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Movement coordination patterns in triple jump training drills

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Abstract

The aim of this study was to determine the effectiveness of training drills in replicating the lower extremity coordination patterns used during the triple jump. Three-dimensional kinematic data and synchronized ground reaction force data were collected during the hop–step transition of a triple jump and four related training drills. Relative motion plots and a modified version of the vector coding technique were used to quantify the coordination patterns of the lower extremities. Differences were observed in the coordination patterns between the triple jump and static drills, but not between the triple jump and dynamic drills, and these differences were mainly in the swing (free) leg. The results of this study suggest that if the primary purpose of the training drills is to replicate the movement patterns used in the triple jump, then dynamic drills are more effective than static drills. In addition, coaches should focus on the use of the free leg during these training drills so that the coordination patterns more closely replicate the triple jump. Finally, to provide a more holistic evaluation of training drills, future studies should investigate the similarity of the physical and musculoskeletal demands of jumps and drills.

Keywords: *Coordination, drills, specificity, triple jump*

Introduction

The triple jump is a track and field event in which the goal is to achieve maximum horizontal distance. Unlike in the long jump, where the aim is to exert a maximal effort to attain the greatest distance, the triple jump is a complex movement consisting of three separate yet integrated phases that are carried out in an attempt to maximize the combined distance of all three phases. The ground contacts preceding the hop, step, and jump phases largely determine the flight distance within each phase and it has been suggested that the transition, or contact, between the hop and step phases is the most critical element in successful triple jump performance (Jurgens, 1998). The demands placed on the body during the triple jump are very high, with vertical forces of around 18 body weights experienced during the contact between the hop and step phases (Perttunen, Kyrolainen, Komi, & Heinonen, 2000). Activities with such high demands might therefore have implications for injury and coaches should ensure that the number of training repetitions are limited (Elliott, 1999).

Training practices have previously been used in the development of complex movements, whereby coaches use the concept of specificity to encourage

performance-related adaptations (Irwin, Hanton, & Kerwin, 2004). Practice specificity suggests that maximal retention of the performance of a task is facilitated by practice conditions that mimic task conditions (Henry, 1968) and which therefore ensure ecological validity, and according to Lauder and Payton (1995), training practices or drills should resemble the movement patterns of the target skill. As well as developing a complex movement, training practices may also be used to develop and improve movements when the full skill places very high loads on the body and where repetitions should be limited (Elliott, 1999). In addition, it has been suggested that the learning and development of skills that are highly complex, such as the triple jump, is best achieved through the use of part-practice rather than whole-practice (Magill, 1993).

It has been proposed that every movement performed by the human body is defined behaviourally by a unique set of characteristics defining the coordination or relative motion of that body (Newell, 1985). Humans select their movement coordination patterns via a process of self-organization within the context of organismic, environmental, and task-related constraints imposed on the degrees of freedom of the system (human body) (Newell, 1985).

These coordination patterns selected by the individual can be assessed through the quantification of inter- and intra-limb coordination. Quantifying the similarity between a skill such as the triple jump and training practices or drills in terms of these coordination patterns may provide a better overall assessment of their effectiveness as a training drill (Irwin & Kerwin, 2007). However, the constraints imposed on the system must also be considered. In addition, the effectiveness of the drills may differ according to the stage of learning of the performer and therefore the stages of coordination and control as proposed by Newell (1985) need also to be considered when determining how effective learning practices/drills are.

The aim of this study, therefore, was to examine the differences between full triple jump trials and four plyometric drills that are employed in training, in terms of the coordination strategies adopted by the lower extremities during the hop-step transition phase. It was hypothesized that the coordination patterns of the drills employed in training are similar to those used in full triple jump trials. In addition, different drills will vary in their similarity to the triple jump and therefore in their effectiveness.

Methods

Three male and two female competitive triple jumpers (mean $\pm$ s: age 20.6 ± 1.5 years; body mass 69.7 ± 15.4 kg; height 1.79 ± 0.11 m) were recruited to participate in the study. All of the participants were members of the same training group with the same coach and had personal bests of more than 70% of the respective world record. All participants were free from injury and, at the time of the study, were at the end of their competitive season. Ethical approval for the study was obtained from the Research Ethics Committee of the University of Wales Institute Cardiff and each participant provided written informed consent before the onset of data collection.

