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# INDIVIDUAL STRATEGIES FOR GENERATING ANGULAR IMPULSE DURING TURN INITIATION

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## SUMMARY
Strategies used for generating angular impulse during turning tasks with varying requirements of angular impulse were investigated. As the number of turns increased, the angular impulse generation increased by modifying the horizontal reaction force (RFh) direction, increasing the push leg RFh magnitude, and/ or increasing angular impulse from the turn leg.

## INTRODUCTION
Successful performance of a turn requires rotation of the body about a vertical axis while maintaining balance on one leg [1,2]. During the turn initiation phase of a "piqué" turn, reaction forces of the push leg contribute to the linear impulse needed to translate the total body center of mass (CM) from push to a stance leg and to the angular impulse needed to rotate the body about a vertical axis. During the turn phase (single leg support), the CM position is controlled relative to the base of support in order to successfully maintain both balance and the CM's linear trajectory to continue to the next piqué turn (Figure 1). The "push phase" during turn initiation was defined by the beginning of single leg support until push leg foot departure (Figure 1). The mechanical objectives of the push phase are to (1) generate linear momentum to translate the CM from the center of pressure (COP) of the push leg to the center of pressure of the stance leg and (2) generate angular impulse about the vertical axis.

There are many ways to successfully complete the mechanical objectives of the piqué turn task. It is possible to increase the number of turns completed in the turn phase by increasing angular impulse during turn initiation, increasing duration of the turn phase, and/or decreasing rotational moment of inertia. Angular impulse about a vertical axis can be increased by increasing moment arms between the CM and RFh point of application (COP), increasing the duration RFh is applied, and/or increasing magnitude of RFh perpendicular to the moment arm (either by changing magnitude or RFh angle).

We hypothesized that as the number of turns in a piqué increased, angular impulse generation would be increased by regulating the magnitude and direction of the resultant horizontal reaction force during the push phase. As found previously in other tasks involving rotation [3], we expected that the strategies used to regulate reaction force would be subject-specific.

## METHODS
Collegiate dancers with similar levels of dance experience and training (N=2) performed a series of piqué turns requiring varying degrees of rotation. Turns were performed with each foot supported by a forceplate (Kistler, 1200Hz). Body segment kinematics were captured simultaneously in the frontal, sagittal, and transverse planes. A metronome was used as a timing constraint, just as dancers would normally adhere to a music based tempo requirement to control turn initiation and turn phase duration. The amount of rotation required during each piqué was progressively increased (0° (pk0), 360° (pk1), 720° (pk2), 1080° (pk3)) to systematically increase the rotation and balance control requirements between turn conditions.

The ground reaction forces, specifically the RFh, were compared across turn conditions to determine how each dancer satisfied the linear and angular momentum requirements of the turn during the push phase of a piqué. The net linear impulse generated by the push (PL) and support leg (SL) directed between the PL COP and SL COP was used to determine how RFh generated by each leg contribute to the shift from double leg stance to single leg stance. The moment calculated from the CM trajectory, COPs, and RFhs was used to determine how angular impulse was generated during the push phase.

## RESULTS AND DISCUSSION
Angular impulse in push phase generally increased as turn number increased as expected (Figure 2A). There was a large contribution to total angular impulse due to the angular impulse that resulted from the turn leg's initial contact RFh during push leg departure (Figure 2A, Subject 1 pk2 and pk3).

Linear impulse generation patterns were subject-specific. For subject 2, linear impulse was larger and similar in pk1, pk2, and pk3 compared to pk0 (Figure2B, Subject 2). However, subject 1 increased linear impulse only for pk1 turn condition (Figure 2B, Subject 1) which suggests that for pk2 and pk3, this could be due to the RFh redirection such that minimal RFh was directed in the CM trajectory direction as a way to increase angular impulse (Figure 5).

There were slight modifications in peak RFh magnitude and greater modifications in RFh direction at peak RFh. The mean push leg peak RFh increased when there was a turn performed (Figure 3A, pk1, pk2, pk3). Modifications in RFh direction were apparent in both legs and consistent with increasing the angular impulse (Figure 3B).

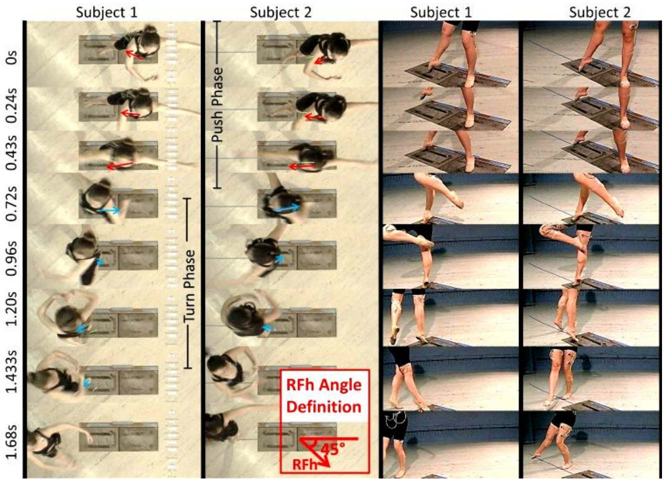


**Figure 1**: Kinematic and kinetic context of an exemplar 360° piqué turn (pk1) for each subject. Forceplate reference system definition of RFh angle also depicted.

