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Lower extremity control during turns initiated with and without hip external rotation

Antonia M. Zaferiou [a,*,1], Henryk Flashner [b], Rand R. Wilcox [c], Jill L. McNitt-Gray [a,d,2]

[a] Department of Biomedical Engineering, University of Southern California, 3616 Trousdale Parkway, Los Angeles, CA 90089, USA
[b] Department of Aerospace and Mechanical Engineering, University of Southern California, OHE 430E, Los Angeles, CA 90089, USA
[c] Department of Psychology, University of Southern California, 3620 South McClintock Ave., SGM501, Los Angeles, CA 90089, USA
[d] Department of Biological Sciences, University of Southern California, 3616 Trousdale Parkway, AHF-252, Los Angeles, CA 90089, USA

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ABSTRACT

The pirouette turn is often initiated in neutral and externally rotated hip positions by dancers. This provides an opportunity to investigate how dancers satisfy the same mechanical objectives at the whole-body level when using different leg kinematics. The purpose of this study was to compare lower extremity control strategies during the turn initiation phase of pirouettes performed with and without hip external rotation. Skilled dancers ($n=5$) performed pirouette turns with and without hip external rotation. Joint kinetics during turn initiation were determined for both legs using ground reaction forces (GRFs) and segment kinematics. Hip muscle activations were monitored using electromyography. Using probability-based statistical methods, variables were compared across turn conditions as a group and within-dancer. Despite differences in GRFs and impulse generation between turn conditions, at least 90% of each GRF was aligned with the respective leg plane. A majority of the net joint moments at the ankle, knee, and hip acted about an axis perpendicular to the leg plane. However, differences in shank alignment relative to the leg plane affected the distribution of the knee net joint moment when represented with respect to the shank versus the thigh. During the initiation of both turns, most participants used ankle plantar flexor moments, knee extensor moments, flexor and abductor moments at the push leg's hip, and extensor and abductor moments at the turn leg's hip. Representation of joint kinetics using multiple reference systems assisted in understanding control priorities.

1. Introduction

Turns often involve satisfying multiple and competing mechanical objectives at the whole-body and segment levels. At the whole-body level, the ground reaction force (GRF) generated by each leg must be regulated in relation to the center of mass (CM) so that the net impulse requirements are satisfied. At the segment level, the GRF generated must be coordinated in relation to segment motion to facilitate multi-joint control. Failure to simultaneously satisfy these mechanical objectives at the whole-body and segment levels can result in poor outcomes (e.g., loss of balance). Studying how an individual satisfies the mechanical objectives of comparable tasks with varied kinematic contexts has been effective in elucidating subject-specific control preferences in goal-directed movements such as diving and sit-to-stand tasks (Mathiyakom et al., 2007, 2006a, 2006b, McNitt-Gray et al., 2001). Knowledge of the control and dynamics used to perform turns under a variety of conditions can inform development of tools to facilitate skill acquisition (McNitt-Gray et al., 2015).

Dance turns are well practiced and goal-directed tasks that can be performed using different initial kinematic contexts. Classical ballet turns are typically initiated and performed with the hips externally rotated, whereas, modern choreography requires dancers to also be proficient in performing tasks with neutral hip alignment. The pirouette dance turn is often initiated in neutral and externally rotated hip positions by contemporary, modern, and contemporary-ballet dancers (Fig. 1). This provides an opportunity to investigate how dancers satisfy the same mechanical objectives at the whole body level when generating ground reaction forces (GRFs) using different leg kinematics.

In postural movements, motor recruitment patterns and joint torques have been found to be coordinated with the direction of

* Correspondence to: Director of Motion Analysis for Division of Sports Medicine, Department of Orthopedic Surgery, Rush University Medical Center, USA.
E-mail addresses: zaferiou@alumni.usc.edu (A.M. Zaferiou), hflashne@usc.edu (H. Flashner), rwilcox@usc.edu (R.R. Wilcox), mcnitt@usc.edu (J.L. McNitt-Gray).
[1] Present Address: Department of Orthopedic Surgery, 1611 W. Harrison St. Suite 204, Chicago, IL 60612, USA.
[2] Address: USC Biomechanics Research Laboratory, Departments of Biological Sciences and Biomedical Engineering, University of Southern California, 3616 Trousdale Parkway, AHF-252, Los Angeles, CA 90089, USA.

