GENERATION OF VERTICAL VELOCITY IN TOE-PICK FIGURE SKATING JUMPS

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The primary purpose of this study was to determine the techniques by which skaters generate vertical velocity during toe-pick figure skating jumps. Data were collected from seven male skaters completing triple Lutzes during the 1999 State Farm Figure Skating Championship in Salt Lake City, UT using four high speed video cameras. During the propulsive phase of the triple Lutz, the relative contribution of the arms and free leg was, on average, only 2.89% of the vertical momentum of the skater. During the first half of this phase, the radial velocity of the take-off leg was negative while the vertical velocity of the COM was positive. This suggests that the skaters were able to utilize eccentric muscle actions to increase the ground reaction during the first half of the propulsive phase of the triple Lutz.

KEY WORDS: biomechanics, figure skating, vertical momentum, jumping, take-off

INTRODUCTION: There are two categories of jumps performed in figure skating. Edge jumps and toe-pick jumps. During edge jumps, the skater approaches the jump gliding on one skate and performs the take-off from the glide leg. During toe-pick jumps, the skater approaches the jump gliding on one skate and prior to take-off 'picks' the toe of the other blade into the ice. This pick foot then becomes the take-off foot for the jump. Of the toe-pick jumps currently performed in competition, the hardest is the Lutz. At the elite level, both male and female skaters must be able to perform a triple Lutz and many are able to perform this jump in combination with another triple jump. The Lutz is also the most difficult quadruple jump being performed by male skaters.
Two important variables that relate to the success of a figure skating jump are the vertical velocity and angular momentum of the skater at take-off. Higher vertical velocities will allow longer time in the air to complete the required revolutions, and greater angular momenta will allow faster angular velocities given identical moments of inertia. To date, however, the majority of research on figure skating jumps has focused on double and triple Axels (Albert & Miller, 1996; Aleshinsky, 1988; King, Arnold, & Smith, 1994; King, 1997, 1999). The triple Axel is the most difficult triple jump performed by skaters, and a quadruple Axel has yet to be attempted by figure skaters The majority of the vertical velocity from take-off for the triple Axel is generated from the extension of the take-off leg (King, 1999). The relative vertical momentum of the arms and free leg contribute on average 6.6% of the total body vertical momentum (King, 2000).
However, the Axel is an edge jump. Thus, while biomechanical studies of double and triple Axels have been provided detailed information on the techniques used by skaters to complete these jumps, the Axel is a fundamentally different type of jump then the Lutz. Since the triple Lutz is a necessity for success in figure skating at the international level for both men's and women's skating, it is important to understand the mechanisms used by skaters in generating the required vertical velocity for completing this jump. Lastly, since the Lutz is the most difficult quadruple jump performed to date, a biomechanical analysis of the triple Lutz jump may prove beneficial for coaches and skaters beginning to master the quadruple Lutz. Thus, the purpose of this study was to determine the segmental contributions of the arms and free leg and the utilization of the toe-pick in generating vertical velocity for the triple Lutz.

METHODS: Four high speed digital cameras (Speed Vision, CA) operating at 125 Hz were used to collect data during the men's practice and competition sessions at the1999 State Farm Figure Skating Championships in Salt Lake City, Utah. Written informed consent was obtained from all junior and senior level male competitors. The cameras were placed in the stands so that all four cameras were focused on an approximate 5 x 2.5 m patch of ice where skaters were performing triple Lutzes in their programs. Prior to data collection two separate calibration frames measuring 2.2 x 1.0 x 2.2 m volume were used simultaneously to calibrate a 2.5 x 5 x 2.2 m volume on the ice using a variation of a multiphase calibration procedure (Challis, 1995). During data collection, the cameras were set to record for 15 seconds and triggered individually as a skater approached the analysis zone on the ice. The data were then downloaded to mini DV tapes and later copied to SVHS tapes for data analysis. Eight triple Lutzes performed by 4 skaters were recorded.

Following data collection, each jump was manually digitized using a Peak Motus system (Peak Technologies, Inc.) to create a 12-segment model of the skater. The individual cameras data were filtered using a 6 Hz low pass Butterworth filter and then the multiple camera views were time synchronized using a software algorithm developed by Yeadon and King (1999). The 2D data were then combined to form 3D coordinates using the direct linear transformation procedure (Abdel-Aziz & Karara, 1971). Total body center of mass (COM) location was calculated based on data from Zatsiorsky and Seluyanov (1983). A custom software program written in LabView (v. 5.1, National Instruments, Inc.) was used to calculate and total body vertical momentum and segmental relative momentum based on methods of Lees and Barton (1996), and radial and tangential velocity components of the take-off leg and COM velocity. Descriptive statistics were calculated for each variable.

