SAGITTAL COUPLING ANALYSIS IN THE ROUNDHOUSE KICK IN TAEKWONDO

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Analysis of coordination in taekwondo has been carried out by heterogeneous methods but no analysis of segment coupling has been done. The aim of this study was to analyse intralimb coordination in the roundhouse kick in taekwondo using Vector Coding. Four experienced (right-footed) female athletes participated in the study. Motion analysis was measured by two 3-D force plates and an eight-camera motion capture system. Data analyses were processed using Visual 3D and Matlab softwares. The prevalant coordination pattern changed throughout the roundhouse kick, with each phase of the movement having a different primary movement pattern.

KEY WORDS: kinematic, coordination, coupling, taekwondo.

INTRODUCTION: Some of the studies in the biomechanics of combat sports literature (i.e., Estevan, Jandacka, & Falco, 2013) have reported the kinematics and kinetics of individual joints or segments rather than addressing the interaction between these joints or segments. It is valuable as a description of the movement of a segment, but it must be noted that the human body is made up of multiple joints and segments that must operate in a smooth harmonious pattern to produce movement (Hamill, Haddad & McDermott, 2000). Thus, analyses of coordination that address the dynamical nature of movement, combined with more common approaches that examine continuous movement at discrete intervals, are likely to provide greater understanding of the motor control required to perform task (Bartlett, Wheat, Robins, 2007).
Coordination patterns in taekwondo kicks have been studied by Kim, Kim, & Im (2011), providing an index of inter-joint coordination. They found that as the kicking leg gradually approaches the target, close to the impact, hip and knee joints couple in phase. However, Kim et al. (2010) found different relative contributions in hip and knee joints. Moreover, there still is a lack of knowledge about lower limb coordination patterns in combat sports. In this line, Kloiber, Baca, Preuschl and Horsak's (2009) pointed out that the kick movement is a crucial factor for performing and analyzing the technique in combat sports. Thus, the purpose of this study was to analyse segment coordination in the sagittal plane in joints of the kicking limb by computing vector coding in the roundhouse kick in taekwondo.

METHODS: Participants: Four female experienced taekwondo athletes (all of them right-footed) participated in this study (mean age, weight height and experience were 19.8 ± 0.5 years, 62.75 ± 3.69 kg, 1.68 ± 0.06 m, and 9.8 ± 1.5 years).
Instrumentation: Participants were standing on two 3-D force plates (Kistler 9286AA, Switzerland) (1235 Hz), kinematic data during the roundhouse kick were collected at 247 Hz with an eight-camera motion capture system (Qualisys Oqus, Sweden). An LED was placed on the target and all the equipment was synchronized (Estevan et al., 2013).
Experimental design: After a personal warm-up and during the test, each athlete's foot was positioned on the force plates. The kicking leg was the rear foot. Retro reflective markers were attached to the left and right foot, left and right shank, left and right thigh, pelvis and trunk according to the recommendation of the C-motion Company (C-motion, Rockville, MD, USA). Each participant's preferred target distance as the execution distance and the sternum height as the height distance (Estevan et al., 2013) were used. They performed five kicks

with their feet beginning in a stance position of 45º (Estevan et al., 2013). The kick began when indicated by the illumination of an LED light.

Analytical methods: Markers data were processed using Visual 3D software (C-motion, Rockville, MD, USA). All extremity segments were modeled as a frustum of right circular cones whilst the torso and pelvis were modeled as cylinders. During the movement, four main instants were selected: the kicking leg raised 1% of GRF (1), the toe left the force platform (2), the knee raised the maximum flexion (3) and the impact (4). Three phases were established: stance phase (between instants 1 and 2); first swing phase (between instants 2 and 3); second swing phase (between instants 3 and 4). Finally, angular displacement of thigh and shank was normalized to 100% of each phase (see Figures 2 a-c). Only sagittal plane data were used for further analysis. Kinematic data were averaged across trials for each subject, and these means were used to calculate group means.

To assess segment coordination, the relative phase between segments has been described as an appropriate variable (Hamill et al., 2000). That is, to calculate coordination, segment angles were vector coded, averaged with circular statistics, and reported according to defined patterns of segment coupling; in phase, anti-phase, exclusive thigh rotation (proximal), exclusive shank rotation (distal) (Chang et al., 2008). Mean coupling angles were categorized into one of these four coordination patterns (see table 1).

Table 1
Scheme used to categorize coordination patterns (adapted from Chang et al., 2008).