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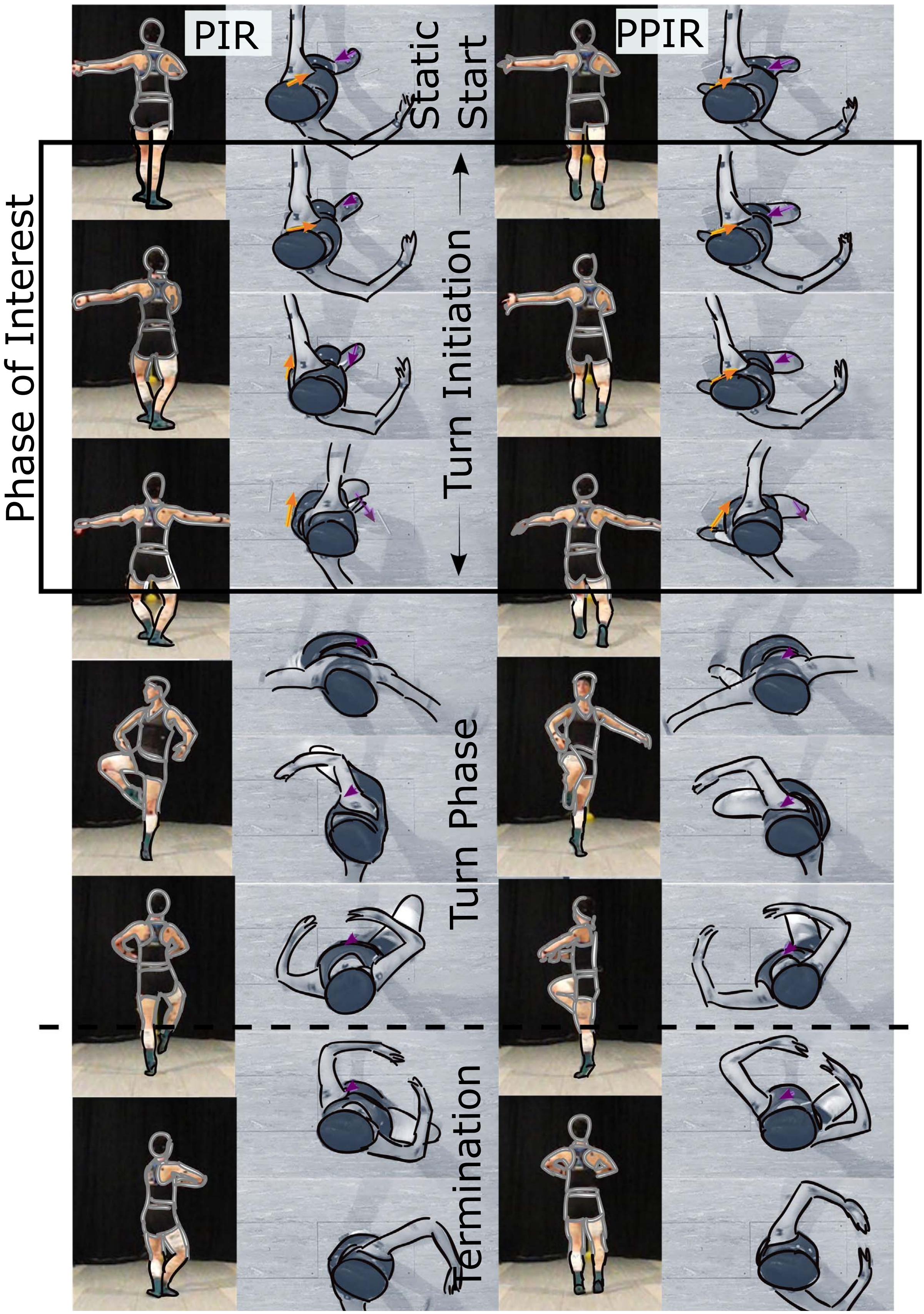

Fig. 1. Phases and exemplar kinetics and kinematics during a single classical pirouette (pir, left column) and a single parallel pirouette (ppir, right column) (Subject 4). On the transverse plane images, vectors indicate the horizontal reaction force for the push leg (orange) and turn leg (purple). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)