A Kinematic Analysis Between Triple and Quadruple Revolution Figure Skating Jump

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INTRODUCTION
To remain internationally competitive in figure skating, US athletes must be able to perform jumps consistently and safely. Male skaters in particular must be able to perform quadruple revolution jumps. Thus, coaches are challenged to distinguish between particular elements of a triple jump that must be changed to perform the quadruple. Biomechanical analyses can assist coaches in this endeavor. In the past, much emphasis has been given to increasing jump height. However, it is not known that jump height is as critical as other factors, such as moment of inertia, angular momentum, or various segmental angles (Aleshinsky, 1988; King, et. al. 1994; King, 1999a). This study will compare successful quadruple jumps to successful triple jumps of the same type performed by the same athletes to determine the critical factors for completing quadruple jumps.

METHODS
Data were collected at the 2000 State Farm National Championships in Cleveland, OH. All participants signed a consent form giving written permission to participate in the study. Height, weight, and age were recorded at this time.

Data were taken during competition and selected on ice practices. Four high speed (120-pictures/second) pan and tilt cameras (Peak Performance Technologies, Inc.) were used to film the approach through landing of selected skills. The cameras were placed approximately 90 degrees apart in the stands, so that two cameras were on each side of the rink. The cameras on the same side of the rink were gen-locked. Eight survey poles were used for the calibration of the cameras. A calibration was taken before each day of competition to ensure accuracy.

All video data were manually digitized using Peak Motus Pan and Tilt software. Only two of the four camera views were used in the analysis of each jump. Due to the fact that there are only a limited number of skaters that can perform the quadruple jumps (4 skaters attempted quads at this competition), only five toe-loops and two Salchows were performed cleanly by three different skaters. Cleanly completed triple Salchows and triple toe-loops from these same three athletes were also analyzed. Custom software written in LabView (National Instruments, Inc.) was used to analyze the jumps.

RESULTS AND DISCUSSION
In order to increase the revolutions of a jump, the skater must either jump higher or rotate faster or do both. The jump height and the air time did increase from the triple to quadruple Salchow jumps (Table 1). Additionally, angular velocity was higher at take off and in flight due to lower moments of inertia at takeoff and during flight for the quadruple Salchow as compared to the triple Salchow. Angular momentum was slightly less in the quadruple Salchow as compared to the triple Salchow.
For the toe-loop jumps, jump height and air time were very similar for both the triple and quadruple jumps. While angular momentum was slightly greater in the quadruple toe-loop as compared to the triple, the greatest difference in these jumps was the angular velocity. The angular velocity at take-off and maximum angular velocity during flight were greater for the quadruple toe loop as compared to the triple (Table 1). This was due to smaller moments of inertia at take-off and during flight. In the triple Salchow, positive vertical velocity was accompanied by rapid knee extension throughout the propulsive phase. However, in the quadruple Salchow, when the COM began to rise, the take-off leg was still flexing (Figure 1). Thus, the skater may have been utilizing the larger force producing capabilities of the quadriceps muscle during eccentric actions (whilst the knee was flexing) to generate larger ground reaction forces whilst the COM was already rising. Additionally, note that the greater vertical velocity was accompanied by a slower approach, as shown by the horizontal velocity at takeoff (Table 1).

**CONCLUSION**

To increase the revolutions of a toe-loop or a Salchow from a triple to a quadruple, angular velocity must be increased. Decreased moments of inertia permit this to happen. Angular momentum is needed to complete any level of jump; however, the trend shows that it is not increased from the triple to the quadruple. In the Salchow, vertical velocity was also increased from triple to quadruple. This lead to higher jump heights and longer flight times, allowing the extra revolution. A slower approach speed accompanied the greater vertical velocities, as did a different pattern of knee motion during propulsion. This may have allowed the skater to take advantage of eccentric muscle actions in the generation of positive vertical velocity.

**REFERENCES**


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**Table 1. Basic Characteristics of Triple and Quad Salchows and Toe-Loops.** Q = quadruple, T = triple, Vel = Velocity, Ang = Angular, TO = Take-off. Values are average ± SD, except the T Salchow where N = 1.

<table>
<thead>
<tr>
<th></th>
<th>Jump Height (m)</th>
<th>Time of Jump (sec)</th>
<th>Ang. Momentum @TO (kgm/s)</th>
<th>Moment of Inertia @ TO (kgm²)</th>
<th>Moment of Inertia min (kgm²)</th>
<th>Angular Vel @TO (rev/sec)</th>
<th>Max Angular Velocity (rev/sec)</th>
<th>Horizontal Vel @TO (m/s)</th>
<th>Vertical Vel @TO (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q Salchow</td>
<td>0.44±0.07</td>
<td>0.66±0.02</td>
<td>20.1±1.5</td>
<td>1.39±0.80</td>
<td>0.79±0.00</td>
<td>2.31±0.64</td>
<td>4.58±0.19</td>
<td>3.04±0.01</td>
<td>2.90±0.12</td>
</tr>
<tr>
<td>T Salchow</td>
<td>0.36</td>
<td>0.55</td>
<td>24.2</td>
<td>1.84</td>
<td>0.86</td>
<td>2.09</td>
<td>3.95</td>
<td>4.14</td>
<td>2.67</td>
</tr>
<tr>
<td>Q Toe loop</td>
<td>0.48±0.03</td>
<td>0.64±0.01</td>
<td>28.0±1.3</td>
<td>1.53±0.26</td>
<td>0.74±0.03</td>
<td>3.02±0.66</td>
<td>4.84±0.30</td>
<td>3.33±0.15</td>
<td>3.23±0.18</td>
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<tr>
<td>T Toe loop</td>
<td>0.47±0.01</td>
<td>0.62±0.0</td>
<td>26.1±0.9</td>
<td>1.64±0.45</td>
<td>0.90±0.18</td>
<td>2.60±1.10</td>
<td>4.58±0.08</td>
<td>4.25±0.59</td>
<td>3.24±0.21</td>
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