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STRATEGY OF BALANCE CONTROL DURING PIRUETTÉ IN CLASSICAL BALLET

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The purpose of this study was to investigate how ballet dancers control their balance on one leg during *pirouetté* in classical ballet. The hypothesis was that the classical ballet dancer balances letting the COP locate under the centre of mass (COM) of the whole body by translating the supporting leg. *Piruettés* by four Russian and one Japanese male ballet dancers were captured. COM, COP and supporting foot kinematics were analysed. The dancers' COPs move after the COMs during the first half of one revolution. Then the COP began to stop near the COM and dancers' body axes became more straight during latter half of one revolution. Most dancers translate the COP under the COM, controlling the COP locations in the supporting foot.

KEY WORDS: turn, axis of rotation, ballet.

INTRODUCTION: Laws (2012) reported that the vector from COP to COM leans during performing *pirouetté* in classical ballet. And that maintenance of the balance on single leg during *pirouetté* is not brought by precession considering the angular velocity of the turn (about 11 rad/s). Hence, the dancers would balance by controlling their COP not to topple. The purpose of this study was to investigate how dancers control their balance on one leg during *pirouetté* in classical ballet. The hypothesis was that the classical ballet dancer balances, locating the COP under the centre of mass (COM) of the whole body by translating the whole supporting leg.

METHODS: Four Russian and one Japanese male ballet dancers performed *pirouettés* of multiple revolutions (from single to six or seven revolutions per one kick). The performances were recorded using eight VICON MX cameras at a frame rate of 250 Hz. The ground reaction forces acting on supporting foot was recorded simultaneously with the cameras.
The one revolution of each dancer's best turn was analysed: the revolution in which a vector from COP to COM (name as a "vector of body axis" in this study) was leaned the most. This lean was calculated as angle between the vertical axis of the global coordinate system and the body axis. The COM was determined from the markers on the dancers using the coefficients reported by Ae et al. (1992). Distances of translations about the COM and foot were determined using the markers. The COM, foot and COP linear velocities were determined in global and supporting foot coordinate systems. The correlation between the lean of the vector and distances of the COM and supporting foot translations were investigated. After determining the correlation coefficients, significance of the correlation coefficient was tested using a paired two-tailed t-test with a significance level of 0.05.

RESULTS: There was a positive correlation between distance of COM translation and lean of the vector of body axis (R=0.42, t(n-2)=82, p=0.00*, Figure 1). No correlation was found between that of the supporting foot and the lean of the vector (R=-0.06, t (n-2)=82, p=0.61). The foot translated in the direction of the lean of the vector at the beginning of one revolution (Figure 2 a). However, The COM and foot velocities did not change in phase about four dancers (Figure 3 a). The foot translated in the direction the body axis leaned at the beginning of one revolution (Figure 2 a). However, the foot velocity did not change, coincided with the COM velocity about four dancers (Figure 3 a). Their COP velocities changed, coincided with the COM velocity in the supporting foot coordinate system (Figure 4 a). A dancer whose COM and foot velocities changed similarly did not change the COP velocity along with the COM velocity in the supporting foot coordinate system (Figure 3 b, 4 b). His lean of the body axis was smallest of the five revolutions (0.03 rad, averaged though one revolution).

