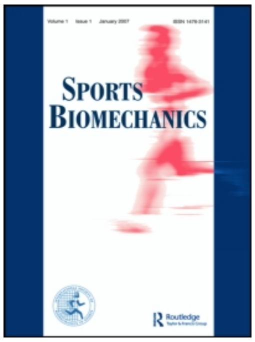

Routledge
Taylor & Francis Group

Sports Biomechanics

ISSN: 1476-3141 (Print) 1752-6116 (Online) Journal homepage: https://www.tandfonline.com/loi/rspb20

Skating

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To cite this article: Kelly L. Lockwood , Pierre J. Gervais & Donald R. Mccreary (2006) Skating, Sports Biomechanics, 5:2, 231-241, DOI: 10.1080/14763140608522876

To link to this article: https://doi.org/10.1080/14763140608522876

Landing for Success: A Biomechanical and Perceptual Analysis of On-Ice Jumps in Figure Skating

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ABSTRACT

Technical evaluation in the sport of figure skating is characterized by a subjective marking system. Figure skating judges are responsible for quickly and accurately discerning the quality of technical elements as well as assigning a score to the overall aesthetic appearance of a performance. Traditionally, overall placement marks are assigned for the entire performance; however, the landing of a jump is widely acknowledged as one of the most critical elements of a skater's program. Therefore, our aims were to identify the biomechanical variables that contribute to technical success in executing landings and to establish whether landings rated as biomechanically optimal are also awarded high technical merit scores by judges. Ten nationally ranked competitive figure skaters were asked to execute on-ice, double and triple revolution jumps and to try to land the jumps void of technical faults within a calibrated space. Data were collected at 60 Hz using standard three-dimensional videography. Data reduction was done using the APAS system (Ariel Dynamics Inc). Concurrently, videotapes were viewed and evaluated by 42 accredited judges to determine the perceived technical quality of the landing performances. Judges were asked to evaluate the landing phase of each jump against a landing criteria document. A comparative criteria model was developed to facilitate an assessment of excellence in landing performances through both empirical and subjective analyses. Results of these analyses were twofold: a biomechanical profile of on-ice landings was obtained, and on-ice jump landing strategies rated by empirical evaluations were in agreement with judge's perceptions of the same performances.

Keywords: biomechanics, figure skating, jumps, judging, landing, perception.

INTRODUCTION

In the demanding environment of competitive sport, the difference between standing on the podium and finishing in the pack can often be represented by

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fractions of a percentage point. Biomechanists, exercise physiologists, sport psychologists, engineers and computer scientists assist coaches and athletes in an attempt to unleash the athlete's ultimate performance capability. In many sports, the integration of these disciplines often translates to the competitive success of an athlete; for example, the fastest runner, the highest jumper or the athlete capable of lifting the heaviest weight. However, this is not the case in all sports. Technical evaluation in the sport of figure skating is characterized by a subjective marking system that is often scrutinized for lack of objectivity. In the competitive environment, figure skating judges are responsible for quickly and accurately discerning the quality of technical elements, as well as assigning a score to the overall aesthetic appearance of a performance based upon their perception of the performance. Therefore, judging in this sport could be defined as a measurement process without the use of quantitative measurement tools. This measurement process includes assigning numbers to specific elements in a performance with the intent of accurately representing the quality of these elements or relationships numerically. The numerical evaluation is derived by subtracting deductions owing to faults in performance from an arbitrary base score. Thus, the measurement process, defined by the International Skating Union (ISU) and put into practice by figure skating judges, is to define the rules of numerical assignment for performance errors.

Traditionally, overall placement marks are assigned for the entire performance; however, the landing of a jump is widely acknowledged as one of the most critical elements of a skater's program. In the short program, 3 of the 8 required elements are jump related and in the long program, skaters execute an average of 8–12 jumps within a 4–4:30 min period. Therefore, it is implicitly understood that jumps have the potential to affect performance scores significantly. Furthermore, because of the nature of the sport, jumps form lasting impressions that are retained in the judge's memory as marks are assigned. Thus, poorly executed landings are detrimental to a skater's score.

To date, there have been no reports of empirical evaluations of jump landings in the sport of figure skating, whether biomechanical, perceptual or technical. However in gymnastics, a similarly subjective jump-related sport, an evaluation at the 1993 World Gymnastics Championships revealed that 96% of the landings executed by senior men received point deductions for technical or perceived technical faults. This suggested that a significant number of landings were executed with what judges perceived to be less than optimal technique or control (Fink, 1993).