RESULTS AND DISCUSSION: The basic characteristics of the triple Lutz, such as horizontal and vertical velocities, angular momenta, moments of inertia, maximum jump height and flight time are presented in Table 1. Note that from toe-pick to take-off, horizontal velocity decreased on average 37 ± 5 % and vertical velocity of the skaters increased on average 81 ± 5 %. The phase from toe-pick to take-off was termed the propulsive phase (Figure 2). During this phase, the angular momentum of the skater about a longitudinal axis through the trunk increase on average 30 ± 20%.

Table 1 Descriptive Characteristics of the Triple Lutz as Performed by Eight Male Skaters at the 1999 State Farm Figure Skating Championships (All values are means ± standard deviations.)

	Toe-Pick	Take-Off
Horizontal Velocity ($m \cdot s^{-1}$)	5.60 ±0.40	3.45 ±0.12
Vertical Velocity ($m \cdot s^{-1}$)	0.37 ± 0.44	3.03 ± 0.42
Angular Momentum ($kg \cdot m^2 \cdot s^{-1}$)	18.9 ± 4.50	26.9 ± 7.09
Moment of Inertia ($kg \cdot m^2$)	3.20 ± 0.31	1.99 ± 0.71
	Flight	
Maximum Jump Height (m)	0.48 ± 0.12	
Flight Time (s)	0.62 ± 0.01	

Of the 'free' segments (both arms and the non pick leg), the left arm had the largest relative vertical momentum contribution (2.32 ± 0.81%) during the propulsive phase. The relative momentum of a segment is due to the segment's vertical velocity relative to the proximal joint of that segment. The total relative contribution from the free limbs was on average 2.89 ± 1.28%. The asynchronous movement of the arms and free leg was one reason that the relative contribution of the free limbs to the total body vertical momentum was so small (< 5%) (Figure 2).

Due to the small relative contribution of the free limbs to the vertical momentum of the skaters, the majority of the skater's vertical velocity for take-off must come from another source. Immediately following toe-pick, the vertical velocity of the COM of the skater is positive. Simultaneously, however, the radial velocity of the pick leg is negative (the length of the pick leg as measured from the hip to ankle is decreasing). Thus, while the COM of the skater is rising, the knee of the pick leg is flexing. This suggests that the knee extensors are acting eccentrically during this phase. The eccentric action of the knee extensors will allow high levels of force to be developed while the vertical velocity of the COM is positive, which will help increase the ground reaction force of the skater. Similar techniques have been observed for high jumpers, for whom the radial velocity of the COM is negative while the vertical velocity of the COM is positive. This allows the jumper to utilize the high force generating eccentric actions of the take-off leg to produce large ground reaction forces (Dapena & Chung, 1988).

