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# COMMON MULTIJOINT CONTROL STRATEGIES FOR GENERATING BACKWARD ANGULAR MOMENTUM IN FORWARD AND BACKWARD TRANSLATING TASKS

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## SUMMARY
Multijoint control strategies used by same individual under various conditions provide insight as to inherent priorities within an individual's control logic. In this study, two different joint extension patterns for generating angular momentum in forward and backward translation tasks emerged: simultaneous knee-hip extension (KH) and hip extension initiated with the knee stabilized (KStab). KH strategists initiated joint extension by selective activation of the biarticular knee flexor and hip extensor muscles, whereas the KStab strategists delayed activation until just prior to take-off. Knee extensor net joint moments (NJM) tended to be twice as large for KH strategists than for KStab strategists due to between group differences in shank angle. NJM work at the knee was larger for KH subjects due to larger knee NJMs, whereas NJM work at the hip was larger in KStab subjects due to larger hip angular velocities. The observed multijoint control strategies were the same within subject across tasks.

## INTRODUCTION
Satisfying mechanical objectives at the total body level involves multijoint control of the ongoing interaction between the body and the environment. Observation of complex whole-body movements, such as jumping, suggests that the nervous system organizes the human body into a number of operational subsystems that are coordinated by using some type of hierarchical control [1]. Identification of common multijoint control strategies used by same individual under various conditions advances our understanding of the control structure and inherent priorities specific to an individual [2].

Generation of backward angular impulse during foot contact with the ground is achieved by orienting the ground reaction force (RF) anterior to the total body center of mass (CM) regardless of translation direction (Figure 1; Back somersault (BS); Reverse Somersault (RS)). During the take-off phase of the BS and RS, the RF-time characteristics, knee-hip coordination, and neuromuscular control strategies during the take-off phase were found to be comparable within subject and across tasks [3,4,5]. While direction of translation varies between RS and BS tasks, the orientation of the RF relative to the lower extremity segments was maintained, resulting in greater hip NJMs in relation to knee NJMs. The distribution of mechanical demand imposed across the lower extremity within-subject was maintained across tasks, however between subject differences in joint extension patterns were observed [6].

In this study, we hypothesized that individuals using different knee-hip coordination strategies during the push phase of BS and RS would exhibit differences in mechanical load distribution across the lower extremity joints. We tested this hypothesis by comparing the knee and hip NJMs and NJM work done prior to and after the initiation of hip extension.

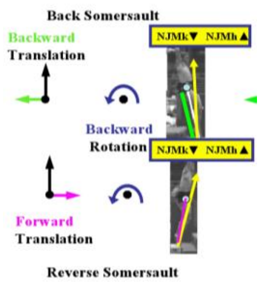


**Figure 1.** Total body kinetics for an exemplary subject during the take-off phase of back and reverse somersaults. During joint extension, the reaction force (yellow vector) passes anterior to the center of mass creating backward rotation of the body.

## METHODS
Seven (5 males, 2 females) skilled performers (national level divers) participated in this study in accordance with the institutional review board. Each subject performed a series of BS and RS tasks. Each task was initiated from an instrumented platform as done during competition, onto a landing mat, as done during dry-land training. During the take-off phase, sagittal plane kinematics was recorded with a high speed camera (200 Hz). Reaction forces (AMTI, Watertown, MA) and activation of the lower extremity muscles (Gluteus Maximus (Gmax), Semimembranosus (SM), Biceps Femoris (BF), Rectus Femoris (RFem), Vastus Lateralis (VL)) were recorded simultaneously (1200 Hz) using surface electrodes (Konigsberg, Pasadena, CA).

The distribution of NJM work across the ankle, knee, and hip during the take-off phase was determined by integrating NJM power (product of NJM and joint angular velocity) prior to and following the initiation of hip extension. Lower extremity muscle activation patterns were filtered (10-350 Hz, $4^{th}$-order, recursive Butterworth filter). The magnitude of muscle activation was quantified using root-mean-squared method (20 ms binned) [7] and normalized to the maximum contraction obtained during manual muscle tests [8] and averaged for each bin.

