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Letter

Bicycle kick in soccer: is the virtuosity systematically entrainable?

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Abstract In soccer, the bicycle kick has provided viewers moments of breathtaking spectacle that seem virtuosic in scope. The novelty of such moments is underscored by the rarity with which players have performed this complex skill during national or international tournaments. The rarity of these occurrences is both a product of perceptions that it is a high-risk, low return skill and by the fact that there is a dearth of scientific research on the biomechanics of the technique. Two genera can be discerned based on starting position: 1) back-facing the goal, and 2) side-facing the goal. The current study, using 3D motion capture technology and full-body biomechanical modeling, identifies elements that govern entrainment of the technique by examining jumping, kicking and falling phases of the skill execution. Motor sequencing during the first two phases can be characterized by analyzing the following parameters: 1) angle between the player's thighs (humerus bones) upon take-off, 2) the whip-like control of the kicking leg, 3) timing between ball motion and joint coordination and, for the side-facing bicycle kick, 4) rotation of the player's trunk during the jumping phase. Dispersion of energy during falling after the kick is accomplished by sharing the load using a sequence of partial landings. Collectively, this information could help entrainment of the skill. Virtuosic in appearance, more frequent use of the kick can only enhance the excitement of the game.

Keywords 3D motion capture · Biomechanical modeling · Whip-like movement · Joint flexibility · Impact absorption of falling

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In soccer, the bicycle kick has provided viewers moments of breathtaking spectacle that seem virtuosic in scope [1]; but, can such virtuosity be systematically entrainable? Perhaps the most memorable bicycle kick of all time was performed by Pelé from Brazil in 1965 [2]. More recently, a bicycle kick of English footballer Wayne Rooney was voted as the Best Goal in England Premier League History [3] and Tim Cahill's bicycle kick goal helped Australia defeat China in Asian Cup 2015 [4]. The novelty of these moments is underscored by the rarity with which players have performed this complex skill during national or international tournaments since its invention almost hundred years ago [5]. The rarity of these occurrences is both a product of perceptions that it is a high-risk, low return skill and by the fact that there is a dearth of scientific research on the biomechanics of the technique. Recent biomechanics researches suggest soccer kicking skills can be improved through scientific methodologies [6, 7]. Thus skills that are virtuosic in appearance may be eminently trainable and less a product of improvisatory abilities of individual players. A parallel circumstance might be found by examining the practice of the "slam-dunk" in basketball, where few players used the technique before 1960s [8] and its common use today has enhanced the excitement of the game. The current research identifies the biomechanical elements that govern entrainment of the bicycle kick technique.

A bicycle kick involves a player jumping, and as his/her trunk approaches horizontal, a kicking motion is executed above the head. Two genera can be discerned based on starting position: (1) back-facing the goal and (2) side-facing the goal. To investigate these skills, a 3D motion-capture system provided data for a case study of two experienced soccer players who could safely perform this rare manoeuver. This allowed discrimination of body segments and joints anatomically significant for human movement via a 15 segment biomechanical model [9]. Such a biomechanical model can be applied to identify the motor control patterns used in most complex human motor skills [6, 9].

Since the bicycle kick occurs while the player is airborne, its effectiveness is governed by the law of conservation of angular momentum. Thus, the two legs compensate for each other; movement of a kicking leg must be balanced by the other leg. Additionally, in a powerful kick, the desired whip-like movement of the kicking leg and foot depended on an initial bending of the knee to decrease the moment of inertia of the leg, allowing a maximal angular acceleration of the hip. Such a control mechanism is necessary for a whip-like movement to occur in the final phase of the kick [6, 7]. Several kinematic parameters influencing kick quality have been identified through comparisons of the trials. Kicking power in the back-facing orientation is dependent on three main parameters: the angle between the player's thighs (α) at the instance of take-off (Fig. 1a), the control of knee (β, Fig. 1a), and the timing between ball motion and the joints' coordination; while the side-facing technique incorporates a fourth: rotation of the player's trunk during jumping phase. Power is increased by using a larger angle α and faster acceleration of the foot. Since hip flexibility is the anatomical determinant of α, a skilful soccer kick acts as an