The experimental set-up consisted of a 12-camera Vicon MX13 motion analysis system (Oxford Metrics, Oxford, UK), sampling at 100 Hz and calibrated to the manufacturer's instructions. Ground reaction force data were sampled simultaneously at 1000 Hz using a Kistler 9287BA piezo-electric force platform. The cameras were positioned equally around the force platform to produce a field of view of about 6 m. The take-off board for the initial phase of a triple jump (hop) was located such that the participant landed on the force platform for the hop-step transition. The take-off board position was adjusted for each participant.

After a self-directed warm-up, each participant completed practice jumps as undertaken during competition. Subsequently, 39 retro-reflective spherical markers of 12.5 mm diameter were attached to

specific anatomical landmarks on the participant for use with the Plug-In-Gait model (Vicon, Oxford Metrics, Oxford, UK). The markers were located on the following anatomical landmarks for calibration purposes: 7th cervical vertebra, 10th thoracic vertebra, clavicle, sternum, and right scapula; plus the left and right temple, back of head, acromio-clavicular joint, lateral epicondyle, lateral wrist, medial wrist, finger (middle knuckle), anterior superior iliac spine, posterior superior iliac spine, lower lateral third surface of thigh, knee, lower third surface of shank, lateral malleolus, calcaneus, and second metatarsal head. The final four markers were attached for tracking purposes to generate the kinematic data.

Each participant completed a total of three triple jump trials and a series of drills. Three trials were considered sufficient as the research question was not concerned with variability. More trials than this may have resulted in sub-maximal performances, particularly with the full triple jump trials. The drills were selected following interviews with coaches and were all based on the replication of the hop-step transition. The drills were as follows: a static hop-step (D1), a 3-stride hop-step (D2), a static hop-step from a 30-cm platform (D3), and a 3-stride hop-step from a 30-cm platform (D4). The static drills refer to drills performed from a standing / stationary start. Each of the drills was repeated three times. A sufficient rest was allowed between jumps and between drills such that fatigue was not a factor. All trials were completed on an indoor Mondo athletics track.

Three-dimensional kinematic data were recorded during the hop-step transition phase of each of the triple jump trials and the drills. Coordinates for each of the 39 reflective markers were reconstructed using Workstation software (version 5.2.4, Oxford Metrics, Oxford, UK). Three-dimensional Euler angles were subsequently calculated for the ankle, knee, and hip joints. The joint angle data were smoothed using a generalized cross-validatory spline (Woltring, 1986). Only sagittal plane data were used for further analysis as these data were considered most appropriate for performance-based analyses. The frames associated with touchdown and toe-off of the hop-step transition phase for each trial were established using the ground reaction force data. The angle data between touchdown and toe-off were then interpolated to 101 data points using a cubic spline technique. The transition point between the braking and propulsive phases of the contact phase was identified from the horizontal ground reaction force.

The joint coordination was quantified using relative motion (angle-angle) profiles and a modified version of the vector coding technique (Heiderscheit, Hamill, & van Emmerik, 2002; Sparrow, Donovan, van Emmerik, & Barry, 1987). This technique was chosen because of its simplicity and ease of

understanding and because of the problems (e.g. normalization) associated with alternative techniques such as continuous relative phase. Intra-limb couplings were created for ankle flexion/extension–knee flexion/extension of the stance leg (coupling 1), for knee flexion/extension–hip flexion/extension of the stance leg (coupling 2), and for knee flexion/extension–hip flexion/extension of the swing leg (coupling 3). These couplings were chosen on the basis of the importance of knee flexion/extension of the support limb and the use of the free limbs during triple jump performances. Relative motion plots were created for each coupling with the abscissa and ordinate comprising the proximal and distal segments respectively. Coupling angles were calculated using the orientation of the resultant vector to the right horizontal between two adjacent points on the relative motion plots. Following conversion from radians to degrees, the resulting range of values for the coupling angles was between 0° and 180° .

The stance phase of each trial was divided into 20% intervals so that the movement coordination during specified phases of the trials could be investigated. The mean coupling angle during each of the five intervals was calculated for all trials. This procedure was repeated for each intra-limb coupling. For each coupling, a two-way repeated-measures analysis of variance (ANOVA) was employed (trial main effect; phase main effect; trial $\times$ phase interaction effect) to examine any differences in movement coordination patterns between jump and drill trials. Where significant interaction effects were identified, paired *t*-tests were employed *post hoc* to determine where the significant differences lay. Statistical significance was set at $P < 0.05$. Effect sizes (Cohen's *d*) were calculated using the method of Cohen (1988). A large effect was considered when $d > 0.8$, a moderate effect when $d > 0.5$ and a small effect when $d > 0.2$. In addition, the root mean squared difference between the jump and drill trials was calculated throughout the whole of the contact phase.