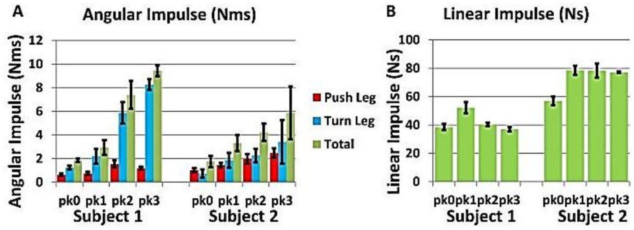


**Figure 2**: Mean (standard deviation) of (A) angular and (B) linear impulse of push leg (red), turn leg (blue), and total (green)

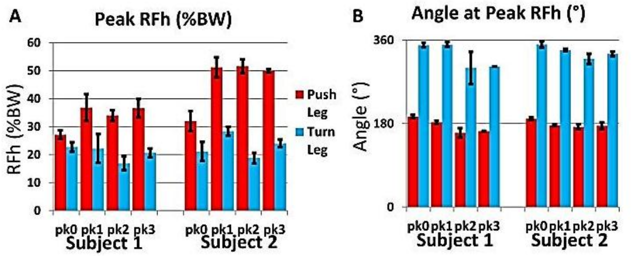


**Figure 3**: Mean (standard deviation) (A) peak RFh and (B) angle of RFh at peak RFh.

Moment and force time curves also show subject-specific strategies to increase angular impulse (Figure 4). For subject 1, angular impulse was generated during linear impulse generation, and decreasing phase durations as number of turns increased implies that increasing duration of the push phase was not a method used to increase angular impulse. However, for subject 2, the delayed timing of angular impulse generation corresponds to the increase in moment arm for the push leg and the contribution to angular impulse from the turn leg.

The orientation of the RFh differed between dancers across turns that was not depicted by analysis at peak RFh (Figure3). In subject 1 pk2 and pk3 turns, there were two distinct angle ranges the push leg's RFh resided, which was not found in subject 1 pk0 and pk1, or subject 2 (Figure 5).

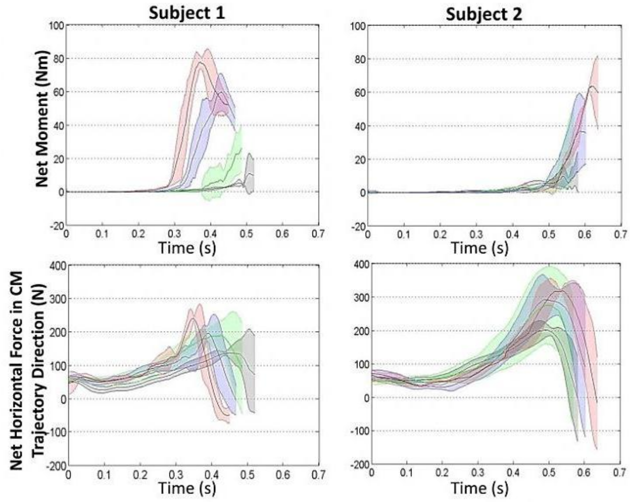


**Figure 4**: Net moment and net horizontal force in CM trajectory direction with standard deviation for pk0 (gray), pk1 (green), pk2 (blue), and pk3 (red).

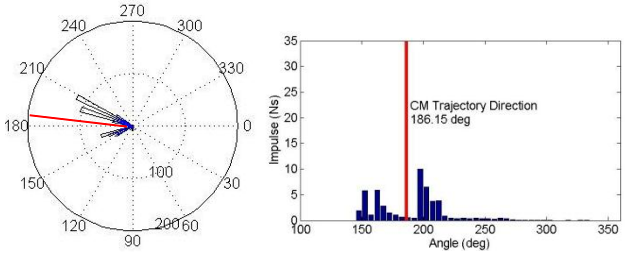


**Figure 5**: RFh angle histograms for exemplar pk2 task for subject 1. Left depicts number of RFh samples within 5 degree bins, right depicts impulse in each 5 degree bins.

The differences in angular impulses as number of turns increased were smaller than expected, but is consistent with the findings of increased turn phase duration and that the angular impulse due to the RFh of the turn leg's initial contact was larger than due to push leg RFh (Figure2A, turn leg). This suggests that the turn leg's contribution immediately following the push phase may be critical to increase angular impulse. Future efforts will be focused on understanding angular impulse generation at the beginning of the turn phase and studying the angular impulse generation techniques of more dancers.

## CONCLUSIONS

Subject-specific modifications in angular impulse generation strategies during turn initiation of a piqué turn were found. General increases in angular impulse generation with number of rotations were due to RFh redirection, increases in push leg RFh magnitude, and/ or increased angular impulse from the initial contact of the turn leg as the push leg departed.


## ACKNOWLEDGEMENTS

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## REFERENCES


1. Winter DA. *J Biomech*. **13(11)**:923-27, 1980
2. Mathiyakom W & McNitt-Gray JL J. *Rehabil Res Dev* **45(8):**1237-48, 2008
3. McNitt-Gray, et al. *Sport Science*. (Epub)