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Lower extremity control and dynamics during backward angular impulse generation in forward translating tasks

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Abstract

Observation of complex whole body movements suggests that the nervous system coordinates multiple operational subsystems using some type of hierarchical control. When comparing two forward translating tasks performed with and without backward angular impulse, we have learned that both trunk-leg coordination and reaction force-time characteristics are significantly different between tasks. This led us to hypothesize that differences in trunk-leg coordination and reaction force generation would induce between-task differences in the control of the lower extremity joints during impulse generation phase of the tasks. Eight highly skilled performers executed a series of forward jumps with and without backward rotation (reverse somersault and reverse timer, respectively). Sagittal plane kinematics, reaction forces, and electromyograms of lower extremity muscles were acquired during the take-off phase of both tasks. Lower extremity joint kinetics were calculated using inverse dynamics. The results demonstrated between-task differences in the relative angles between the lower extremity segments and the net joint forces/reaction force and the joint angular velocity profiles. Significantly less knee extensor net joint moments and net joint moment work and greater hip extensor net joint moments and net joint moment work were observed during the push interval of the reverse somersault as compared to the reverse timer. Between-task differences in lower extremity joint kinetics were regulated by selectively activating the bi-articular muscles crossing the knee and hip. These results indicate that between-task differences in the control of the center of mass relative to the reaction force alters control and dynamics of the multijoint lower extremity subsystem.

Keywords: Total body center of mass; Reaction force; Angular impulse; Joint kinetics; Muscle activation pattern

1. Introduction

Task-specific modification of total body momentum requires that the performer generates net linear and angular impulse during contact with the environment. Observation of complex whole body movements, such as jumping, suggests the nervous system organizes the human body into a number of operational subsystems that are coordinated by using some type of hierarchical control (Arabyan and Tsai, 1998; Flashner et al., 1988; Requejo et al., 2002). For example, during the impulse generation phase, the motion of multiple body segments is coordinated so that the position of the center of mass (CoM) relative to the reaction force (RF) satisfies both the linear and angular impulse requirements of the task. During the impulse generation phase of a standing forward jump, the segments are configured such that the CoM is aligned with the forward-directed

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RF (Ridderikhoff et al., 1999). In contrast, during the take-off phase of a forward jump with backward rotation (reverse somersault), the segments are configured such that the CoM is positioned posterior to the line of action of forward directed RF. As a result, both upward and forward linear impulse and backward angular impulse requirements of the task are satisfied (Mathiyakom et al., accepted). By determining how coordination between subsystems change between tasks performed under various conditions (Bernstein, 1967), we can advance our understanding of the control structure.

Regulation of CoM position relative to the RF involves coordination between the trunk and leg subsystems during weight bearing tasks. The magnitude of the RF is regulated by the rate of lower extremity joint extension (Bobbert and van Ingen Schenau, 1988; Ridderikhoff et al., 1999), whereas the position of the CoM relative to the feet is most sensitive to trunk motion (Horak and Nashner, 1986; Shenckman et al., 1996; McNitt-Gray et al., 2001). Although modifications in trunk-leg coordination provide a mechanism for regulating the position of the CoM relative to the RF during impulse generation, between-task differences in lower extremity segment orientation relative to the RF is expected to influence how the lower extremities contribute to the linear and angular impulse required to perform the task (McNitt-Gray et al., 2001).

Comparison of two related, well-practiced tasks with common linear impulse and different angular impulse requirements performed by the same highly skilled performers provides us with a unique opportunity to determine how control and coordination of local subsystems are modified to achieve specific task objectives at the total body level (Miller et al., 1990). Previous study of reverse somersaults and reverse timers (common linear impulse requirement (forward, upward) with and without angular impulse) indicates that trunk-leg subsystem coordination, lower extremity joint coordination, and reaction force-time characteristics were significantly different between these two tasks (Mathiyakom et al., accepted). These results led us to hypothesize that lower extremity control, as indicated by (a) net joint moment (NJM), net joint moment power (NJMP), work done by the NJM, and (b) muscle activation patterns would be different between these two tasks (McNitt-Gray et al., 2001; McNitt-Gray, 1993; McFadyen and Winter, 1988; Elftman, 1939). The

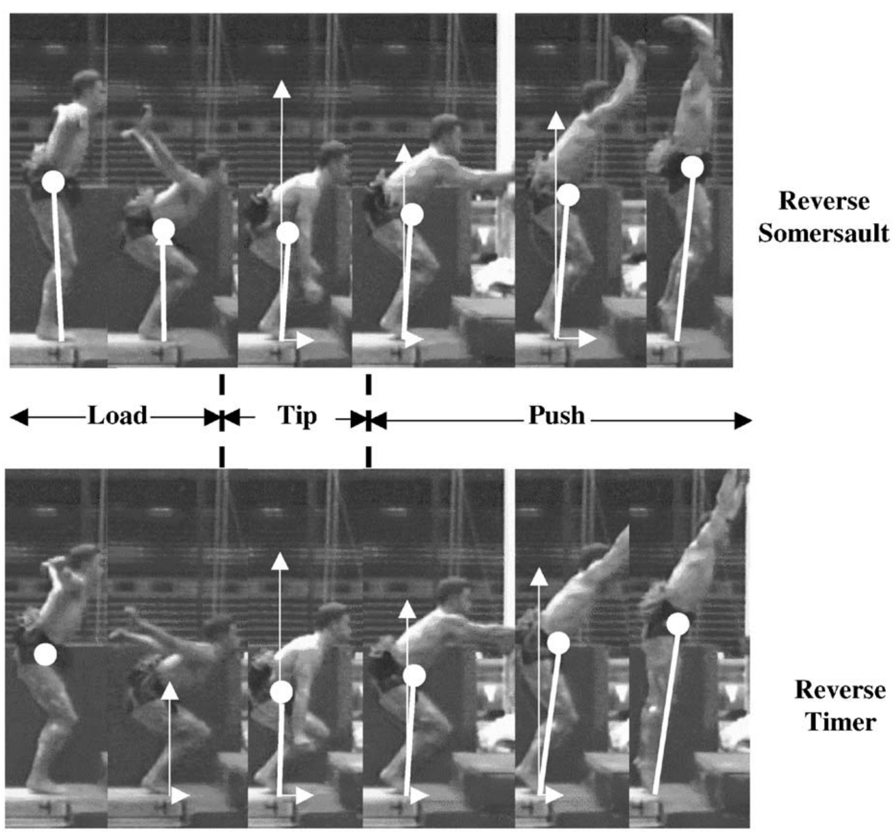

Fig. 1. Body configuration, estimated total body center of mass position (●), and forward horizontal (→) and upward (↑) vertical reaction force during the take-off phase of the reverse somersault (top) and reverse timer (bottom) of an exemplar subject. During the take-off phase of both tasks, the performers need to generate forward and upward linear impulse. In addition, the performers need to generate backward angular impulse during the take-off phase of the reverse somersault.