Letter

Analysis of Pirouette Execution for Improved Performance

To the Editor–A parameter called the *performance index* was derived to assess the success of a pirouette. Measured by this parameter, the best turns were performed from a distance of 40% of a dancer's leg length. It was also found that the position of maximum torque does not correspond to the position from which the best turn was produced.

Ballerinas turn, but why are some turns more successful than others? In this note, we propose a method that provides a quantitative estimate of how the initial starting position affects the success of *en dehors* pirouette on toes; the proposed method is not limited by the type of the turn.

The motivations for the present work are the author's own experiences as a dancer and the seminal paper by Sugano and Laws[1] which established the dependence of the success of a turn on the initial starting position. He classified the turn in a binary fashion, assigning 1 for "good turns" and 0 for "bad turns." In this preliminary work, an attempt was made to assess the turn quality in a more general manner by relying on measurements rather than subjective evaluation.

The length of the preparation position produces a force couple, generating the torque for the turn.[2,3] The present experiment assesses and quantifies how the initial position affects the success of the pirouette defined in terms of a new parameter called the *performance index* (*PI*), and establishes empirical relations between *PI*, initial position,and the torque. In torque calculations, the friction factor between the load cell surface and the dancer's slipper was assumed to be equal to 1.

Methods and Data Analysis: The experimental set-up was similar to the one described by Laws,[1] except force measurements were taken with a load cell mounted on a wooden platform (Fig. 1); load cell output was continuously recorded on a laptop computer. Each turn was filmed on a DVD for frame-by-frame analysis. Five professional dancers from the Boulder Ballet Company participated in the experiment. IRB approval, granted by the Summit Middle School (BVSD) IRB (coordinated by Haydee Phelps), was obtained prior to experimentation.

Data included dancer's leg length (to top of the hip) and weight. The dancer situated herself in a "comfortable" fourth position which was measured as the reference distance. Three additional distances 2, 4, and 8 inches longer than the reference distance were marked. The dancer performed three turns from each distance.

Performance Index: The quality of a turn was measured as the deviation of the dancer's turn axis from the vertical axis (body force axis) obtained from frame-by-frame analysis for each turn as suggested by Sugano and Laws.[1] The full frontal image of the dancer was printed, and the quantities *AL* (axis length) and *D* (deviation) were obtained by directly measuring from the printed frame (Fig. 1). The deviation angle, α, is defined as:

$$\alpha = \sin^{-1}\left(\frac{D}{AL}\right)$$

and α_{min} is the smallest α from all turns. *PD* is the performance deviation for each turn:

$$PD = \frac{\alpha - \alpha_{min}}{\alpha_{min}}$$

Defining PD_{max} as the largest performance deviation and PD_{min} as the smallest performance deviation for all the turns, the performance index, *PI* is defined:

$$PI = \frac{PD_{max} - PD}{PD_{max} - PD_{min}}$$

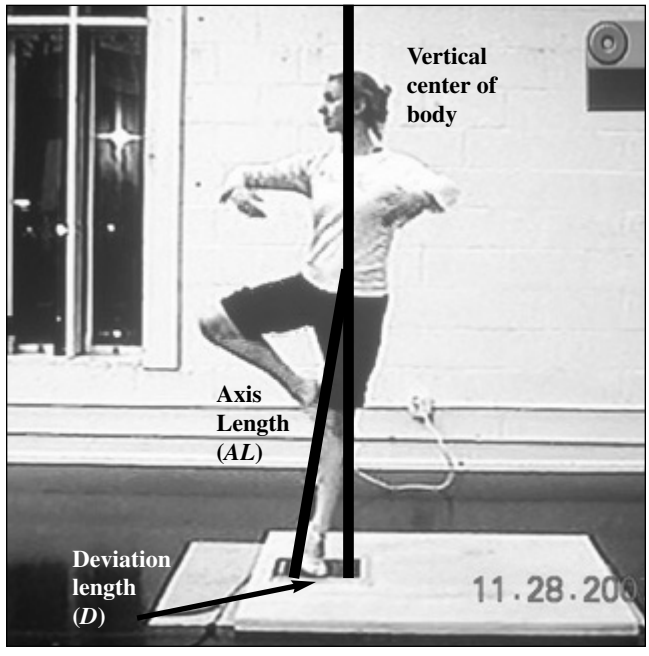

FIGURE 1. Experimental setup and definition of parameters. The dancer is Nicole Miller, of the Boulder Ballet.

This project was featured in the Summit Middle School Science Fair, District Science Fair (1st place, Physics 2008), and Colorado Science and Engineering Fair (4th Place, Physics 2008) with special award from The Office of Naval Research.

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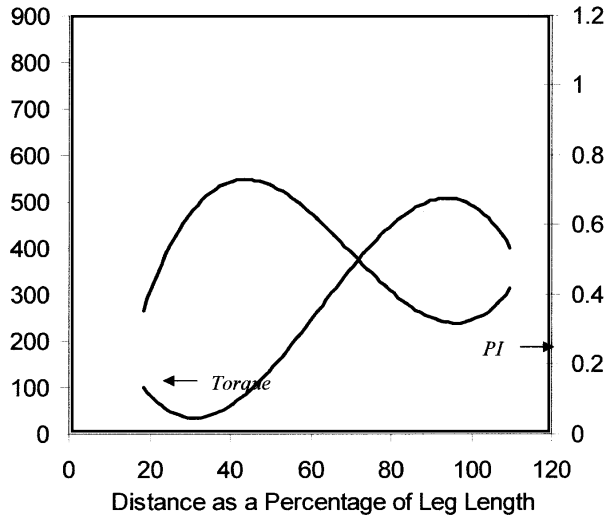

FIGURE 2. Torque (N-m, shown in the *left vertical axis*), and performance index (*right vertical axis*) plotted against distance (*bottom axis*) as a percentage of leg length.

For the best turn, $PI = 1$, this value decreases as α increases and the quality of the turn diminishes.

RESULTS: Figure 2 was obtained as a third-degree polynomial trend line fitted to the data using MS Excel (Microsoft Corp., Redmond, WA), and shows that the successful turns (high *PI* values) were executed from approximately 40% of the dancer's leg length. This number will be different for individual dancers, but it represents a statistical average for dancers in this cohort. The shape of the curve and the starting position were compatible with Sugano and Laws' analysis[1] in which 35% of the length was the optimum starting position.

Figure 2 also reveals that the average torque produced at optimum starting distance is approximately 100 Newton-meters, 20% of the maximum torque produced by this cohort. Torque was calculated as the product of the force exerted at start of the turn and the starting distance. This plot indicates that indeed the torque increases with distance, but the *PI* value corresponding to the best turn does not occur at the position of maximum torque. Further work with a larger sample size is necessary to validate these preliminary results including other turns.

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