JUMP HEIGHT IN LADIES SINGLE FIGURE SKATING
IN THE 18TH WINTER OLYMPIC GAMES IN NAGANO 1998

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As a part of the IOC Olympic Biomechanics Research Projects conducted at the 1998 Nagano Olympic Winter Games, jump height was examined for the free program session of ladies single figure skating. Jump height varied according to the number of rotations and the type of jump. Jumps using toe-picks, such as Lutz, Flip and Toe-Loop tended to be higher than jumps involving a swinging free leg style such as the Axel, Loop and Salchow. There was no remarkable difference for the maximum jumping height among groups with different competition ranking. Though jump height tended to decrease in the latter half of the performance, the decrease was smaller in skaters with a higher standing in the competition.

KEY WORDS: figure skate, jump, endurance, IOC Biomechanics Projects, Olympic

INTRODUCTION: Although figure skating has evolved into a highly artistic sport, various kinds of jumps are the most important factor in recent competitions. In top level world competitions, almost all ladies skaters successfully complete triple jumps. For the success of the jumps with three rotations of the skaters' body, the ability to jump high and to rotate the body quickly is requisite.

In single's skating, the short program (2'40") comprises one-third of the total marks, the remainder is decided based on a free program of four minutes (± 10 seconds) for ladies. Not only the excellence of the individual jumps must be considered, but also the endurance ability of keeping the height of several jumps consistent over the course of four minutes.

There are six types of jumps in figure skating, namely Axel (AX), Flip (FL), Loop (LP), Lutz (LZ), Salchow (SL), and Toe-loop (TL). In all of the jumps, the direction of the body rotation in the air is the same and the landings are on the backward outside edge of the blade. The definition of these jumps was identified in Table 1. The Axel is the only jump that takes off moving forward. The six jumps are divided into two groups according to the usage of toe tapping during the take-off. Flip, Lutz, and Toe-Loop are the toe-tapping take-off jumps in which the jagged toe pick of the free leg is used to give a kick to the surface of the ice. Axel, Loop and Salchow are the edge take-off jumps with a swinging free leg style.

Table 1   Legend list of jumps with 2   and 3 rotations of the body in the air

Jump	Figure	Description	Name	Examples		
AX		fo 2½ T bo	Double Axel	f : forward		: outside
FL		bi ! 3 T bo	Triple Flip	b : backward		: inside
LP		bo 3 T bo	Triple Loop	o : outside		: right (outside)
LZ		bo ! 3 C bo	Triple Lutz	i : inside		: left (inside)
SL		bi 3 T bo	Triple Salchow	! : toe push		
TL		bo ! 3 T bo	Triple Toe Loop			

T : natural rotation (in the sence of a three turn)
C : counter rotation (in the sence of a counter turn)
: revolution of 360 degrees in the air
: revolution of 180 degrees in the air

(modified from ISU regulations

There have been very few studies in biomechanics of the jumping movements in figure skating. The purposes of this study were to examine the jump height during the free program of ladies single figure skating in the 18th Winter Olympic Games in Nagano '98, and to obtain the fundamental information required for successful performance in figure skating.

METHODS: Free skating in ladies single at the 18th Winter Olympic Games in Nagano '98 was recorded with a Hi-8 video camera. Recording frequency was 60 fields per second with 11500 s shutter speed. The camera was panned to follow the skater and the zoom was adjusted to get a clear image of the skater's body through four minutes of the session.

After super-imposing the field count onto the video image, duration (T: in second) from the take-off to the landing for each jump was obtained. In this study, the field immediately after the skate edge left and touched the ice was assigned as the instants of take-off and landing, respectively. Jump height (H: in meter) was estimated using the formula: $H = (g * T * T) 18$, where g is a gravitational acceleration (9.8 $m/s/s$).

Among 28 participants, 24 competitors performed in a free skating session after the short program elimination. All the individual jumps including those with a fall were examined (total number=138), except for jump combinations and jump sequences.

An analysis of variance was used to test whether jump height varied among jump types, subject groups with different competition rankings, and between the first and latter half of the session at the $p < 0.05$ level of significance.

RESULTS AND DISCUSSION:

1. Jump height and number of rotations: Table 2 shows the average jump height in conjunction with jump type and rotation number. There was a tendency for jumps with more rotations to be higher than those with fewer rotations. However height of a single Lutz was higher than for a double Lutz. Jump height does not necessarily determine the possible rotation number in the air.

