ANALYSIS OF THE AERIAL AND LANDING PHASES OF THE GRAND JETÉ

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The purpose of this study was to quantify the ground reaction forces, moments of forces and moment powers during the landing from the ballet jump called the grand jeté. In addition, the flight phase was examined to determine whether the illusion of linear motion occurred. Laws (2002) has stated that it is possible for dancers to give the illusion of "floating" or traveling linearly rather than parabolically during the flight phase of a grand jeté by raising the arms and/or the legs at an appropriate speed.

KEY WORDS: inverse dynamics, moment powers, jumping, ballet, dance.

INTRODUCTION: Jumping is a fundamental human movement that requires complex coordination between both the upper and lower body segments (Ashby & Heegaard, 2002). The grand jeté is considered one of the most memorable jumps in ballet. The body of a dancer during the grand jeté can portray elegant grace appearing to glide across the floor and through the air. For this reason, the study was conducted to examine the dancer's illusion in the air and the forces endured upon landing. It is essential to understand how the body lands successive jumps like the grand jeté to prevent and avoid injuries to the lower extremity. The main purpose of studying the aerial phase was to determine if the subjects could create the illusion of a non-parabolic movement. The landing phase was analyzed to determine the force attenuation of the lower segments.

METHODS: Two experienced dancers who were also instructors volunteered for the study. Each subject was outfitted with 12 reflective markers (Figure 1) in specified locations (ear, greater tubercle, medial epicondyle left, medial epicondyle right, ulnar styloid process right, ulnar styloid process right, greater trochanter, apex of head of fibula, lateral malleolus, heel, head of first metatarsal, tip of first phalange). The subjects were videotaped (60 Hz) while performing five grand jetés landings onto a force platform (Kistler) using a running start. BioWare software collected the force platform data at 240 hertz. APAS and Biomech software was used to digitize and compute segmental and joint kinematics and perform inverse dynamics analysis and the computation of moment powers.

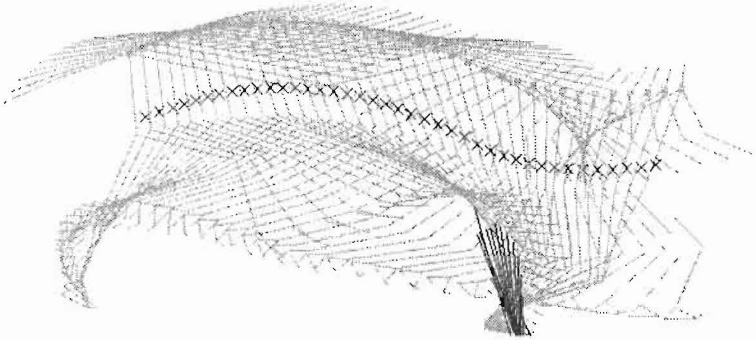

Figure 1: Stick-figures of a typical grand jeté (Xs identify path of centre of gravity, asterisks mark path of the shoulder, black lines show ground reaction forces at landing).

RESULTS: The human eye perceives the aerial phase of the grand jeté movement to be horizontal in nature, however, as expected, the experimental data showed the center of gravity clearly traversing a parabolic path (figure 1). The dancers extended one leg forward and one backwards, which resulted in positions where both legs were perpendicular to the torso. The arm on the opposite side of the leading leg extended forward and reached an angle that

was horizontal to the plane of the jumping surface. Conversely, the arm on the same side of the leading leg extended backwards and attained a parallel orientation similar to the opposite arm. This fully extended position was achieved at the peak height of the aerial phase.
The experimental data did not reveal a significant linear phase for the head and shoulders as reported by Laws (2002) during the flight period of the grand jeté. This suggests that the limbs did not perform large motions to significantly alter the paths of the head and trunk from a parabolic path. The majority of the movements involved in extending the arms and legs in opposite directions occurred just prior to the flight period and were completed (maximum limb extension; parallel to jumping surface) at the highest point in the parabolic trajectory.

Landing Phase - Ground Reaction Forces: Figure 2 shows the vertical force histories of the landings of one subject (left pane) and the ensemble averaged ground reaction force components of the other subject (right pane). In both subjects, the landing durations were approximately 0.4 seconds. Notice that the forward horizontal force (Fy, the lower curve in the right pane) was always negative. This large braking force was necessary to prevent the dancer from slipping during the landing. The force vectors in figure 1 also show the backwards directed nature of the ground reaction force. The second subject's peak vertical forces (Fz) were smaller than those of the first subject partly due to a smaller body weight (534 N vs 623 N) but was mainly due to the ensemble averaging process and the fact that the peaks did not occur at the same instant after landing. The average peak vertical forces for the two subjects were 2790±404 N and 1954±130 N or 4.5 and 3.6 times body weight, respectively.

