ANKLE AND KNEE COORDINATION FOR SINGLE-LEGGED VERTICAL JUMPING COMPARED TO RUNNING

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Similar basic movement patterns in ground reaction forces and ankle frontal plane kinematics of single-legged vertical jumping (JUMP) compared to running (RUN) have already been identified in earlier investigations. To broaden these findings, lower extremity kinematics of 25 subjects were recorded executing RUN and JUMP. Special focus was laid on the knee and ankle coordination of tibial endorotation and ankle eversion as well as on knee and ankle flexion/extension by applying a modified vector coding technique. RUN and JUMP demonstrated similar knee and ankle joint coordination patterns. However, differences in coupling angles unveiled phases, where joint coordination of ankle eversion/tibial endorotation was adjusted in JUMP. By comparing knee and ankle coordination of JUMP in healthy athletes with athletes suffering from anterior knee pain, common in sports with high jumping occurrences, key differences in execution leading to this overuse injury might be unveiled.

KEY WORDS: running, jumping, single-legged jump, joint coupling, vector coding

INTRODUCTION: Jumping is an athletic skill that is used in various sports (e.g. basketball, volleyball) and is carried out in a variety of techniques (e.g. single-/two-legged, standing/running). When jumping, high loads act on the human body during take-off and landing. Thus, jumps need to be analyzed with respect to performance and injury prevention criteria, since Cumps et al. (2007) found Jumper's knee diagnosis to have the highest overuse injury rate in high level basketball athletes.

Numerous biomechanical investigations have focused on lower extremity kinematics and kinetics in (McClay, 2000). Especially walking and running have been studied intensively, also because their movement patterns serve as a basis to more complex movements, e.g. jumping. We were able to demonstrate, that athletes use similar rearfoot striking patterns in single-legged vertical jumps (JUMP) and heel-to-toe running (RUN) (Brauner et al., 2009). McClay et al. (1994) analyzed the kinematics of professional basketball players in sport basketball specific tasks. They found no significant differences in sagittal and frontal knee and ankle kinematics in lay-up takeoffs compared to running. Other than that, little attention has been spent on the kinematical analysis of JUMP, so far.

Whereas these previous studies looked only at single joint kinematics, more recently, kinesiologists have concentrated on the combined analysis of motion of different joints by investigating interactive mechanisms, potentially being the cause of injuries or different levels of performance (DeLeo et al., 2004). Heiderscheidt et al. (2002) proposed the vector coding technique (VC) for the analysis of joint coupling and investigated the coordination of internal tibia rotation to rearfoot eversion since asynchrony between these two motions is discussed to increase the occurrences of overuse injuries (Tiberio, 1987; DeLeo et al., 2004).

However, to our knowledge, VC has not been used to analyze sagittal plane kinematics of knee and ankle joint in jumping so far. This is surprising, since coordination of multiple joint motions is of special interest in the research of jumping (Jacobs et al., 1996) Therefore, as new insights into the lower extremity coordination of jumping can be obtained by application of VC, an optimization of athletes jumping performance might be possible.

Based on these thoughts, the purpose of this study was to analyze the basic patterns in ankle and knee kinematics of RUN and JUMP with specific consideration of the movement coupling of these joints. The technique of VC was chosen for this goal since it allows a complex consideration of joint coordination.

METHODS: 25 subjects (9♀, 16♂; 25.1±4.2yrs; 1.78±0.11m; 72.7±11.1kg) participated in this laboratory study. Written consent was obtained of each subject prior to data collection. All subjects wore the same running shoe model (*PUMA Complete Eutopia*) for running and jumping.

Subjects familiarized themselves with the two movement task during warm-up. Thereby, their dominant leg was determined (20 left, 5 right). For data collection, the two movement tasks, heel-toe running (RUN) and single-legged running jumps (JUMP), were performed in randomized order. Six valid trials were recorded for each condition:

- RUN: heel-toe running on a 13m runway at a given speed of 3.5 m/s (±0.1) controlled by two light barriers, dominant foot on the force plate
- JUMP: single-legged jumps using a three-step running approach, take-off from the force plate with the dominant leg, goal was maximum vertical jumping height

Kinetic data were recorded at 960Hz by a force plate (*Kistler 9287BA*). An 11-camera (MX-3) (*Vicon, Oxford Metrics, UK*) system was used to collect kinematic data at 240Hz. For kinematic analysis, a three segment approach was applied (thigh, shank, foot) using calibration markers on anatomical landmarks and tracking markers on the segments (Heiderscheidt et al., 2002). Calibration markers were fixed to left/right great trochanter, lateral/medial epicondyllus, lateral/medial malleoli, and first /fifth metatarsal head. 4-Marker cluster were used as tracking markers on the lateral side of thigh and shank, a 3-marker cluster was attached to the heel cap to represent foot movement.
Kinematic and kinetic time series data was analyzed using Visual 3D™ (*Version 3.99, C-Motion Inc, Rockville, MD, USA*). Joints were assigned six degrees of freedom and knee and ankle angles were calculated using Cardan sequence of rotations in X-Y-Z order (Cole et al., 1993) with X-axis being medio-lateral oriented, Y-axis anterior-posterior, and Z-axis proximal-distal.
Kinetic and kinematic data of ground contact were normalized to 101 data points. Angle-time curves of all trials were averaged and used for VC analysis. Angle-angle diagrams of the knee (KAX) and ankle (AAX) in the sagittal plane as well as for knee in transverse (KAZ) and ankle in frontal plane (AAY) were created. Coupling angles (CA) were calculated as the orientation of a vector adjoining to consecutive data points relative to the right horizontal (Heiderscheidt et al., 2002) by using the below given formula:

$$CA_i = \tan^{-1}\left(\frac{y_{i+1} - y_i}{x_{i+1} - x_i}\right), \quad where \quad i = 0,1,2,...,99$$

CA were analyzed by applying four coordination patterns (in-phase, anti-phase, knee phase and ankle phase) following a modified approach of the one introduced by Chang et al. (2008). Whereas knee and ankle phases are characterized by single joint movements of knee respectively ankle only, movements in both joints can be observed in Anti-phase and In-phase. In Anti-phase, the joints move in anatomically “opposite” direction (e.g. knee extension and ankle plantar flexion). Thus, in-phase CA show a movement in the “same” direction to a similar extent (e.g. knee extension and ankle dorsal extension).

Table 1: Coordination patterns categorized by a scheme adapted from Chang et al. (2008)

Coordination pattern	Coupling angle definitions
Anti-phase	112.5° ≤ CA < 157.5°, 292.5° ≤ CA < 337.5°
In-phase	22.5° ≤ CA < 67.5°, 202.5° ≤ CA < 247.5°
Knee phase	0° ≤ CA < 22.5°, 157.5° ≤ CA < 202.5°, 337.5° ≤ CA ≤ 360°
Ankle phase	67.5° ≤ CA < 112.5°, 247.5° ≤ CA < 292.5°

RESULTS AND DISCUSSION: Ankle and knee joint kinematics show similar general movement patterns in RUN and JUMP. In JUMP, however, midstance phase seems to be prolonged and push-off phase shortened, whereas impact phase is similar in length between conditions.

In contradiction to McClay et al. (1994), we found significant higher maximum ankle eversion, ankle eversion excursions and ankle eversion velocity values in JUMP compared to RUN (Figure 1).

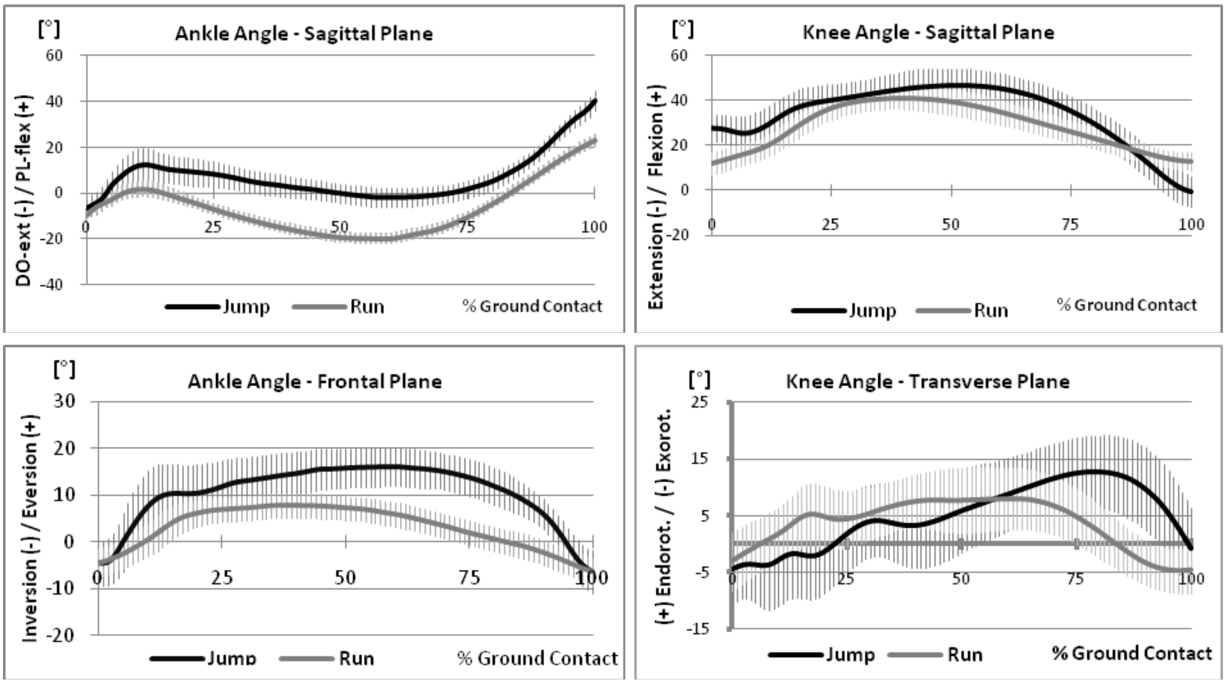

Figure 1: Angle-time diagrams of AAX (top-left), KAX (top-right), AAY (bottom-left), and KAZ (bottom right).