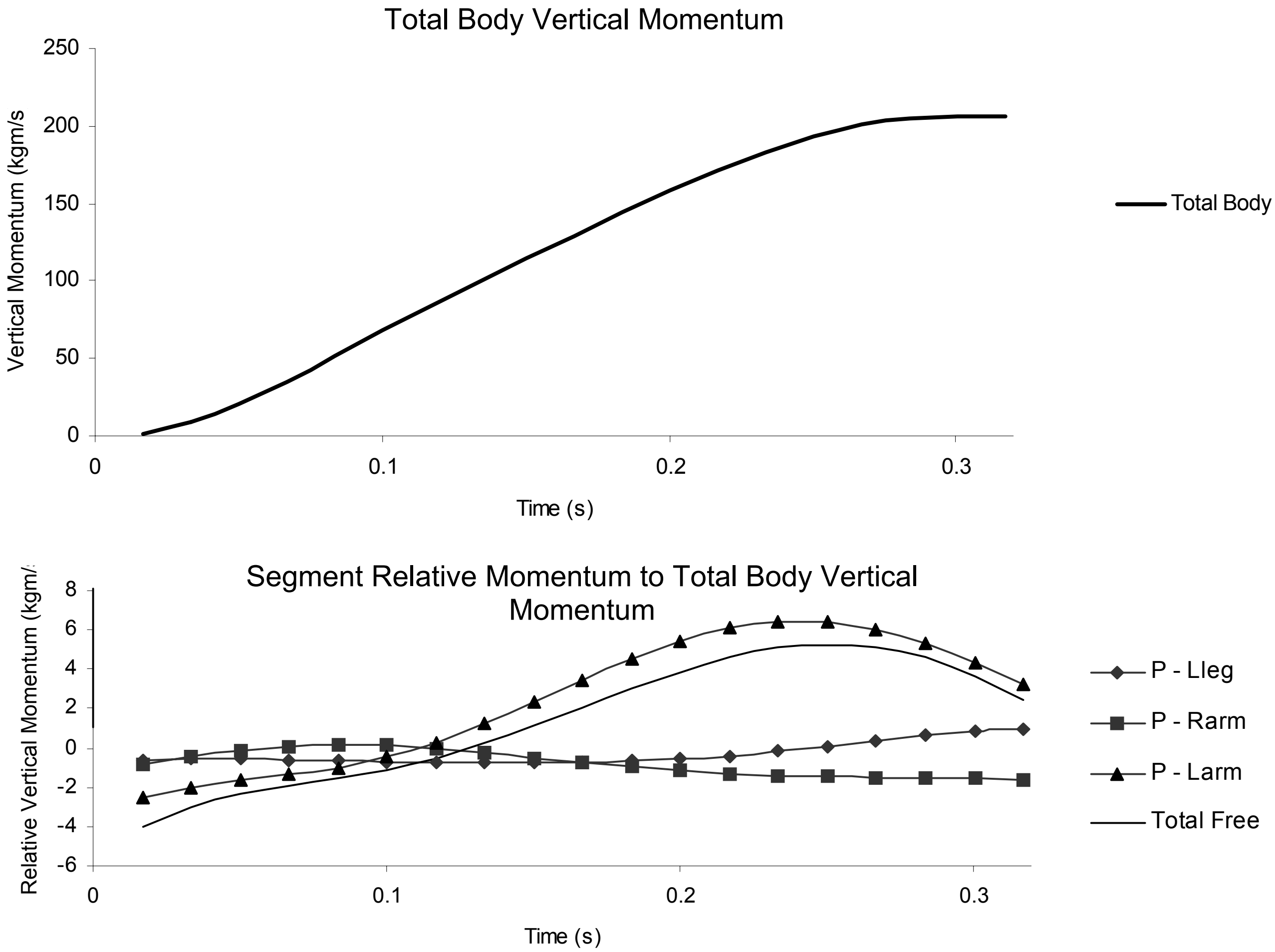

Figure 2 - Segmental relative momentum contributions to total body vertical momentum during the propulsive phase of a triple Lutz. 'Total free' is the sum of the three free limbs (both arms and non pick leg). Note the different y scales. Data are from a male skater age 21, height 1.7 m, mass 66 kg.

CONCLUSION: During the triple Lutz, skaters use the toe-pick to help generate vertical velocity for the jump. The knee of the pick leg undergoes brief and rapid flexion while the COM of the skater is rising. The movements of the free limbs make minor contributions to the generation of vertical velocity. Thus, skaters should benefit from a fast approach and a well-extended leg at toe-pick to take advantage of eccentric muscle actions contributing to vertical velocity at take-off

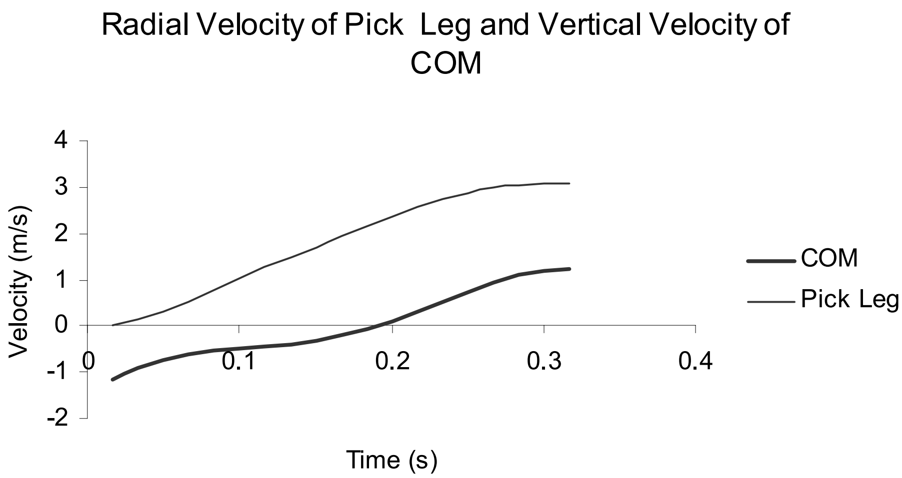

Figure 3 - Illustration of shortening of the take-off leg (negative radial velocity) during the first half of the propulsive phases while the vertical velocity of the COM is positive. Data are from a male skater age 21, height 1.7 m, mass 66 kg.

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