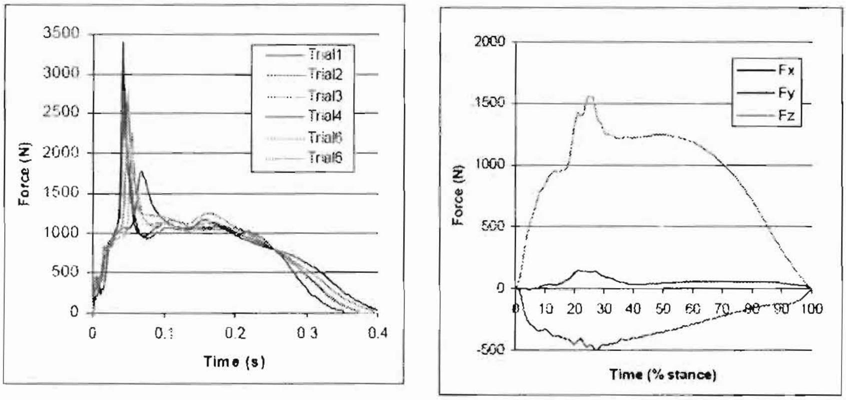

Figure 2: Left: vertical ground reaction forces of one subject's six landings from a grand jeté. Right: ensemble averages of ground reaction forces (Fx, Fy and Fz) of another subject's landings from a grand jeté (n=5).

Landing Phase - Inverse Dynamics Analysis:
Figure 3 shows the moments of force normalized to body mass (left pane) and their associated powers (right pane) for subject 2.
Hip. The hip extensors contracted eccentrically before foot-strike (FS) in preparation for landing. After FS the flexors dominated producing a very high moment of force of about 300 N.m or 5.5 N.m/kg. Initially this activity did negative work but quickly became positive work producing a peak power of 700 watts.
Knee. There was a flexor knee moment of force prior to landing that did negative work but after landing (FS) the knee moment became extensor. The knee extensor moment during first 2/3s of the stance phase performed negative work to cushion the landing. This moment was also very high peaking at about 275 N.m or 5 N.m/kg. The peak power during this phase exceeded -1000 watts. There was a final burst of positive power prior to toe-off to assist with extending the knee for the next jump.
Ankle. Prior to FS the ankle moment of force was essentially quiet. During the stance phase the

plantar flexors dominated throughout with a relatively small peak moment of force of about -100 N.m or -1.8 Nm/kg. The plantar flexors acted eccentrically for the entire stance phase with a peak power output of approximately 1000 watts.

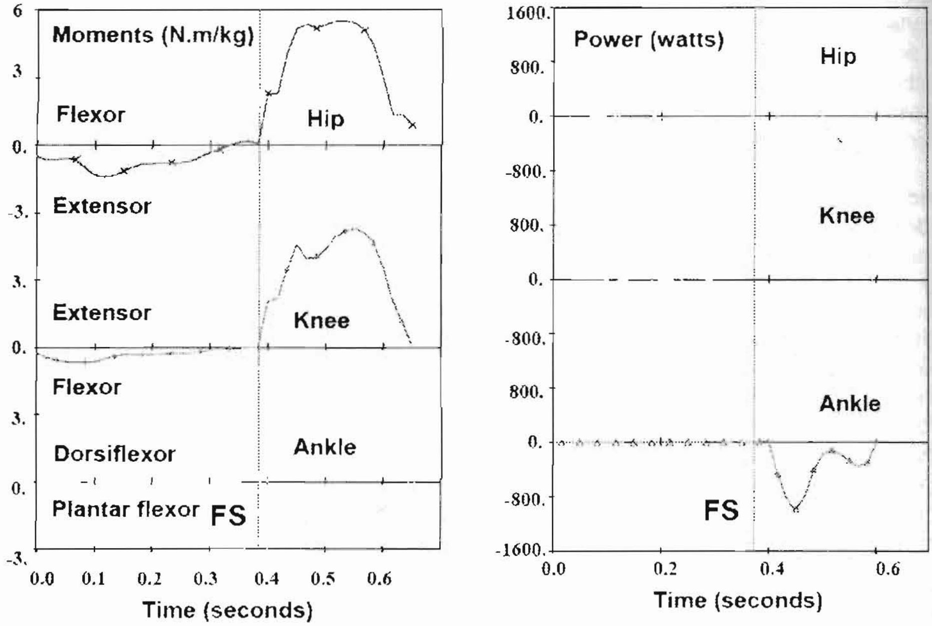

Figure 3: Left figure shows net moments of force (normalized to body mass) at hip, knee and ankle. Right figure shows powers produced by the moments of force. FS indicates instant of foot-strike (start of landing phase).

DISCUSSION: Future avenues of research could possibly test the enhanced floating illusion created by a more dynamic motion. If the arms and legs were to extend past the horizontal during mid-flight, there could be a significant improvement in the floating illusion. Thereby augmenting the impression that the dancer was traveling more horizontally, as opposed to the actual parabolic motion.

Moment power analysis revealed that the largest negative work was done by the knee extensors, followed by the ankle plantar flexors and the hip flexors. The largest moment of force was found at the hip flexors, followed closely by the knee extensors, and then the ankle plantar flexors. Thus, training of muscles associated with these moments is recommended. In the case the knee and ankle extensors eccentric training was indicated but both concentric and eccentric training is needed for the hip flexors.

An explanation for the large moments of force about the knee and hip could be the sheer magnitude of the jump but may also be due to the stiffness of the laboratory surface. Dancers usually perform on a floor with some shock attenuating properties and therefore do not require footwear with much cushioning. Force platforms are usually mounted in very rigid structures and have very stiff surfaces themselves. This undoubtedly increased the shock experienced by the dancers in the laboratory setting. Nevertheless it is clear that dancers must be very cautious whenever performing on surfaces similar to this laboratory setting since the magnitudes of these ground reaction forces are likely to cause injury.

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