COORDINATION IN TRACK & FIELD SPRINTERS WHILE PERFORMING THE COUNTERMOVEMENT JUMP

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The aim of this study was to assess coordination, coordination variability and their evolution with time, during the countermovement jump. For this purpose a population of track & field sprinters was analysed through a Dynamic Systems approach. Five testing sessions over the year were considered. The kinematics of lower limbs was recorded by an optoelectronic system, and the continuous relative phase of the hip-knee and knee-ankle joints was considered. Results showed different behaviours for the two couplings across the functional phases of the movement, with an increased variability and a less in-phase relationship during transitions between phases. No relevant changes were reported over the subsequent testing sessions.

KEY WORDS: joint coupling, countermovement jump, performance monitoring.

INTRODUCTION: Coordination in sports activities plays a fundamental role for the achievement of successful performances. Sports movements usually involve a large number of body segments, which are subjected to high intensity biomechanical demands and have to act synergically in order to produce the desired outcome. A poor organisation of the elements that concur to the realisation of an harmonious action may cause a bad result and may increase the risk of injury (Hamill et al., 1999; Kurz & Stergiou, 2004). Traditional biomechanical analyses make use of kinematic and kinetic variables to describe the characteristics of the movement and to understand the underlying factors that generated it. Although very useful, these approaches are not very effective in addressing motor coordination, because they describe measures from single joints or segments rather than investigating the interaction between multiple elements of the system. Dynamic Systems Theory (DST) has given new means for inspecting the organisation of the locomotor system and for gaining more insight into the multifactorial nature of human motion (Hamill et al., 1999; Kurz & Stergiou, 2004). According to DST human limbs are seen as a system of coupled pendulums that oscillate about joints. Quantitative information regarding how joint coordination evolves may be drawn by observing the continuous phasing relationships (CRP) between the different elements that participate to the movement (Hamill et al., 1999; Kurz & Stergiou, 2004). Changes in the mutual relations between body segments or adjacent joints may give important indications about the inherent coordinative factors of the neuro-musculo-skeletal system. In particular, the amount of variability in the relative phase relationships over many repetition of the same task has been used by some authors to understand how external perturbations, developmental stages, pathologies or detrimental behaviours may influence the choice of a particular motor solution (Hamill et al., 1999; Kurz & Stergiou, 2004). DST may be exploited for the analysis of sports movements, too. Similar performances in sporting events are often the result of different motor strategies, both within and between individuals. These subtle discrepancies are typically less detectable than the ones that emerge in clinical studies, and are often concealed by the presence of variability. Hence, the observation of discrete variables and time varying measures are not always effective, while the exploration of motor coordination might unveil either hidden changes or anomalous functionalities. The athlete’s phase portraits and CRP measures derived thereof are very likely to be influenced by training programs and motor learning. Furthermore, they may manifest the presence of detrimental behaviour. DST tools may represent a valuable tool either for gauging the progresses that are achieved over time or for injury prevention purposes.

To our knowledge, there is no published research about a DST analysis of the countermovement jump (CMJ), which is a common field test for explosive force. Furthermore there is a lack of information concerning longitudinal monitoring thorugh DST. Therefore the aim of this work was to assess coordinative patterns in a population of track and field athletes that performed CMJ and that were followed over a whole competitive year.

METHODS: Participants: Four male and 2 female track & field sprinters (age: 21.2±4.7 years; height: 1.74±0.06 m, weight: 65.8±6.4 kg) of national and regional level were the subjects of this study. Their season best in the 100 m event ranged between 10.71 s and 11.19 s for males, between 13.14 s and 13.15 s for females. All the participants had the same coach and were used to perform from 5 to 8 sessions a week.

Instrumentation: An 8-TVCs optoelectronic system (Elite2002, BTS, Italy), working at 100 Hz, and a force platform (AMTI OR6-7-1000, USA), whose sampling rate was 500 Hz, were used to capture the 3D kinematics of body segments and ground reaction forces (GRF) during vertical jumping.

Data Collection: The SAFLo (Frigo et al., 1998) marker set was chosen. It is a total body protocol that matches experimental needs for practicality and freedom of movement, to reliability of measures. After a standard 20 min warm up, each subject was asked to perform 24 (4 sets of 6 reps) double-leg maximal countermovement jumps, keeping their arms akimbo. Trials were executed alternating the right and left limb on the force platform. Two and 9 minutes recovery was respected between subsequent repetition and sets to avoid fatigue. 5 testing sessions (TS1-TS5) were collected over the year, corresponding to different phases of the training programme: TS1 in April, TS2 in June, TS3 in September, TS4 in November and TS5 in March of the next year.

