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Intralimb joint coordination of the lower extremities in resistance training exercises

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ABSTRACT

To facilitate the greatest transfer of improvements to athletic performance or daily activity, the resistance training exercises employed by athletic or recreationally trained individuals must be selected considering biomechanical similarity to meet the specific demands of their sport or activity. The purpose of this study was to compare intralimb joint coordination in eight experienced lifters performing three conventional strength-training exercises: the forward lunge, the dead lift, and the forward step-up. Lower-extremity angular displacement curves, maximum joint excursions, and mean absolute relative phases were determined. Results revealed general in-phase, interjoint relationships while comparing exercises. Forward lunge interjoint relationships were more out-of-phase when compared with the other two exercises. It is suggested that in-phase coordination was the predominant pattern employed while performing the closed kinetic chain exercises normally used in strength training, in particular for knee-hip relationship. Nevertheless the forward component of movement can change the coordination strategy when performing lunges.

1. Introduction

When prescribing lower-extremity exercises, functional exercises (multijoint, closed-kinetic-chain exercises) are often the activities of choice because they more closely reflect the movement patterns of common and sport activities, train several muscle groups simultaneously, and require minimal specialized equipment (Stone et al., 2000). These exercises (e.g., squat, lunge, dead lift, step-up, etc.) are widely employed to enhance performance, rehabilitation, and as assessment tools for measuring strength, flexibility and balance (Cook, 2001). One of the fundamental characteristic of the functional exercises is the closed-kinetic-chain execution. This condition occurs when the distal aspect of the extremity is fixed to a stationary object (e.g. the ground) (Ellenbecker and Davies, 2001). Motion then results from movement of the proximal segment with respect to the fixed distal segment, and each joint segment affects those above and below under control of the Central Nervous System (CNS) that combines body parts movements with different timing respect to the intended goal. Control of these complex movements requires integration of muscle actions in a coordinative structure.

The concept of coordinative structure has been derived from the important work of Bernstein (1967) in the area of movement coordination and control. Coordinative structures are considered movement patterns that originate from the individual muscles and neuropathways working together to achieve functional outcomes that meet the constraints of the system. Such coordinative structures often span more than one joint.

Inter-joint coordination may provide more information on how the CNS organizes the various degrees of freedom to perform functional activities. It is suspected that while changing the task demands, the nervous system may adapt the interjoint coordination and preserve the same goal and create synergies. Abundance of degree of freedom is a complex problem that should be resolved by the nervous system when generating motor patterns. Bernstein (1967) reported this as “the degrees of freedom problem or motor equivalence problem”. The coordinative structure resolves this problem reducing the degree of freedom, and allowing muscles and joints to work cooperatively (Kurz and Stergiou, 2004).

Efficacy in organizing the multiple degrees of freedom present in the neuromuscular system has been theoretically proposed as a necessity for healthy functional movement patterns (Turvey, 1990). On the basis of this notion, we could also theoretically suggest that the inability to control the many degree of freedom is a hallmark of low performance levels.

As described in literature (Kurz and Stergiou, 2004; Hamill et al., 1999), a Dynamical System approach is particularly fruitful

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to study coordination features of motor behavior; it provides useful tools that allow the analysis of the variability and stability of human movement. When analyzing a particular motor behavior as a dynamic system, the first step is to characterize the movement patterns using collective variables: the order parameters. The identification of a system's order parameters allows one to discover the conditions that change motor patterns, determine the effect of different parameter manipulations on a pattern's stability, and provide a basis for the precise and formal modeling of a behavior's coordinative patterns, and the generation of predictions about system behavior that can be tested experimentally (Barela et al., 2000; Diedrich and Warren, 1995). Particular conditions or limitations that constrain the system through its behavioral states are identified as control parameters (e.g. direction, velocity, and fatigue). When a control parameter reaches a critical value (e.g. a critical velocity of locomotion), the system exhibits a transition to a new or different pattern of coordination, providing the conditions necessary for identifying a system's order parameters (Byrne et al., 2002). Changes of control parameters are reflected upon the order parameters and therefore reveal the dynamics of the system (Kelso, 1995). Relative phase is a low dimensional order parameter that combines information on joint angular positions and velocities. Furthermore, phase coordination differences can be assessed. Since ensembles of non-linear, limit cycle oscillatory processes are used to characterize biological systems, their properties via relative phase are used to predict the patterns of inter-limb and inter-joint coordination (Kelso et al., 1981).

To date, lower limb interjoint coordination comparisons of resistance training activities has not been investigated despite the ability of this type of analysis to compare similar exercises targeting appropriate joints and muscular synergies.