In addition to the coordination analysis, the joint angular velocities of the ankle, knee, and hip joints of the stance leg and knee and hip joints of the swing leg were analysed. Following the determination of the

mean joint angular velocity time history values for all participants, the root mean squared differences between jump and drill trials were calculated as a percentage of the range of mean joint angular velocity.

Results

The root mean squared differences in coupling angle between the triple jump trials and each drill, for each of the three couplings, are presented in Table I. Greater differences were observed for coupling 3 than coupling 1 or coupling 2. In addition, greater differences were observed for the static drills (1 and 3) than for the 3-stride drills (2 and 4). Figure 1 shows the coupling angles for couplings 1, 2, and 3 for each of the four training drills and the full triple jump.

No significant interaction effects between the triple jump trials and drills were found for coupling 1. For coupling 2, a significant difference was observed between the jump and drill 1 ($P = 0.046$, $d = 2.7$). For coupling 3, significant differences were observed between the jump and drills 1 ($P = 0.032$, $d = 4.0$) and 3 ($P = 0.032$, $d = 3.8$) (see Table II).

For coupling 2, the difference between drill 1 and the triple jump was found to lie in the first 20% of the stance phase ($91.8 \pm 7.3^\circ$ for jump vs. $115.5 \pm 8.8^\circ$ for drill 1, $P = 0.046$). For coupling 3, significant differences between the triple jump and both drill 1 and 3 were found in the middle 20% (40–60%) of the stance phase ($39.6 \pm 15.8^\circ$ for jump vs. $10.0 \pm 5.5^\circ$ for drill 1, $P = 0.032$ and $11.4 \pm 5.8^\circ$ for drill 3, $P = 0.032$). In all trials, the transition point between the braking and propulsive phases of the contact phase occurred between 40% and 60% of the stance phase.

The root mean squared differences between the triple jump trials and each drill, for the ankle, knee, and hip angular velocities of the stance leg and the knee and hip angular velocities of the swing leg, are presented in Table III.

Discussion

This aim of this study was to examine the differences in coordination patterns of the lower extremities

Table I. Root mean squared differences in coupling angle between triple jump and drills.

Drill	Coupling		
	C1: Ankle flexion/ extension–knee flexion/ extension (stance) ($^\circ$)	C2: Knee flexion/ extension–hip flexion/ extension (stance) ($^\circ$)	C3: Knee flexion/ extension–hip flexion/ extension (swing) ($^\circ$)
D1: Static hop–step	17	16	19
D2: 3-stride hop–step	9	8	14
D3: Static hop–step (30-cm platform)	11	13	16
D4: 3-stride hop–step (30-cm platform)	8	8	10

Figure 1. Coupling angles for couplings 1, 2, and 3 for the triple jump and drills.

Table II. Interaction effects from an ANOVA for differences in coupling angles (C1–C3) between the phases of the triple jump and drills (D1–D4).

Drill	Coupling		
	C1: Ankle flexion/ extension–knee flexion/ extension (stance) (°)	C2: Knee flexion/ extension–hip flexion/ extension (stance) (°)	C3: Knee flexion/ extension–hip flexion/ extension (swing) (°)
D1: Static hop–step	$P = 0.282$	$P = 0.046$	$P = 0.032$
D2: 3-stride hop–step	$P = 0.465$	$P = 0.499$	$P = 0.055$
D3: Static hop–step (30-cm platform)	$P = 0.871$	$P = 0.159$	$P = 0.032$
D4: 3-stride hop–step (30-cm platform)	$P = 0.996$	$P = 0.289$	$P = 0.200$

Note: Significant interaction effects are displayed in **bold**.

Table III. Root mean squared differences in joint angular velocity between triple jump and drills.

Drill	Hip (stance) (%)	Knee (stance) (%)	Ankle (stance) (%)	Hip (swing) (%)	Knee (swing) (%)
D1: Static hop-step	28.0	16.1	13.0	43.2	36.7
D2: 3-stride hop-step	22.2	9.9	8.4	26.7	27.0
D3: Static hop-step (30-cm platform)	24.8	13.3	11.9	32.1	34.1
D4: 3-stride hop-step (30-cm platform)	21.6	8.4	9.7	20.7	24.4

during the hop-step transition phase between training drills and the full triple jump movement. If the primary purpose of the training drills, as suggested by coaches, is to replicate the movement patterns used in the triple jump, then the use of coordination strategies may provide a better overall assessment of their effectiveness as a training drill compared with single joint kinematics. The results of this study suggest that the dynamic drills are more similar to the triple jump than the static drills.