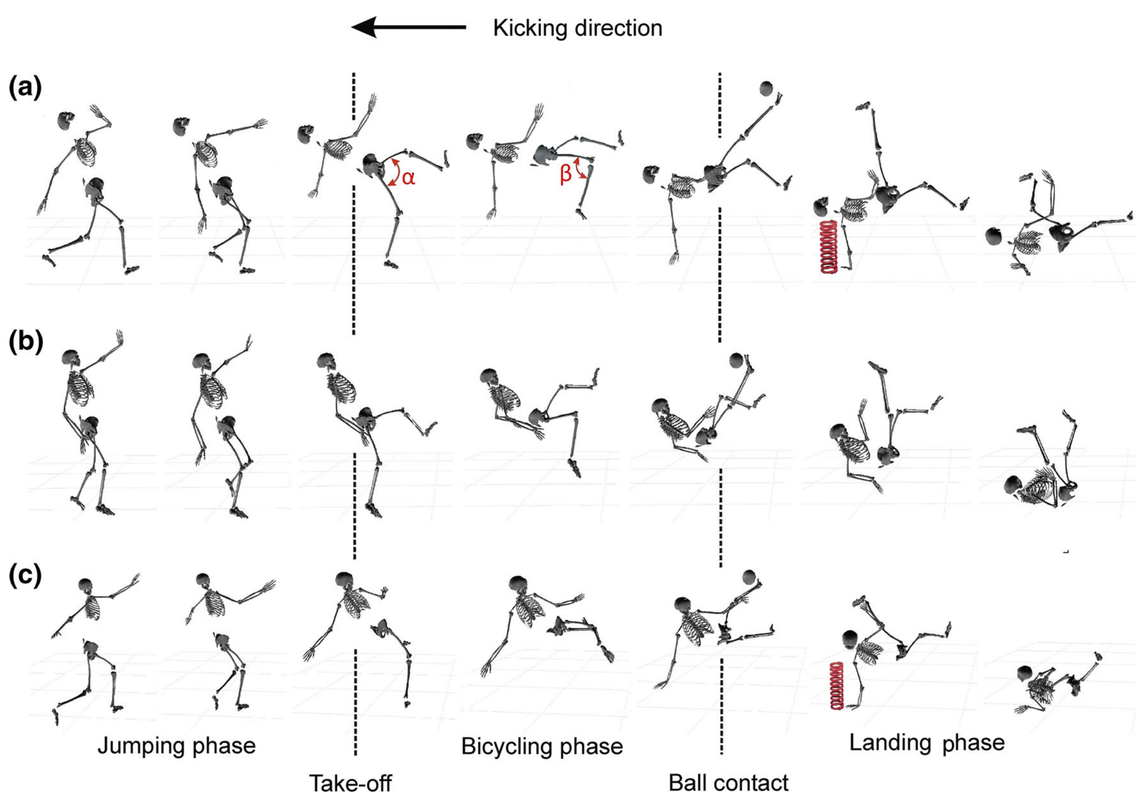

Fig. 1 (Color online) Biomechanics of bicycle kick and identified dominant factors related to kick quality. Two events—take-off and ball contact—divide bicycle kick into three phases—jumping phase for creating optimal conditions for the kick, bicycle phase for accelerating kick-foot as fast as possible and landing phase for minimizing landing impact to avoid injury. **a** Sequential 3D reconstruction of back-facing-goal bicycle kick of Subject 1; **b** sequential 3D reconstruction of back-facing-goal bicycle kick of Subject 2, a less effective one than Subject 1, i.e. less inclination of trunk and flexed non-kick leg during bicycling, resulting slower kick-foot velocity 14.8 m/s vs. 17.8 m/s of Subject 1 as well as hip landing instead of arm–hip landing; **c** sequential 3D reconstruction of side-facing-goal bicycle kick of Subject 1, the most effective style, resulting a kick-foot velocity of 20.8 m/s

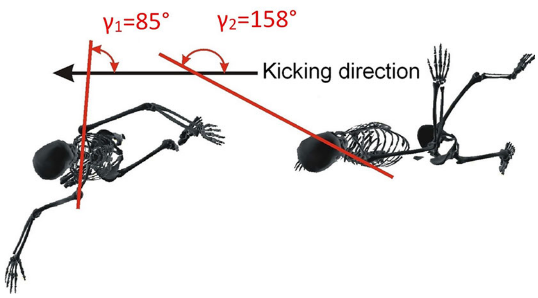

Fig. 2 (Color online) A representation of trunk rotation during jumping phase of the side-facing-goal bicycle kick (top view). The current study observed a range of trunk rotation of 73° ($\gamma_2 - \gamma_1$)

open kinetic chain where the kicking leg performs a whip-like movement towards the ball; kicking is initiated at the hip and movement follows a proximal to distal segmental sequence, a sequential flow of energy and momentum transfer [10]. Therefore, flexibility of hips and hip–knee–foot timely coordination should be emphasized during training and the training should pay special attention to the timing between ball motion and the joints' coordination. For the side-facing orientation, the current case study can be understood as indicative of the degree to which rotation of a player's trunk comes into play. Rotation is executed during the jumping phase where the trunk first rotates away from and then towards the kick direction (Figs. 1c, 2). For this particular player, the range of motion of the trunk is 73° (Fig. 2: 158°–85° = 73°). Because of the additional energy gained for the kicking leg from trunk rotation, the side-facing-goal bicycle kick proved to be more powerful than the back-facing-goal one (~17 % greater foot velocity). Just like back-facing-goal bicycle kick, timing is also a crucial element for side-facing-goal bicycle kick.

One of the reasons the bicycle kick is considered to be high risk is that it involves the player necessarily falling to the ground. There is realistic fear of injury during the landing phase. Gymnastics studies show that landing forces on the feet can be as high as 10–15 times a gymnast's body weight [11, 12]. Since the feet and legs are naturally designed for absorbing energy impacts from aerobic activity and the arms and body are not, understanding how to dissipate energy during the falling phase of a bicycle kick is vital. The data of Subject 1 show one possible motor control mechanism for absorption of the high impact of falling. Essentially, energy is dispersed by sharing the load using a sequence of partial landings. The first partial uses a flexed hand-arm system which acts as a spring (Fig. 1a, c), and the second one employs the hip, first to contact the ground and then to distribute the forces gradually by a body rotation. This strategy dissipates the momentum of the body by sharing the load among multiple contact points.

In summary, entraining the bicycle kick should focus on increasing the flexibility of the hip, the efficiency of the whip-like movement of the proximal to distal acceleration of the kicking leg, and the damping mechanism of an arm-hip landing system. Accurate timing is crucial for a successful kick and can only be achieved through repetitive training. This underscores the need for athletes to use a landing sequence that minimizes risk of injury during practice and execution of the skill. Certainly the bicycle kick is one of the most complex skills in soccer, one that is eminently trainable. Virtuosic in appearance, more frequent use of the kick can only enhance the excitement of the game.

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Conflict of interest The authors declare that they have no conflict of interest.

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