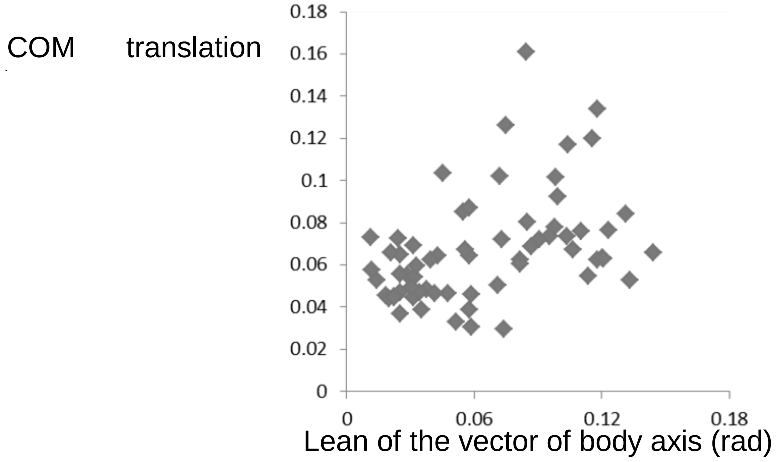


Figure 1. Correlation of the CON translation and lean of the vector of body axis

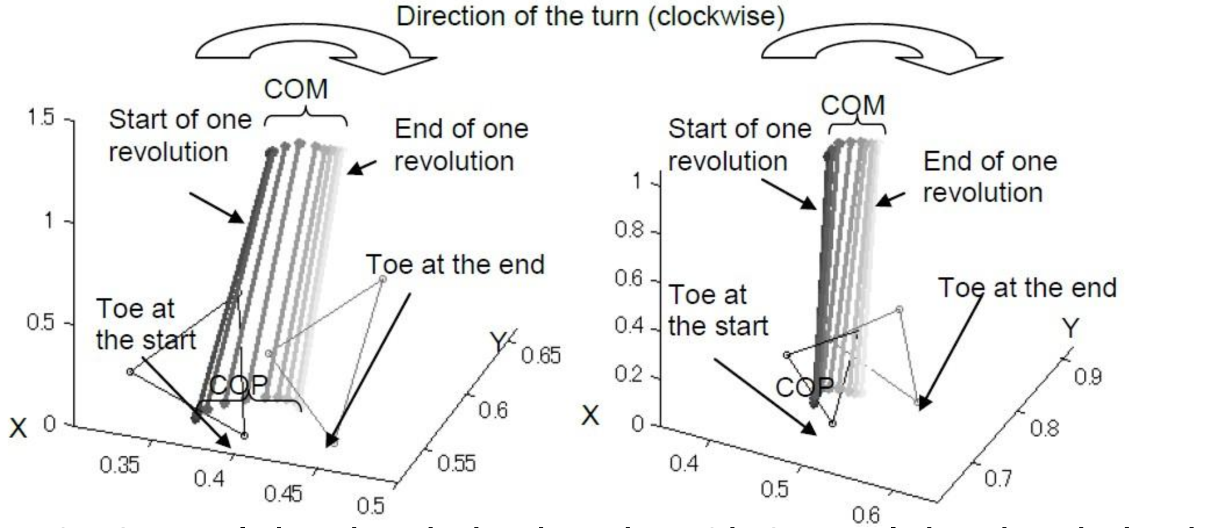


Figure 2 a. One revolution whose body axis was most leaned, 0.12 rad (averaged through one revolution. Data of a representative dancer.

Figure 2 b. One revolution whose body axis was most straight, 0.01 rad (averaged through one revolution. Data of the same dancer as Figure 2a).

