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Original article

Integrating biomechanical and motor control principles in elite high jumpers: A transdisciplinary approach to enhancing sport performance

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Abstract

Background: In recent years, there has been a proliferation of technology and sport science utilized within an athlete's training, especially at the elite level. However, the sport science is a broad field, encompassing disciplines such as biomechanics, motor control and learning, exercise physiology, sports medicine, sport psychology to name a few. Rarely are these disciplines applied in an integrated manner. The purpose of this study was to document the effectiveness of an integrated biomechanics and motor control protocol for improving athlete's performance in the high jump.
Methods: Four elite high jumpers performed baseline jumps under normal conditions and then jumps using a specific external focus of attention cue designed to improve their running posture. Three-dimensional biomechanical analysis was used to quantify the upright posture throughout the approach as well as horizontal velocity at plant and vertical velocity at takeoff.
Results: The results showed that when using the external focus of attention cue, the jumpers were significantly more upright during the approach, had significantly higher horizontal velocities at plant, and generated significantly greater vertical velocities during the takeoff.
Conclusion: The results of this study lay the foundation for future work examining how integrating sport science disciplines can improve performance of elite level athletes.

Keywords: Biomechanics; High jump; Motor control; Sport performance

1. Introduction

In recent years the integration of sport science and technology within training environments of professional and amateur athletes has become increasingly common. The sub-disciplines of sport science are diverse and constitute a breadth of scientific disciplines including strength and conditioning, sports medicine, exercise physiology, nutrition, biomechanics, motor control and learning, psychology, and sociology. While training for sport has come a long way from relying on tradition and belief systems, the integration of sub-disciplines within sport science is severely lacking. Often times, practitioners try to enhance sport performance while utilizing just one sub-discipline creating a singular or modular approach. However, truly optimizing sport performance requires integrating multiple of the sport science sub-disciplines into one training program. This study documents an approach to integrate biomechanical and motor control principles to enhance performance in elite high jumpers.

From a biomechanical perspective, the high jump consists of an approach phase, takeoff, and flight phase. Of the three, the approach phase is the most critical for jump success. The approach phase is composed of a straight portion consisting of four to seven steps run perpendicular to the bar, followed by a curved portion consisting of five steps. The goals of the approach are two-fold. First, the jumper seeks to arrive at takeoff with the highest tolerable horizontal velocity as this will help them generate the necessary vertical velocity during the takeoff.[1,2] Second, the jumper seeks to arrive at the plant of the takeoff foot in a posture which facilitates the generation of angular momentum, ultimately leading to an effective bar clearance during the flight phase. The posture adopted by the jumper during the approach phase plays a critical role in their ability to accomplish these goals.

During the initial steps of the approach the athlete uses acceleration mechanics which are marked by a forward lean of the body, long ground contact times, and large movements of the free limbs. However, a step before they begin the curved portion of the approach the athlete should have achieved an upright erect posture, as it allows the athlete to smoothly transition from the

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straight to curved portions of the approach, and will facilitate proper force application during the curved portion of the approach.[3] An erect posture is also critical during the last two steps of the approach. The athlete must facilitate the development of appropriate amounts of angular momentum without sacrificing horizontal velocity. The ability to do this is dependent on the athlete being upright as their penultimate foot contacts the ground. The takeoff foot touches down well in front of the hips and shoulders. This position is set up during the penultimate step and is accomplished by the athlete thrusting the hips forward during the second half of the penultimate step.[4] If the athlete is not upright as the penultimate step touches down, it will be more difficult for them to achieve the desired posture at plant and will require more time to thrust the hips forward of the shoulders. This means the athlete spends more time on the penultimate step resulting in a greater loss of horizontal velocity.

Given the importance of an upright posture, an appropriate question to consider is: “how can practitioners help athletes change their posture during the approach?” The answer to this question can be obtained through the motor control and learning literature. Recently, there has been much research on how the attentional focus of a performer affects the control and learning of new movement patterns or the refinement of existing ones. According to Wulf,[5] performers can allocate their attention in two different ways prior to or during the performance of a motor skill. When a performer adopts an internal focus of attention, he or she is thinking about the movements of their body. In contrast, an external focus of attention is utilized when a performer thinks about the effects of their movements on the environment. The focus of attention literature overwhelmingly suggests that compared to an internal focus of attentions, when performers adopt an external focus of attention, they demonstrate better outcome and performance production measures.[5–9] The literature also suggests that high level performers benefit more from using an external focus of attention than novice performers.[10–12] Therefore, using appropriate focus of attention cues is critical for optimizing elite level sport performance.

When reviewing the biomechanical literature on the high jump and the current findings within the attentional focus literature of motor control, one can see the natural relationship between biomechanics and motor control/learning. One addresses “what” athletes are supposed to do, while the other addresses “how” practitioners get them do it. In an effort to demonstrate the effectiveness of integrating principles of biomechanics and motor control, this study investigated the effects of an external focus of attention on running posture during high jump approach in elite high jumpers. It was hypothesized that an external focus of attention targeted at improving posture during the curve approach would enhance high jump performance compared to athlete’s normal performances.

2. Methods

2.1. Participants and data collection environment

Participants in this study were four elite female high jumpers participating in an USA Track and Field Sport Performance Workshop. The workshop environment is specifically designed for sports science staff to work with athletes one-on-one directly on the track to address performance limiting factors in their technique. These four jumpers were identified based on previous data suggesting that their posture during the approach was a limiting factor in their performance. Participants were classified as elite performers based on their high finishes at recent USA Track and Field National Championships. Specific information regarding each athlete is shown in Table 1. All procedures were done in accordance with the Declaration of Helsinki and all participants provided informed consent prior to participation.

Table 1
Participant characteristics.

	Age (year)	Height (m)	Personal best (m)
Jumper 1	24	1.67	1.74
Jumper 2	22	1.80	1.90
Jumper 3	24	1.82	1.86
Jumper 4	23	1.80	1.92

2.2. Experimental protocol

Each participant completed their own individual warm-up prior to jumping. This was followed by each athlete completing a baseline jump using their normal approach. The bar was set to a height the participants would routinely use in a practice setting. Following the baseline jump the intervention was introduced. For the intervention a small piece of athletic tape was placed on the athlete’s shirt, approximately at the level of the navel. In an effort to ensure that the athlete adopted an upright posture prior to entering the curve, while also focusing their attention externally, the participants were instructed to “*lead with the tape*” as they transitioned from the 4th to 5th steps of the approach. Participants completed two practice runs while being verbally cued between the 4th and 5th steps, and then completed a second jump for analysis.

2.3. Data collection and analysis

Each jump was recorded with two video cameras (GC-PX10; JCV Corp., Wayne, NJ, USA) sampling at 60 frames per second with a shutter speeds of 1/1000 s. A volume encompassing the curved portion of the approach was calibrated using a 68-point calibration structure and the multiphase calibration technique described by Challis.[13] Twenty individual body landmarks were manually digitized over the last six steps of the approach, takeoff, and flight. The two cameras were synchronized based on the frames of foot contact and toe off[14] and a Direct Linear Transformation[15] reconstruction was used to obtain three-dimensional (3D) coordinates. The *X-Y-Z* coordinates of individual body landmarks were smoothed using quintic spine functions.[16] The location of the whole body center of mass (COM) was calculated as the weighted sum of the individual segments based on Dempster’s data[17] and the quantic spline equations were used to calculate the instantaneous velocity of the COM throughout the approach. The forward lean of the torso at each instant during the approach was calculated based on the orientation of the torso relative to the global *X*