2. Jump height and type of jump: Figure 1 shows the average height for jumps with 2 1/2 and 3 rotations of the body for each type of jump. Triple Lutz was the highest and was significantly higher than any of the other jumps except for Flip. The Lutz, Flip, and Toe-Loop, the three highest jumps, were all so-called "toe jumps". Because friction force on ice is extremely small in the direction of the skate's blade, it is very difficult to convert the approaching velocity into vertical direction. With toe-tapping at the take-off, kinetic energy of preparatory skating can be effectively used in the toe jumps. It could be the major reason that the toe jumps such as Flip, Lutz, and Toe-Loop were the three highest jumps. In all jumps except Lutz, the rotation of the body in the air is in the same direction as the take-off edge. The Lutz is the only jump that rotates against the take-off edge, and thus triple Lutz needs the full three rotations of the body in the air. Therefore the Lutz needs the highest jumping height of any other triple jumps.

Table 2   Average jumping height for each jump

jump		single		double		triple		total	
		1	1.5	2	2.5	3		mean	S.E.
AX	Axel		(5) 0.349		(19) 0.410			(24)	0.398	0.010
FL	Flip			(7) 0.425		(16) 0.462		(23)	0.451	0.011
LP	Loop	(2) 0.213		(6) 0.353		(14) 0.421		(22)	0.383	0.020
U	Lutz	(4) 0.446		(5) 0.421		(17) 0.518		(26)	0.488	0.020
SL	Salchow			(9) 0.310		(14) 0.387		(23)	0.357	0.013
TL	Toe-Loop			(7) 0.385		(13) 0.433		(20)	0.416	0.012

Note Values are (number of jumps) and the average jumping height for all the jumps.

3. Jump height and rank of skater: Skaters were divided into three groups according to the placing in the free program, namely group A for 1st to 8th place, group B for 9th to 16th, and group C for 17th to 24th. Figure 2 shows the average values of the maximum jump height for each skater for the three groups. There was no statistically significant difference among the three groups. The height of the highest jumps observed was 0.629 meter which were performed by four skaters, namely Malinina (UZB, 8th, Lutz), Carter (AUS, 12th, Lutz), Sebestyen (HUN, 15th, Lutz), and Rechnio (POL, 20th, Lutz).

4. Decline of jump height in latter half: Figure 3 shows the comparison of the jumping height between the first half (0-2 min) and the latter half (2-4 min) of the free-program session. There was a strong tendency for the jump height to decline in the latter half of the skating program (average: 0.448m in first half, 0.381m in latter half). There are three possible primary factors to explain the decline of jump height, namely jumps with fewer rotations, less toe-jumps, and fatigue in the latter half of the program.

5. Endurance ability in jump height and rank of skater: To investigate the effect of fatigue on the decline of the jump height in the latter half of the program, the heights of all the jumps were normalized. Each jump height was divided by the average height of the corresponding type of jump shown in the second to the last column of Table 2. Average values of We normalized jump height for each group during the first and latter half of the skating program are plotted in Figure 4. Skaters in excellent placing (group A) showed the smallest decrease of jumping height in the latter half of the program among the three groups. It is suggested that the endurance ability to maintain jump height in the latter half of the performance is best in group A.

CONCLUSION: The results of this study suggest that the success of jumps with many rotations is primarily based on a high jumping ability. Jumps using toe-picks, such as Lutz, Flip and Toe-Loop tended to be higher than jumps involving a swinging free leg style such as Axel, Loop and Salchow. There was no remarkable difference for the maximum jumping height among groups with different competition ranking. One of the key factors for good results in the free program is the endurance ability to keep the jumping height until the latter half of the performance. This study also suggests that there is every possibility of obtaining effective information using very simple methods of recording and analysis of the competition.