Data Analysis: Anthropometric measures and specially designed algorithms were used to estimate and filter (D'Amico & Ferrigno, 1990; Frigo et al., 1998) 3D coordinates of internal joint centres and joint angles. Lower limb joint angles (hip, knee and ankle) and angular velocities in the sagittal plane were considered for this study. They were selected because they may be considered the most reliable and representative measures of lower limb kinematics during vertical jumping. The analysed movement was defined as the interval (Δt) between the beginning of the countermovement (t_i) and the instant the toes lose contact with the ground (t_f). Kinematic time series were time normalised to 100 points, so that t_i corresponded to 0% and t_f to 100% of the movement. Phase portraits (angular velocity – angle) and phase angles of the hip (ϕ_h), knee (ϕ_k) and ankle (ϕ_a) were estimated and normalised according to Hamill et al. (1999). Continuous relative phase (CRP) between adjacent joints ($\theta_{pd}(t)=\phi_p(t)-\phi_d(t)$, where p=proximal and d=distal) was studied to assess coordination patterns: hip-knee and knee-ankle intra-limb couplings were considered. These couplings were chosen in accordance with the proximal to distal activation sequence suggested by some authors' studies on vertical jumping performances (Bobbert & van Ingen Schenau, 1988). The mean±standard deviation curves of CRP ($\Theta_{pd}(t)\pm\sigma_{pd}(t)$) were created for each subject, intra-limb coupling and session. Coordination and coordination variability between intra-limb joints was evaluated by measuring, respectively: the Mean Absolute Relative Phase (MARP), which is the mean $\Theta_{pd}(t)$ across the whole of the movement; the Deviation Phase (DP), which is the average standard deviation between trials, over Δt. Furthermore, the movement was divided into 3 functional phases (Δt_1, Δt_2, Δt_3) and the same analysis was carried out on each of them. Δt_1 was between the beginning of the countermovement and the minimum of GRF; it represented the passive joint flexion under gravity force. Δt_2 was between the minimum of GRF and maximal knee flexion; it represented the braking phase and the eccentric muscular action. Δt_3 was between maximal knee flexion and take off; it represented the propulsive phase with concentric muscular efforts. Nonparametric statistics (median and IQR) were used to describe individual and group measures. Nonparametric tests (Kruskal-Wallis and Friedman, $P<0.05$) and Bonferroni post-hoc comparisons ($P<0.05$) were used to assess significance of changes between functional phases or testing sessions.

RESULTS: The overall average (median and IQR) transitions from Δt_1 to Δt_2 and from Δt_2 to Δt_3 occurred, respectively, at 38.5% (7%) and at 67.5% (5%) of the movement. Hip-knee and knee-ankle couplings presented different CRP, concerning both the shape and the magnitude of patterns (Figure 1a and 1b). $\Theta_{hk}(t)$ ran about the baseline during Δt_1 and showed 2 peaks (10 and 22 deg respectively) at 45% and 82% of the movement. $\Theta_{ka}(t)$ was close to antiphase (160 deg) at the beginning, it decreased rapidly between Δt_1 and Δt_2 (50 deg at the minimum of GRF), and stayed around the zero line till the end of the movement. $MARP_{hk}$ and $MARP_{ka}$ were (Figure 1c): 11.4 (2.2) and 132.1 (10.6) in Δt_1; 7.9 (1.3) and 19.3 (2.5) in Δt_2; 13.4 (2.4) and 8.6 (2.0) in Δt_3. CRP variability manifested more similar behaviours between the two couplings (Figure 1d and 1e). Both $\sigma_{hk}(t)$ and $\sigma_{ka}(t)$: increased during the transition between Δt_1 and Δt_2; decreased during Δt_2, with a "valley" between Δt_2 and Δt_3; raised again in late Δt_3. The magnitude (36 deg for $\sigma_{hk}(t)$ and 28 deg for $\sigma_{ka}(t)$) and occurrence (next to minimum GRF) of peaks was comparable. CRP variability was higher at the beginning of the movement for the knee-ankle coupling, while $\sigma_{hk}(t)$ showed increased values at the end of Δt_3. DP_{hk} and DP_{ka} were (Figure 1f): 7.6 (2.0) and 9.5 (5.0) in Δt_1; 6.3 (2.0) and 6.4 (0.6) in Δt_2; 6.1 (1.8) and 4.3 (0.5) in Δt_3.