Modern biomechanical analyses have the ability to go beyond the perceptual domain and provide an empirical measure for proficiency in sport performances. In other sports, the relationship between mechanical variables and subjective data or perceived evaluation of performance has been studied using single-individual designs, as when analysing the mechanics of an athlete's performance in relationship to how he or she feels about their performance. Lake and Lafortune (1998) studied the relationship of mechanical inputs and the perception of lower extremity impact loading severity using a human pendulum apparatus and found high correlations between the mechanical input variables and subjective ratings. Different running-related studies show that high correlations exist between subjective impact perception and biomechanical variables that are associated with running injuries (Milani *et al.*, 1977). However, comparing an athlete's mechanical variables to an evaluator's perceptions of his or her performance adds another dimension that remains unclear and invites further investigation.

In this study, on-ice jump landings were evaluated by the traditional method of a judge's perception of performance and then compared to the outcomes of biomechanical analyses of excellence. The aims of the study were to identify the biomechanical variables that contribute to technical success in executing on-ice landings and to establish if on-ice landings rated as biomechanically optimal are also awarded high technical merit scores by judges. This would be reflected by biomechanical landing profiles that illustrated optimal landing mechanics being positively correlated with the judge's perception of technical excellence.

METHODS

Experimental design

Ten nationally ranked competitive figure skaters and 42 nationally accredited Canadian figure skating judges consented to participate in the study. Data were collected in two phases. During Phase I, the skaters were videotaped executing on-ice, double or triple revolution jumps. The skaters were asked to try to land their jumps without technique fault. Success was defined as landing backwards on one foot upon completion of the required number of revolutions, while maintaining the speed and control possessed at jump take-off. To facilitate a homogeneous sample of data, only those jumps in which the landing phase conformed to the operational definition of a successful landing were assessed. For example, falls or two foot landings were not included. Furthermore, only those jumps that completed the landing phase in the assigned calibration space were considered for analysis. As suggested by Stergiou (2004), although more than one trial per person is preferred for biomechanical studies, it is often the case that the participant's safety owing to potential fatigue effects has to be carefully considered. Furthermore, as was the case here, a study may address comparisons between subjective and objective measures of performance, exclusive of whether or not the individual performance captured the skater's typical performance. Therefore, a single jump was selected for each skater based on a subjective evaluation of the best technical merit.

During Phase II of the study, the videotapes of a landing performance by each of the 10 skaters were analysed by two methods for comparison; first, biomechanically, using motion analysis computer software and, secondly, perceptually, by accredited figure skating judges as described below.

Biomechanical analysis

Before videotaping, skaters were fitted with lightweight retro-reflective markers placed on 19 standardized anatomical landmarks to facilitate subsequent biomechanical analysis (Clauser *et al.*, 1969). Three-dimensional videography was conducted using two JVC DVL-9800 digital video cameras operating at 60 Hz

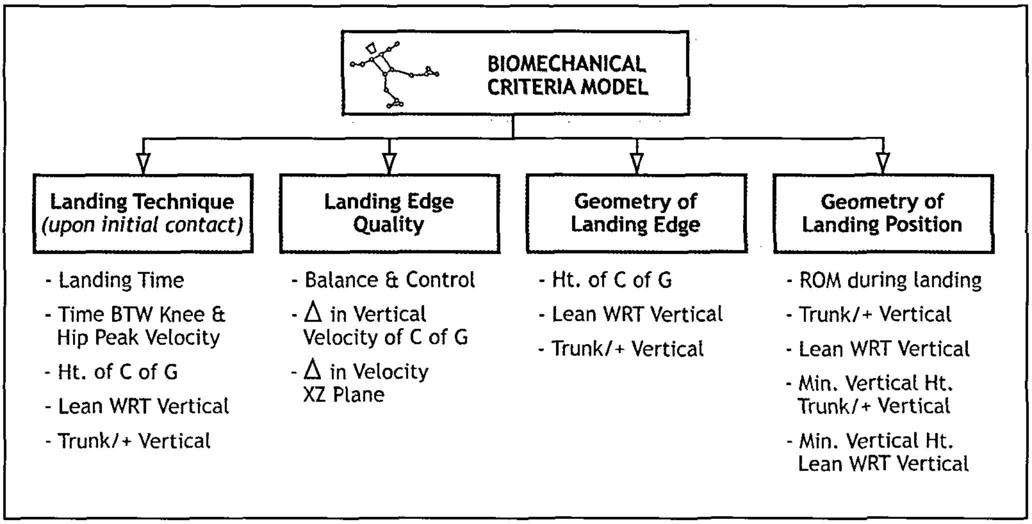

Figure 1 Biomechanical criteria model including four categories of mechanical variables defined to evaluate success jump landings (BTW = between; WRT = with respect to).

and a shutter speed of 1/250 s. The cameras were positioned so that two oblique views of the object space were captured. Because the landing was primarily planar, these two views provided adequate field coverage of the skaters during their landings. The frame rate of 60 Hz was deemed sufficient to capture data required to calculate the select biomechanical measures. Skaters were asked to perform their jumps within a calibrated jump space and to stick their landings - to attempt to land with no technique faults that would result in technical or aesthetic deductions. Only landings executed successfully were used for further analysis. An Ariel Performance Analysis System (APAS, Ariel Dynamics Inc.) was used for data reduction. Three-dimensional coordinates of 19 body points were calculated by combining the video images of two cameras utilizing the direct linear transformation (DLT) method (Abdel-Aziz and Karara, 1971). Selected kinematic measures were calculated to profile on-ice landings biomechanically as listed in Figure 1. A biomechanical criteria model was then developed by grouping the independent kinematic measures into four categories as illustrated in Figure 1. Categories included landing technique, landing edge quality, the geometry of the landing edge, and the geometry of the landing position. These four categories of biomechanical variables were deemed to be critical descriptors of success in on-ice landings.