REFERENCE:
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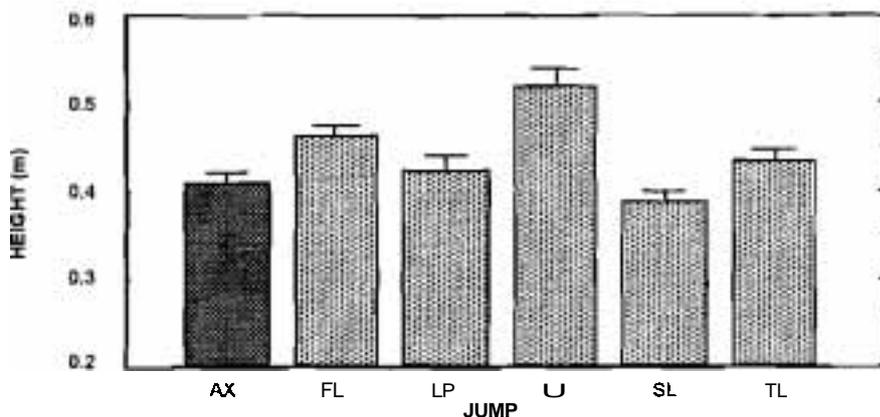

Figure 1 -Comparison of jumping height of each jump with 2112 and 3 rotations of the body
Bar graph shows average and SE value for respective jump
AX : Axel, FL : Flip, LP : Loop, U : Lutz, SL : Salchow, TL : Toe-loop
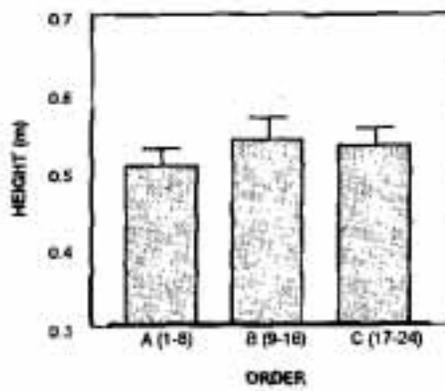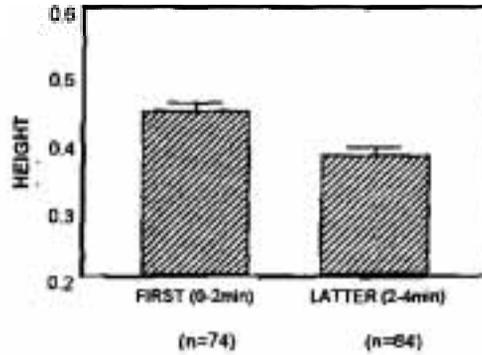
Figure 2 : Comparison of maximum jump height among three groups with different
   Graph shows average and SE values for respective group
   A : placing 1st to 8th, B : 9th to 16th, C : 17th to 24th. n=8, respectively

	FIRST (0-2min)	LATTER (2-4min)
	(n=74)	(n=84)
$2_{1/2}$ - 3 rotations	76 %	58 %
1 - 2 rotations	24 %	42 %
Flip, Lutz, Toe-Loop	62 %	36 %
Axel, Loop, Salchow	38 %	64 %

Bar graph shows average and SE value for respective time period.

Table shows the breakdown of each itemized jump.

Figure 3 · Comparison of jumping height between first half and latter half
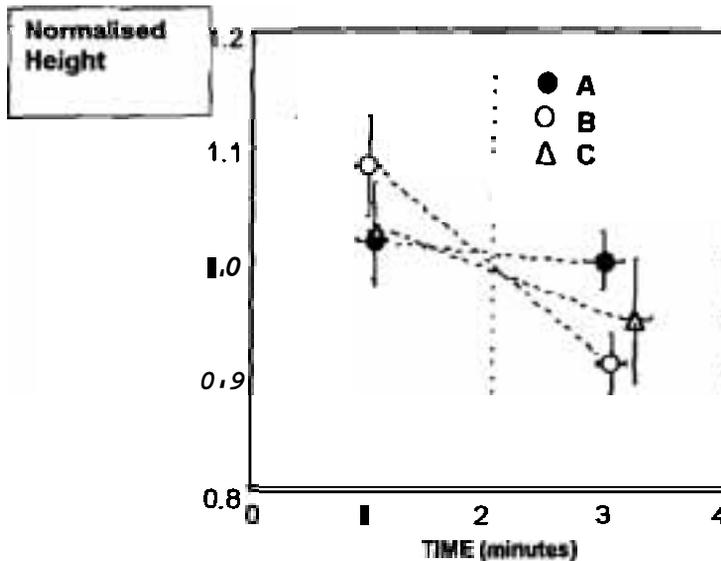

Figure 4 - Jumping height for first and latter half of skating program for three groups with different placing