, similar to that for the elite males and females in Hay (1988). The results of the current study show that visual control also emerged for the non-long jumpers on the fourth-from-last step. When the actual distances from the take-off board are compared across the different levels of experience, it appears that the onset of visual guidance did not occur at a standardized absolute position across groups during the approach, but was related to the remaining number of steps to the take-off board. The absolute distance for the onset of visual guidance was 7.73 m for non-long jumpers. This value fits well with the distance of 7.91 m from the board for novices with some training (Berg et al., 1994), and those of 8.42 m for elite females and 10.73 m for elite males (Hay, 1988) with more extensive training.

Analysis of the data on absolute distance compared to the number of steps relative to the take-off board for the proposed onset of a visual regulation strategy provide further support for the idea of perception-action coupling in goal-directed locomotion. It is feasible to conclude that the onset of the strategy of the visual adjustment of step length may be constrained to appear at a body-scaled value relative to stride length in humans, occurring around four steps from the board. Because of individual differences in such factors as height, limb length, stride length, flexibility, strength and fitness, the absolute distance at which visual adjustment can occur seems to vary considerably.

Take-off accuracy

A major difference between the present investigation and those of Berg et al. (1994) and Hay (1988) is that their data were collected from competitions. The difficulty in interpreting data under competitive conditions is that measures need to be interpreted in the light of the specific competitive strategy implemented by the performer, viewed as an instantaneous intentional constraint. For example, under competitive conditions, an athlete may undershoot the board, thus sacrificing accuracy on the take-off board for one of their jumps in the first three rounds to record a legal jump. If this occurs, the absolute error score for the legal jumps may be affected by making it larger. Alternatively, athletes may decide to reduce the temporal constraints and take off accurately but at a slower velocity of approach to the board. To prevent the emergence of intentionality as a constraint superimposed on stride pattern data, the need to record a safe jump was removed from the current investigation. Although athletes were asked to perform in rounds, there was never any need to perform a safe jump. Subjects were instructed to try to achieve their maximum legal jump distance and were not penalized for fouling. These procedures make it unlikely that they were favouring caution to register a safe jump.

Although the non-long jumpers were able to achieve a similarly low amount of variability in the placement of the last stride, they did not achieve the same degree of accuracy as the novice or elite athletes in previous work. The average toe-board distance for the take-off stride (take-off error) of legal jumps was 25 cm for the non-long jumpers. This value clearly exceeded the
limits of the width of the target area, signifying that they were not typically striking the board. The average take-off error of the elite male athletes of Hay (1988) was 11 cm, and the value for legal jumps of the novice males of Berg and Greer (1995) was 15 cm. Both these values would place the athletes on the take-off board. Therefore, it would appear that, although the use of visual regulation can be inferred for all levels of performance, accuracy at take-off appears to improve with specific task experience.

**Step length adjustment**

Figure 6 shows how the non-long jumpers, novice long jumpers and elite long jumpers dissipated the required adjustment in their final few strides to strike the take-off board accurately. The non-long jumpers spread 77% of the required corrections in stride length over the final three strides. Elite long jumpers (Hay, 1988) and novices (Berg et al., 1993) also demonstrated a similar percentage of stride adjustment over the last three steps (74 and 79% respectively). However, the pattern of adjustment over the final three steps differed between the non-long jumpers and the other samples. Elite (Hay, 1988) and novice (Berg et al., 1994) subjects tend to make the majority of their adjustment (67 and 62% respectively) on the final two steps. Non-long jumpers make the greatest proportion of their adjustments (65%) on the second- and third-to-last steps. Berg et al. (1994) suggested that the similarities between novice and elite long jumpers indicate that regulation of step length in the approach phase of the long jump may be due to the novice and elite long jumpers being constrained in a similar manner (for a detailed discussion of constraints, see Newell, 1986). The findings from the present study suggest that non-long jumpers are not constrained in a similar manner to experienced long jumpers. Because the data in this study were not collected under competitive conditions, it is impossible to determine whether the differences between groups were due to the constraints of competition, the larger amount of footfall variability the non-long jumpers had to deal with, or to a learned functional adaptation to improve the jump distance.

**Conclusions**

In conclusion, the findings of this study show that non-long jumpers, novices and experts have a similar pattern of stride variability. This provides additional support for the hypothesis of Lee et al. (1982), that the final phase of the long jump is under visual control. In light of previous research (Lee et al., 1982; Hay, 1988; Berg et al., 1994), these results also suggest that a strategy of visual regulation during the approach may be the same as that used during other forms of goal-directed gait, which are ubiquitous among humans. If some form of tau is the guiding optical information, then timing in goal-directed gait may have an evolutionary basis and may have the potential to become fine-tuned through learning and development. Further work on

![Figure 6](image)
interceptive actions in inexperienced performers, using natural real-world tasks, is required to verify these suggestions.

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