	AAY-vel	AAY-max	AAY-rom
JUMP	1062.3 °/s	13.5°	17.8°
RUN	544.6 °/s	7.1°	11.7°
t-test	p<0.001	p<0.001	p<0.001

Table 2: Comparison of discrete parameters ankle frontal plane kinematics between JUMP and RUN

Knee and ankle joint coordination show similar patterns in RUN and JUMP (Figure 2) Interestingly, sagittal plane coupling shows almost no In-phase movement, but long periods of Anti-phase movement during midstance and push-off (Figure 2-top).

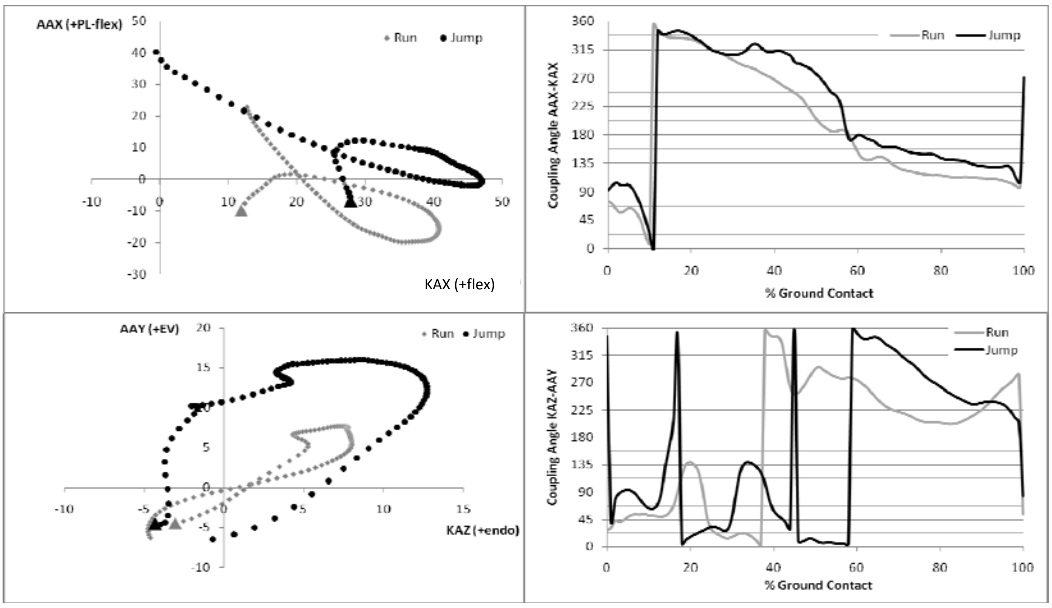

Figure 2: Angle-angle diagram and coupling angles AAX & KAX (top) and AAY & KAZ (bottom). (EV: Eversion, endo: endorotation, PL-flex: plantarflexion)

During the first 10% of ground contact, CA of AAX & KAX in RUN show In-phase motion with ankle and knee flexing simultaneously. In JUMP, however, the ankle is flexed, while the knee joint is stiffened, resulting in Ankle-phase coordination pattern.
Transverse plane knee and frontal plane ankle kinematics show basically a similar coordination pattern in RUN & JUMP, too. However, the angle-angle diagram illustrates the highly increased joint excursion in JUMP in both joints (Figure 2-bottom). In contrast to the sagittal CA, AAY & KAZ show longer periods of In-phase motion throughout stance phase. During the initial 10% of stance, however, CA of AAY&KAZ show Ankle- phase pattern in JUMP, whereas the initial 10% in RUN are executed with In-phase motion.

CONCLUSION: General similarities were found in the coordination patterns of knee and ankle joints in run single-legged vertical jumping compared to running. These similarities confirm the idea of running as a basic human movement pattern that can be adjusted for specific purposes.

Joint coupling in the sagittal plane seems to be more robust across different movement tasks than coupling of ankle frontal and knee transverse plane motion. However, especially in single-legged jumping, internal tibia rotation and ankle eversion show periods of Anti-phase motion, possibly causing high torque in the ankle and knee joint. For this reason and due to the more dynamic nature, single-legged jumping should be used to study coordination of internal tibia rotation and ankle eversion in future investigations.
Vector coding was successfully utilized to compare different sports techniques. By comparing group average curves, we chose a very general approach. Further investigations should focus on individual coordination patterns of athletes as it was proposed originally by Heiderscheidt et al. (2002). Especially, knee and ankle coordination patterns of athletes with anterior knee pain should be compared to those without symptoms.

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