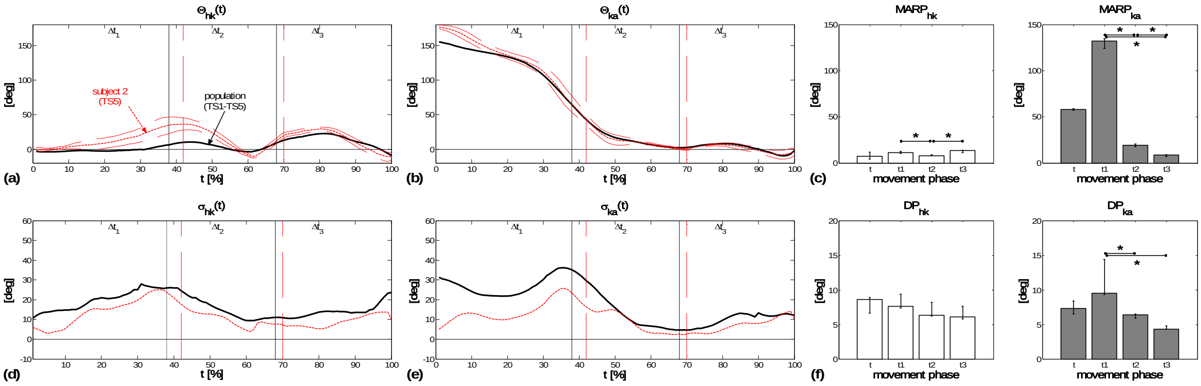

Figure 1 CRP ($\Theta(t)$) and CRP variability ($\sigma(t)$) concerning the hip-knee (a and d) and knee-ankle (b and e) couplings. Solid black curves represent the overall mean (of the whole set of subjects and sessions). Dashed red lines represent an example of individual result during a single testing session (i.e. subject 2 during TS5). Individual CRP data are presented as mean±STD. Vertical lines subdivide the three functional phases of the movement. Figures c and f report bar histograms of MARP and DP for the two articular couplings. (*) indicates P<0.05.

The longitudinal monitoring did not manifest remarkable trends. CRP variability (of the population) tended to slightly decrease over testing sessions in both couplings, but the only significant change emerged in DP_{hk} of the whole movement, between TS2 and TS5. All the other parameters concerning both Δt and the single functional phases did not changed significantly.

DISCUSSION: Lower limbs coordination in the execution of countermovement jumps was studied through a DST approach. A population of track & field sprinters of the same team was analysed five times over a competitive year. Results concerning the average hip-knee and knee-ankle couplings manifested peculiar coordinative behaviour over the whole movement, and in correspondence of the functional phases into which it had been subdivided.

The phasing relation between intra-limb joints was measured through the mean absolute relative phase: the greater the MARP, the more out of phase joints are (Kurz & Stergiou, 2004). The overall MARP was 7.3 (1.9) deg for the hip-knee coupling and 58.2 (1.6) deg for the knee-ankle one, thus evidencing a more in-phase relationship between proximal joints. This findings were in contrast with reports from other authors (Kurz & Stergiou, 2004) who registered increased tuning from proximal to distal segments, both in walking and in running. The higher values of $MARP_{ka}$ are mainly caused by the different dynamics of the knee and the ankle during the first phase of the movement. In Δt_1, in fact, the ankle was more "static"

than the knee. This caused a shift of the CRP toward an out-of-phase relation. The tuning between the knee and the ankle was progressively recovered during Δt_2 and Δt_3. In contrast, $MARP_{hk}$ manifested an in-phase relationship throughout the movement, with two peaks just after each transition between the functional phases. The transition between Δt_1 and Δt_2 was interesting even for CRP variability. Variability of relative phase is a measure of the stability in the organisation of the neuromuscular system. Increased variability has been assumed to correspond to transitions during which the neuromotor system is in search for the most appropriate strategy among the possible coordinative patterns. Despite it may appear as uncertainty, higher variability in CRP has been interpreted as a form of flexibility to overcome local and global perturbations or to redistribute detrimental loads (Hamill et al., 1999; Kurz & Stergiou, 2004). $\sigma_{hk}(t)$ and $\sigma_{ka}(t)$ evidenced a rise of variability about the instant when lower limbs started to contrast the descent of the centre of mass due gravity force. Furthermore, DP decreased across the passage from Δt_1 to Δt_3 in both couplings (significantly for the knee-ankle one). This may be explained by the lack of muscular control during the initial, passive, joint flexion, and by the quick transition to an eccentric action in order to invert the downward movement. In contrast, the transition between the eccentric and the concentric phase did not involve an increase of variability, but only a less in-phase relation between adjacent joints that may derive by the proximal to distal activation described by (Bobbert & van Ingen Schenau (1988) and confirmed by the measured angular time series.
The coordination patterns and the corresponding parameters did not change over the five testing sessions that were collected, both concerning the whole movement and the single phases. This may be interpreted in many ways: (i) the athletes were very familiar with the movement; (ii) the training program they underwent did not change their coordinative characteristics; (iii) individual changes were masked by the analysis of the population.

CONCLUSION: The DST analysis of sports movements may represent an effective mean for investigating the coordinative proprieties of the neuro-musculo-skeletal system. In this study intra-limb coordination during vertical jump exercises was addressed and described by measuring the phasing relationship (MARP) and its variability (DP) between adjacent lower-limb joint. Relations between functional phases of the movement and joint-coupling patterns were evidenced. Furthermore, the possible evolution of coordinative features over a year of training was investigated. However, further efforts must be spent for interpreting data, creating reference databases and provide useful information to athletes and coaches. In particular, further potentialities may come by monitoring coordinative peculiarities and time evolutions of the single individual. This was carried out but was not presented in this work.

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