## RESULTS AND DISCUSSION
Subjects with different knee-hip coordination strategies used different joint kinetics and muscle activation patterns to generate linear and angular impulse during the take-off

phase of BS and RS tasks. Subjects simultaneously extending the knee and hip (KH) during both the BS and RS (4 of 7) had knee NJMs that were twice as large as their knee stabilizing (KStab) counterparts (3 of 7) (Figure 2). Ankle NJM magnitudes were comparable across strategies in that subjects exhibited similar GRFs in relation to the foot segment. In contrast, the more horizontal shank angle for the KH group contributed to relatively larger knee NJMs than for KStab group. Hip NJM magnitudes remained similar between strategies since the proximal and distal moments imposed by the net joint forces (NJF) about the thigh CM were larger for KStab group. Within subject, ratio of hip to knee NJMs prior to hip extension was 2 to 1 in the KH group, whereas it was 4 to 1 in the KStab group.

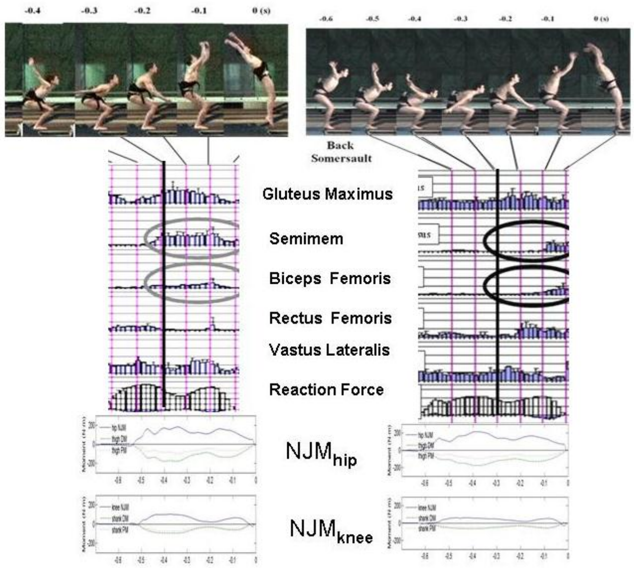


**Figure 2.** Knee and Hip NJMs, RFs , and average muscle activations for an exemplar subject with simultaneous knee-hip extension (left) and an exemplar subject with knee stabilization (right) during a BS. A positive NJM denotes an extensor NJM. Black vertical line denotes time of hip joint extension.

The distribution of mechanical load across the lower extremity was also specific to control strategies. NJM work at the hip was greater than NJM work at the knee and ankle for both control strategies. Greater work at the knee and ankle was observed for the KH group as compared to the KStab group. Between strategy differences in hip NJM work was due to the higher hip angular velocity in the KStab group as compared to the KH group; whereas, the lower knee NJM work was due to the lower knee moment.

NJM work distribution across the lower extremity was similar when comparing BS to RS within subject, except for KH subjects who used larger work at the hip and smaller work in the knee for RS prior to hip extension. This trade-off between hip and knee NJM Hip and knee work were negatively associated within subject; a change in hip work between phases led to a similar negative change in knee work, thus leading to within multi-joint control strategy differences. In general, the time from initiation of the somersault to plate departure was independent of joint control strategy.

KH group demonstrated early onset and prolonged activation of the biarticular SM and BF muscle (circled in gray, Figure 2) as compared to the KStab group (circled in black, Figure 2). Activation of bi-articular hip extensors-knee flexors is consistent with generating a resultant RF anterior to the total body CM resulting in backward angular impulse (Figure 1). Activation of the hip extensors-knee flexors (SM, BF) was also used by KH group during the later portion of the 'push' phase, when knee and hip extension occurred together. Activation of the SM and BF muscles during simultaneous knee and hip joint extension suggests recruitment of these biarticular muscles may occur when the muscle-tendon unit is at a preferred, isometric muscle length [9]. When the hip and knee extend together, the bi-articular muscles to shorten at the hip and lengthen at the knee, respectively.

## CONCLUSIONS

Selective activation of the lower extremity muscles was used by participants in this study to satisfy task-specific linear and angular impulse generation requirements at the whole body level. Regardless of translation direction, activation of the SM and BF was used to redirect the RF anterior to the CM during backwards-rotating tasks. Additionally, individuals satisfied the same mechanical objective using two different multi-joint control strategies (initiated joint extension by extending the knee and hip together or by stabilizing the knee while extending the hip). The observed differences in uni- and bi-articular muscle activation (SM, BF, RFem) in regulating knee and hip extension suggests the presence of subject-specific power generation strategies that need to be considered when modifying technique and individualizing training programs.


## ACKNOWLEDGEMENTS

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