COORDINATIONS IN UNLOADED SQUAT JUMPING

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8 male athletes performed squat jumps in 5 unloading conditions (using counterweight system) and without unloading. Unloading produced a decrease of impulse duration and an alteration of the subject initial position, with more extended ankle and knee joints angles and a more forward antero-posterior projection of CoM. At toe-off, the ankle angle and the antero-posterior projection of CoM increased while the knee amplitude, the maximal hip torque and power decreased. The total and hip works were also weaker. Greater knee extensors and plantar-flexion forces should have prevented the diminution of performance that should have occured consequently to the alteration of initial and final positions associated to the decrease of impulse duration and knee amplitude. Proximo-distal coordination was modified, suggesting a reorganization of muscle functions.

KEY WORDS: squat jump, coordination

INTRODUCTION: Explosive movements are characterized by the production of maximal force at the interface of the environment and the body during a shortest execution time. During such movements, where the duration is less than 400 ms, the musculo-skeletal system exhibits a proximo-distal sequence, *i.e.* the most proximal joint peak velocity occurs before the distal ones. This organisation reflects the transfer of power from the body to the environment (Bobbert *et al.*, 1986). For this purpose, the mono- and bi-articular muscles accomplish specific functions, *i.e.* force production and force transfer and orientation respectively (Jacobs & Ingen Schenau, 1992).

These coordinations have been observed for various human movements, *i.e.* handball throwing (Jöris *et al.*, 1985), football kick while running and walking (Putmam, 1991), speed skating (Ingen Schenau *et al.*, 1980) and artistic ice-skating (Haguenauer *et al.*, 2006).

Considering more specifically vertical jumping, the performance, quantified by the maximal height of the center of mass (CoM) of the subject during the flying phase, is directly related to the duration and intensity of the force applied at the interface of the ground and the feet of the subject.

Mean duration of the impulse phase is about 350 ms, and hip, knee and ankle joints extensions start at 300, 200 and 100 ms before toe-off respectively (Bobbert *et al.*, 1986). Moreover, the contributions of these joints to performance were evaluated for respectively the hip, the knee and the ankle at 10, 56 and 22 % (Luthanen & Komi, 1978).

Van Ingen Schenau (1989) has demonstrated that the proximo-distal delay of lower limb joint extensions is determined by the geometrical and anatomical constraints. The geometrical constraint concerns the conversion of angular motion of body segments to vertical motion of the body's CoM. In vertical jumping, the push-off is characterized by the explosive extension of the knee joint. The more the knee approaches its maximal extension, the less the transformation of the segment angular velocities into linear velocity of the body CoM is effective. Moreover, in order to preserve this joint from any damage, it is necessary to decelerate knee opening before its maximum extension (anatomical constraint).

Several studies suggest that the gravitational constraint could be important in morpho- and onto-genesis, particularly in the development of both neuromuscular and motor systems for mammals (Mei *et al.*, 1983; Ohira *et al.*, 2001). Thus, this importance should be observed as well in motor behaviour. Besides, when a subject is submitted to an unusual value of gravity acceleration, both his inputs and outputs are altered. This phenomenon is called sensori-motor discordances (Lackner *et al.*, 1994; Shadmehr *et al.*, 1994). For example, trajectories are altered for a subject pointing at a target in a rotating room. Adaptation to such conditions can be fast – few dozens of repetitions for simple movements (Kitazawa *et al.*, 1997) – or slower – up to several weeks to alter daily movements. These discordances show gravity as an interesting paradigm in the study of underlying mechanisms of motor behaviour.

Adaptation processes characterized included both structural and functional alterations (Grigoriev *et al.*, 1991; Grigoriev *et al.*, 1992; Nicogossian, 1994). Both muscle contraction processes and mechanisms related to the nervous command would then participate in observed adaptations.
On our knowledge, few studies investigated the execution of explosive movements in altered gravity environments. Most of them focused on adaptations during and after space missions. Vertical squat jump muscular work was studied during space flights showing an alteration of the mechanisms implied in force production (Antonutto *et al.*, 1995). However, such studies were unable to differentiate functional and structural adaptations. In punctual simulated microgravity conditions, structural adaptation processes such as an eventual alteration of fibers type would not occur. Then, in these conditions, functional adaptation only would be responsible of observed adaptations. Thus, an increase of squat jump take-off velocity was found using a punctual unloading protocol (Cavagna *et al.*, 1972). Moreover, prolonged extra load wearing produced a right shift in the force-velocity relation curve (Bosco *et al.*, 1985). Finally, Scholz *et al.*, (1995) found load-dependant coordinations in a squat-lifting task. Varying load conditions seem to induce significant functional adaptations. These results suggest the existence of a gravitational constraint applying to explosive movement's execution. This constraint would imply that the system takes gravity acceleration into account to code the central command. In the case of vertical jump, the direction of the movement is directly opposed to the direction of the gravitational field. However, none of these studies focused on eventual alteration of musculoskeletal coordinations.
Therefore, the main purpose of this study was to investigate the influence of the gravitational constraint on joints coordinations, through simulated unloading conditions. This study was designed to gain deeper insight into the relation between the muscular functions and the proximo-distal pattern observed in explosive movement, such as in vertical jumping.