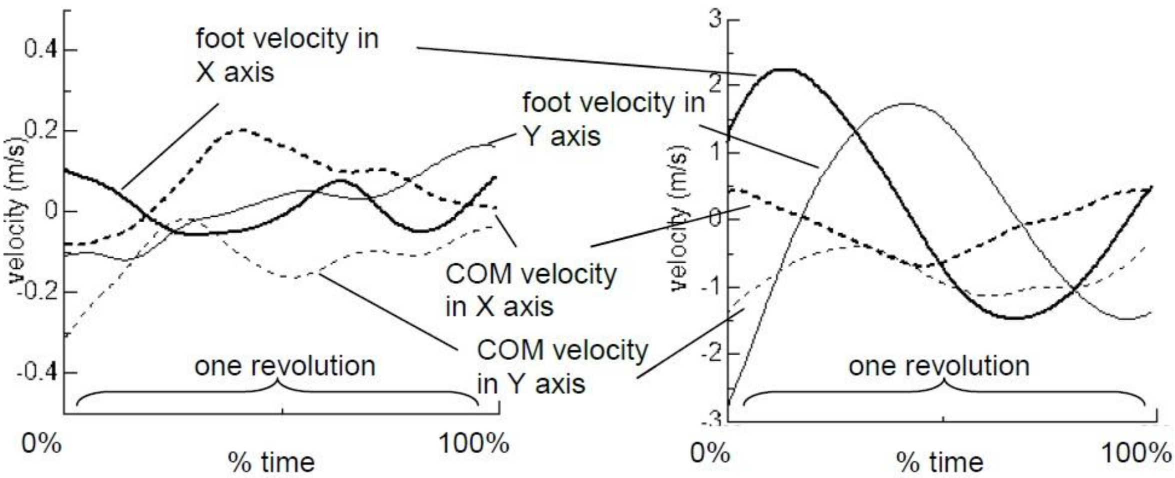
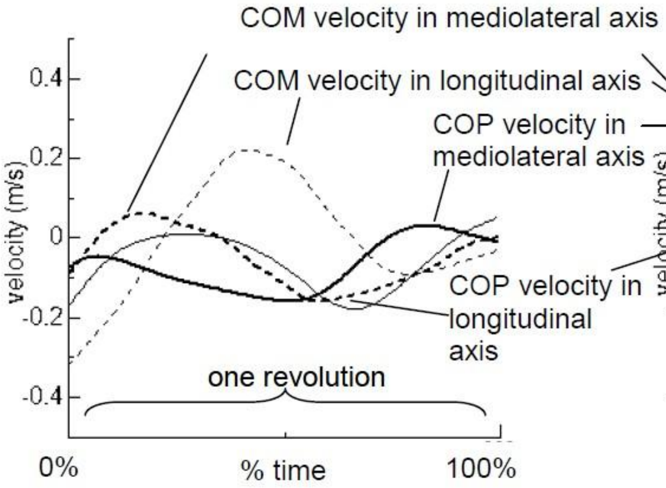


Figure 3 a. COM and foot velocities in global coordinate system (representative data among four dancers).

Figure 3 b. COM and foot velocities in global coordinate system (a dancer whose COM and foot velocities changed in phase).



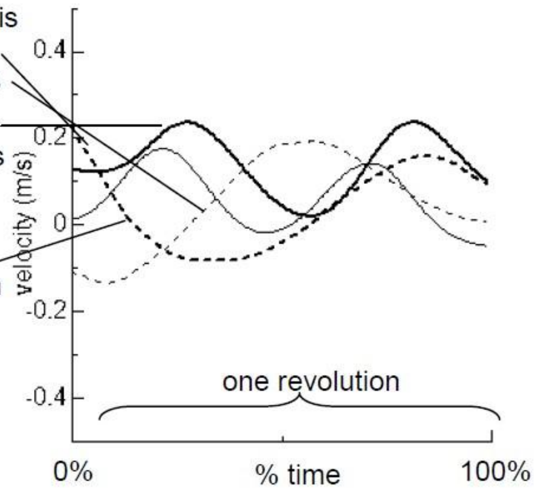


Figure 4 a. COM and COP velocities in supporting foot coordinate system (representative data among four dancers).

Figure 4 b. COM and COP velocities in supporting foot coordinate system (a dancer whose COM and foot velocities changed in phase).

DISCUSSION:

The dancers' vector of body axis leaned during the *pirouetté* in order to balance the asymmetric body configuration on one leg. The dancers' COPs move after the COMs during the first half of one revolution. Then the COP began to stop near the COM and dancers' body axes became straighter during latter half of one revolution. Two patterns of adjustment for this were observed about five dancers in this study. Major strategy by four dancers was that the dancer changed the COP velocity along with the COM velocity in the supporting foot with the supporting leg translated. Another strategy by a dancer was that supporting leg translated towards the COM to locate the COP near the COM without changing the COP velocity along with that of COM in the supporting foot. The former strategy would show that the dancers slightly change the location of body segments during one revolution, allowing slight inclination of the body axis. The latter strategy would require a skilful technique to put the COM on the COP accurately when the dancer begins to turn by kicking. Muscle strength and somatic sense would be required to maintain the distance from body axis to a COM of each body segment. The latter strategy would give the audiences an impression of " straight body".

The COP locations would be changed by the lower limb joint torques even if location of the body segments does not seem to be changed during turning on single leg. The reason for changing lean angles should be considered through investigating kinematics and kinetics of lower limb.

CONCLUSION: The ballet dancers translate their supporting legs under the COM during one revolution of a turn. Moreover, most dancers adjust the COP by controlling it in the supporting foot.

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