Significant differences were found for coupling 2 (knee flexion/extension-hip flexion/extension, stance) between drill 1 (static hop-step) and the full triple jump ($P=0.046$), and for coupling 3 (knee flexion/extension-hip flexion/extension, swing) between both drill 1 and the full triple jump ($P=0.032$) and drill 3 (static hop-step, 30-cm platform) and the full triple jump ($P=0.032$). Hence, all of the significant differences between the drills and the full triple jump were observed for the static drills (drills 1 and 3) only. The drills with a 3-stride approach (dynamic drills) would therefore appear to be more effective in terms of replicating the full triple jump movement pattern. As well as resembling the same movement patterns as the target skill, Lauder and Payton (1995) stated that training practices or drills should be performed at the same speed as the target skill. Although the results of the present study show that none of the drills investigated occur at the same speed as the target skill (the full triple jump), the dynamic drills were more similar than the static drills. It may be that the effectiveness of the drills will change, depending on the performer's stage of learning. For example, while in the "coordination" stage of learning, during which time the performer is trying to assemble the appropriate motions among body parts in the construction of an action (Handford, Davids, Bennett, & Button, 1997), it may be less important for the drills to occur at the same speed as the final skill. If the static drills are easier to perform, it may be that they are more effective in achieving the desired outcome.

The greatest differences in the coordination strategies of the drills and the full movement were found within the free (swing) leg (coupling 3). This suggests that although the drills might be effective in

replicating the movement patterns in the stance leg, they do not appear to be as effective in terms of the free limb. Although the stance leg is clearly an important contributor to the success of the support phase (Yu & Andrews, 1998), the free limb has also been identified as important during this phase of jumping because of its contribution to changes in velocity and angular momentum (Yu & Andrews, 1998) and its effect on the maintenance of balance (Ashby, & Heegaard, 2002; Lees & Barton, 1996). It may therefore be beneficial to study inter-limb coupling given that most changes in gait occur at the inter-limb level (Haddad, van Emmerik, Whittlesey & Hamill, 2006). Regarding the speed of movement, the angular velocities of the stance leg are more closely replicated in the drills than the angular velocities of the swing leg. The importance of free limbs in successful jumping performance highlights that for training drills to be effective, the free limb movement of jump performance must be replicated. One potential reason for the greater differences in the swing leg during the static trials is the need to generate momentum, which will be lower in these drills than in either the dynamic drills or in the full triple jump trials.

Significant differences between drills and jump were found mainly in the middle 20% of the contact phase, which coincides with the transition from braking to propulsion. During this transitional phase, the variation in coordination patterns between jumpers is greater than during any of the other phases within the hop-step transition (Wilson, Simpson, van Emmerik, & Hamill, 2008). Although this might suggest that it is not important to replicate the movement during this phase in training drills because of the variability during the final skill, this is not the case. The variability found during this phase in the hop-step transition was suggested to allow flexibility to adapt to any changes to the constraints (Wilson et al., 2008). The flexibility needed during a drill may be different to that required during a full triple jump due to the potentially different constraints imposed. Irrespective of the levels of functional variability present during the different trials, the drills used should be expected to replicate the final skill (full triple jump) according to the principle

of training specificity (Dick, 2002). It is important here to distinguish between variability within performances of the same skill and differences between training practices and a final or target skill.

In addition to replicating the movement patterns used in the triple jump, these training drills are used to reduce the high joint loading experienced in full triple jumping. This study has only investigated the movement patterns in terms of the coordination strategies, and future studies will be required to investigate whether the drills do in fact reduce the loading on the lower extremity joints. Dick (2002) highlighted the importance of a training drill exposing the performer to the same physical and musculoskeletal demands as the target skill; however, if this is to be achieved, it negates the purpose of reducing the joint loading. Therefore, to provide a more holistic evaluation of the training drills, while still taking into consideration the need to reduce the loading to the lower extremity joints, future studies should also investigate the similarity between the drills and the triple jump in terms of the joint kinetic patterns.

In conclusion, the results of this study demonstrate that the static training drills used by triple jumpers are not as effective as the 3-stride approach (dynamic) drills in replicating the coordination strategies used in triple jumping. Therefore, coaches should avoid using these static drills if their primary purpose is to replicate the movement patterns used during the triple jump.

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