Coordination pattern	Coupling angle definitions
Anti-phase	$112.5^{\circ} \leq \gamma < 157.5^{\circ}$
In-phase	$22.5 \leq \gamma > 67.5^{\circ}$
Exclusive thigh rotation	$0^{\circ} \leq \gamma < 22.5^{\circ}$, $157.5^{\circ} \leq \gamma < 180^{\circ}$
Exclusive shank rotation	$67.5^{\circ} \leq \gamma < 112.5^{\circ}$

RESULTS: Figure 1 provides the frequency of segment coupling into the four distinct coordination patterns. It shows that in the sagittal plane, during the stance phase, motion is distributed with a higher proportion of in-phase and shank rotation. On the other hand, during the first swing phase of kick, there were a dominance of anti-phase and thigh rotation without the existence of in-phase and shank rotation. Finally, during the second swing phase of kick, motion was mostly shank rotation, following by in-phase and thigh rotation.

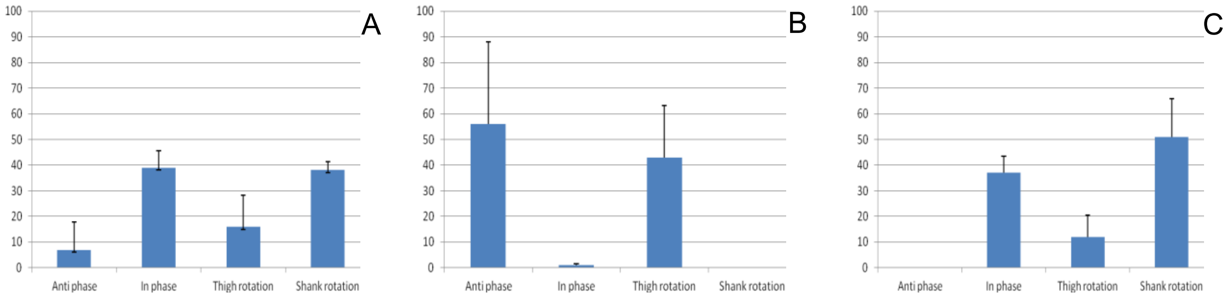

Figure 1: Histograms (group mean ± SD) for segmental coordination in each kick phase: (a) stance; (b) first swing; (c) second swing phase.

Moreover, figure 2 provides detail on inter-segmental coordination by the segmental angle-angle and coupling angle-time graphs in the sagittal plane. During the stance phase, the angle-angle plot suggested gradual changes from one coordination pattern to another (Fig. 2a). During the first swing phase of kick, angle-angle diagram showed a negative diagonal, reflective of anti-phase and thigh segment flexion (Fig. 2b). During the second swing phase, contrary to the prior phase of kick, angle-angle plot traces a positive diagonal, showing a small contribution of thigh extension, in-phase and shank extension pattern (Fig. 2c).