Trainers usually prescribe exercises without any particular attention to coordinative structure considering the movements similar and interchangeable. To maximize transfer to daily activities or sport skills, training should be as specific as possible, especially with regard to movement pattern and contraction velocity (Young, 2006). Strengthening exercises must reproduce the same coordination strategies of target movements in order to obtain maximum enhancement of performance. Differences in movement pattern as amplitude and direction produce significantly different results, although the muscle groups involved may be the same (Verkhoshansky and Siff, 2009). For this reason we considered the coordination strategies as a fundamental factor in designing the most effective training plans.

Unlike previous studies examining single joints or limb biomechanics, this study aimed to develop insight into the intralimb joint coupling motions used during execution of three common resistance training exercises, all characterized by in-phase inter-joint coordination. The goal of the current study was to use a dynamic system approach to describe and compare the patterns of inter-joint coordination of the lower limb while performing the forward lunge, the dead lift, and the forward step up. Our hypothesis is that different executions of a movement pattern do not affect interjoint coordination as quantified by phase relationship. This approach can be useful to classify resistance training exercise from the coordination point of view, thus choosing the best exercise for each training situation.

2. Methods

2.1. Participants

The subjects were recreationally trained with experience in resistance training (seven males, one female of mean height 170.9 ± 5.7 cm; mean body weight 70.4 ± 8.9 kg; mean age 28.8 ± 7.1 years). All subjects had previously performed the three exercises regularly in their training regimens and have employed various loads, repetitions, and combinations of exercises throughout their yearly training cycles. The subjects had mean experience of 9.4 ± 6.8 years in weight training. All subjects were right leg dominant (as defined by the kicking leg) and had no history of lower limb injuries or surgery. Before subjects participated in the study, informed consent was obtained. The protocol was approved by the institutional Ethics Committee of the Dipartimento di Morfologia Umana of the Università degli Studi di Milano.

2.2. Experimental tasks

Instructions for the deadlift, the forward lunge and the forward step up were developed from published recommendations (Baechle et al., 2008) (Fig. 1). The subjects were instructed to reach approximately 90° of knee flexion in all exercises. A visual control was provided during executions. Each participant selected his/her own technique as used in training conditions. For the forward step up, a wooden box with a step height of 40 cm was used. Free weight Olympic bar with weighted plates of different size, based on strength level of each subject, were used.

A pre-test was given to each subject one week before the actual testing session. During the pre-test, the subjects' 15 repetition maximum (15 RM) were established for the three exercises. To assess 15 RM a direct test with incremental load was used. The weight used to perform the 15 repetition to failure was recorded. The mean 15 RM loads that were employed during testing were 54.0 ± 15.2 kg for the deadlift, 46.8 ± 14.5 kg for the forward lunge, and 40.5 ± 11.4 kg for the forward step up. The tested exercises were not novel to the subjects, but there not used continuously in training programs. Additionally, the subjects were used to lift higher loads (>80% of 1 RM). All this can justify a low strength level.

Performance order was randomly assigned to each subject. All subjects performed two to three warm-up sets in preparation for testing. Each exercise was performed in a slow and continuous manner according to individual preference. Cadence was not controlled; we allowed the subjects to perform each exercise with the same time variations they normally employed in training.

Each subject performed five repetitions for each exercise. Data collection began at the end of the first repetition and continued throughout the subsequent three repetitions of each set. Between each repetition, subjects were instructed to pause approximately one second to clearly demarcate repetitions. Each subject rested at least four minutes between exercises to completely recover from the previous set. Fatigue was assumed to be minimal due to the submaximal weight lifted, the low lifting intensity, the small number of repetitions performed for each set, the interval between sets, and the fitness level of the subjects.

2.3. Movement analysis system

Tests were performed one week after the pre-test. During the test, participants were instrumented with spherical reflective markers (15 mm in diameter) attached onto bony landmarks of the right lower extremity as outlined in Fig. 2. An optoelectronic computerized instrument (SMART, Motion Capture System, eMotion S.r.l., Padova, Italy) was used for data acquisition. This passive marker system allowed the automatic analysis of the movement from the three-dimensional coordinates of the different body landmarks which were detected by nine infrared sensitive cameras working at 60 Hz (Mapelli et al., 2013, 2014). The working volume was of 210 cm × 230 cm × 150 cm. Before each acquisition session, a metric calibration and correction of optical and electronic distortions was performed with a resulting mean error of reconstruction of 0.353 ± 0.342 cm using a 60-cm calibration wand.