METHODS: 8 male athletes volunteered to participate in this study. After a standard warm-up routine, subjects performed 5 maximal squat jumps (SJ), for each of 5 randomly different unloading conditions and without unloading. Jumps were realized from an initial static squat position (knee initial position at right angle) without any countermovement. Subjects were instructed to keep hands on hips throughout the movement. Unloading was achieved through a specific experimental procedure based on a counterweight system. The mass of the counterweights was set to exert a force corresponding to different percentages of each subject body weight (10, 20, 30, 40 and 50%). For each subject and condition, the best trial was selected for analysis, according to the greatest jump height. Kinetic and kinematic data were respectively obtained from a force plate (AMTI, 500 Hz) and a video camcorder (50Hz). In order to model the skeleton in a 4 rigid segments system, landmarks were placed on the left fifth metatarsophalangeal, lateral malleolus, lateral femoral epicondyle, greater trochanter and acromion. These spots define the foot, the shank, the thigh and the upper body (Head, Arms and Trunk: HAT). The methodology proposed by Bobbert and Ingen Schenau (1988) was used to analyze the inter-joint coordination patterns. The vertical velocity of each joint relative to the vertical velocity of the HAT mass center was calculated. Therefore, the relative vertical velocity of lower limb joints were obtained from the difference between the vertical velocity of the HAT mass center ($\dot{y}_{HAT}$) and the respective vertical velocity of the hip ($\dot{y}_H$), knee ($\dot{y}_K$) and ankle ($\dot{y}_A$) joints. These relative vertical velocities ($\dot{y}_{HAT} - \dot{y}_H$, $\dot{y}_{HAT} - \dot{y}_K$, $\dot{y}_{HAT} - \dot{y}_A$) were expressed as a function of time. The inter-joint coordination patterns were identified from the instant at which the peak relative vertical velocities occurred. For instance a proximo-distal coordination is characterized by a successive occurrence of the peaks $\dot{y}_{HAT} - \dot{y}_H$, $\dot{y}_{HAT} - \dot{y}_K$ and $\dot{y}_{HAT} - \dot{y}_A$. Segmental moments of inertia, segmental mass centers and segmental masses were estimated from Winter (1990). Positive moments were defined as joint extension. Joint power was calculated as the product of net joint moment and joint angular velocity. The mechanical works of the hip, knee and ankle joints were obtained by integrating joint power over time. Net intersegmental forces and joint moments were calculated using a standard inverse-dynamic procedure (Aleshinsky, 1986). Statistical analysis was realised using linear regression on the six conditions. In the results, for a better readability, only the Body Weight and Maximal Unloading (50%) conditions (BW *vs* MU) will be presented.

RESULTS: The unloading condition is characterized by a decrease of impulse duration (427 *vs* 357 ms), and an alteration of the subject initial position: (i) ankle (89.3 *vs* 98.2°) and knee (93.7 *vs* 99.3°) joint angles and (ii) antero-posterior projection of CoM (0.09 *vs* 0.20 m). At toe-off, the ankle angle (141.8 *vs* 146.9°) and antero-posterior projection of CoM (0.022 *vs* 0.13 m) increased while the knee amplitude (73.6 *vs* 66.4°), the maximal hip torque (267 *vs* 161 Nm) and power (1611 *vs* 715 W) decreased. The total (529 *vs* 335 J) and hip (219 *vs* 8 J) works were also altered.

DISCUSSION: This study aimed to enlighten alterations produced by punctual unloading during the execution of a maximal explosive movement, the squat-jump. On this purpose, both kinematic and dynamic data were used to investigate inter-joint coordinations.
In body weight condition (BW), mean impulse duration and vertical ground reaction force peak (936 N ± 281) were respectively higher and lower compared to those observed by Bobbert *et al.* (1988) with high-level volleyball players. These differences could be explained by the specialization of this last population in squat-jump performance. Concerning unloading conditions, it was previously shown that high reliability can be achieved within few repetitions (Moir *et al.*, 2005).
According to Van Soest & Bobbert (1993), initial position alteration led to changes in toe-off one. However, compared to initial posture, differences were reduced at toe-off. Unloading also produced a decrease of impulse duration. Thus, according to anatomical constraint, joint angular velocities should have decreased. Such results were not observed suggesting that joints, particularly the knee, presenting smaller amplitude, were able to accelerate and decelerate faster their angular velocities. These could be explained by greater forces generation of agonists and antagonists muscles. Concerning geometrical constraint, at the toe-off, the greater plantar-flexion of the ankle would compensate the smaller amplitude of the two proximal joints. Finally, unloading also influenced proximo-distal sequence. The time between occurrences of $\dot{y}_{HAT} - \dot{y}_H$ and $\dot{y}_{HAT} - \dot{y}_K$ peaks increased while it decreased for $\dot{y}_{HAT} - \dot{y}_K$ and $\dot{y}_{HAT} - \dot{y}_A$. The longer proximo-distal sequence between hip and knee joints also suggests that the energy produced by the HAT may be transferred more efficiently toward knee joint.

CONCLUSION: Subjects were able to adapt rapidly to unloaded conditions. Despite decreases of impulse duration, knee amplitude and alteration of both initial and toe-off positions, performance was not affected. Adaptation included particularly greater angular acceleration and deceleration of joints. At muscular level, increased extensors forces would be responsible of observed adjustments. The alteration of the proximo-distal dequence may also induce modifications of muscular activation patterns.

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