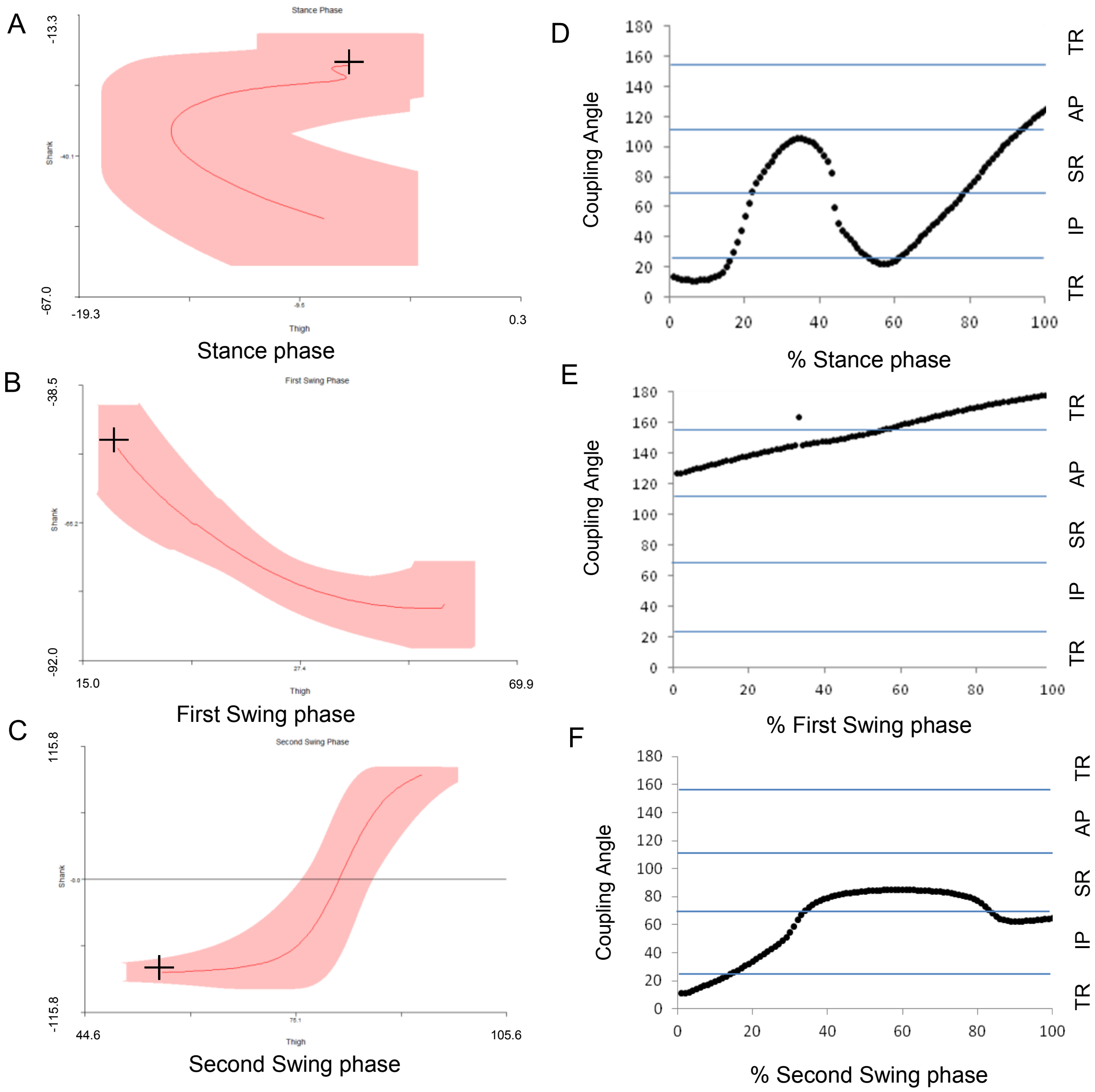

Figure 2. Ensemble mean angle–angle diagrams in sagittal plane for thigh and shank segment angles for stance (a), first swing (b), and second swing (c) phases; positive data means flexion and negative means extension. Coupling angle-time series in sagittal plane are provided for the stance (d), first swing (e), and second swing (f) phases. Initials to the right of figures (d), (e) and (f) refer to; TR; Thigh rotation; IP: In-phase; SR: Shank rotation; AP: Anti-phase. A cross at the angle-angle diagrams means the onset in each kick phase.

DISCUSSION: Several studies in the taekwondo field (i.e., Estevan et al., 2013) have encouraged researchers to develop coordination analysis in order to get thorough knowledge about the movement patterns of segments and how they coordinate. In the words of Chang et al. (2008), the coupling angle represents an instantaneous spatial relationship from which four unique coordination patterns can be identified. In our study, aiming to analyse thigh and shank coordination of the kicking lower limb in the sagittal plane in the roundhouse kick, these patterns were: (1) anti-phase, (2) in-phase, (3) thigh rotation and (4) shank rotation.
The coordination analysis of the execution technique has been operated dividing the kick into three phases. It is shown that coupling showed a gradual evolution (Fig. 1d, e and f) from the stance phase through the first swing phase. That is, at the beginning of the kick (Fig. 1d; 0%-60% of stance phase), thigh and shank segments coupled varying from thigh extension, to in phase and shank flexion and vice versa (inverse U shape) moving to thigh flexion. Not previously described by the literature, our participants demonstrated movement to prepare the lower limb to kick. Later (60-100% of stance phase, first swing phase and 0-30% second

swing phase, approximately), a sequential movement pattern seems to appear involving the four coordination patterns from thigh flexion, in phase, shank extension and anti phase. This result supports Putnam (1993) suggestions, that there is a sequential (proximal-distal) movement pattern during kicks.

Authors who analysed lower limb coordination in taekwondo (i.e., Kim et al., 2011) provided an index of interjoint coordination for different kicks trying to establish a relationship between coordination and performance in the last part of the execution technique. In the roundhouse kick they determined that close to the impact hip and knee coupling in phase motion allows athletes to increase foot velocity. Although in our study, interjoint coordination has not been studied in regard to movement velocity, in the last part of the kick (second swing kick), we have also found a large percentage of in phase coupling between thigh and shank segments (Fig. 1c and 2f). This could support the authors' comments regarding in phase coordination allows increasing velocity of the distal segment.

As a link between coordination patterns and the execution technique, Davids, Glazier, Araújo & Bartlett (2003) stated that motor patterns emerge under different task constraints to achieve stable task outcomes. Being an opposing sport, taekwondo athletes must adapt their execution to constraints (e.g., execution distance, target height, stance position, etc.) constantly. Thus, future studies should cover movement variability analysis in each of the planes of the space (sagittal, frontal and transverse) in order to describe the technique thoroughly, maintaining both an injury prevention and performance perspective, and being able to analyse the capability of taekwondo athletes to adapt them to constraints.

CONCLUSION: According to the results of this study, different coordination patterns appeared during a circular kick. That is, the prevalant coordination pattern changed throughout the roundhouse kick, with each phase of the movement having a different primary movement pattern.

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