Judges' perceptual analysis

Videotapes were viewed and evaluated by 42 accredited judges to determine the perceived technical and aesthetic quality of the ten landing performances. Judges viewed the videotapes in a private and quiet room. Replays were permitted as required to complete a thorough examination of each jump performance. Judges were asked to evaluate the landing phase of each jump using a landing criteria document (Table 1). This document included eighteen variables (Q1–Q19) grouped into five categories (Overall Landing Performance, Landing Technique, Landing Edge Quality, Geometry of Landing Edge and Geometry of Body Position). Question 9 (Q9) was eliminated as it was not possible to decipher the sound on video taped performances. The variables in the criteria document were congruent with variables used during the competitive judging of national events. The only difference was that the jumps assessed in the study were performed in isolation as opposed to within a choreographed program. The first category (A) was created to represent the judges' perception of the overall landing performance. The following four categories (B–E) were parallel to the categories defined in the biomechanical criteria model (Landing Technique, Landing Edge Quality, Geometry of Landing Edge and Geometry of Landing Position). All variables within each category were scored on a five-point Likert scale, with 1 being weak and 5 being a strong rating. Average scores along each of the five categories were computed for each of the 10 jump landings assessed. The perceptual criteria model, therefore, included these five categories of descriptive variables and defined the critical descriptors of on-ice landings as illustrated in Table 1.

Table 1 Comparative model illustrating categories of critical descriptors of landing performance defined within the judges' criteria document.

Comparative categories	*Judges criteria ratings*
A Overall Landing Performance	Q1 – Entire Landing Q2 – Completed Rotation
B Landing Technique Upon Initial Contact	Q3 – Toe to Edge Sequencing Q4 – Position Q5 – Stability – Balance over landing foot Q6 – Flow
C Landing Edge Quality	Q7 – Control Q8 – Smoothness Q9 – Sound Q10 – Speed
D Geometry of Landing Edge	Q11 – Arc Q12 – Length of Landing Arc Q13 – Alignment
E Geometry of Body Position	Q14 – Skating Leg Action Q15 – Free Leg Action Q16 – Free Leg Extension Q17 – Trunk Q18 – Arms Q19 – Eye and Head Focus

*Q9 eliminated owing to no sound on video tape.

Comparative model development

To determine the relationship between mechanical excellence or kinematic variables and perception of success in on-ice landings, a comparative model was developed which tried to compare the qualities of the skill being measured biomechanically to the subjective evaluation of the skill by the judges (Figure 2). This model attempted to equate the variables within the four categories of biomechanical critical descriptors to the five categories of perceptual critical descriptors of success in on-ice landings. Figure 2 illustrates the relationship between specific biomechanical variables as illustrated in Figure 1 to the corresponding perception variables outlined in the judge's criteria document (Q1–Q19) as illustrated in Table 1.

Statistical analysis

Statistical strategies included computing composite scores to assess the relative contribution of select performance variables within each of the categories to the overall performance ratings within and between the biomechanical and judge's perception data. Spearman rank order correlations were performed to assess the degree of associations of five categories of judges jump perceptions. Spearman rank order correlations were also performed to determine the association between the biomechanical evaluation of landing mechanics and the judge's perception of excellence in landing performances. An alpha level of 0.05 was set for significance.

RESULTS

Biomechanical analysis

As illustrated in Figure 1, independent kinematic variables were computed and then combined into four categories to profile the biomechanical characteristics of on-ice landings to be entered into further analyses. Significant correlations were found between related categories indicating their degree of inter relationship ($r = 0.661$–$0.818, p < 0.01$).

Perceptual analysis

Spearman rank order correlations revealed strong correlations among judges' scores. The first analysis indicated that overall perception of landing performance was highly correlated with each of the four categories of critical descriptors ($r = 0.95$–0.99, $p < 0.01$). Furthermore, there was a strong association among each of the categories (Landing Technique, Landing Edge Quality, Geometry of Landing Edge and Geometry of Body Position) ($r = 0.94$–$0.99, p < 0.01$). These results suggested two things: first, a strong association or consistency exists among the judges' perceived ratings of the ten isolated jump performances analyzed, and, secondly, a strong association or consistency existed between the judge's perceptions of the jump dimension categories and their overall perception of the on-ice landing performance.

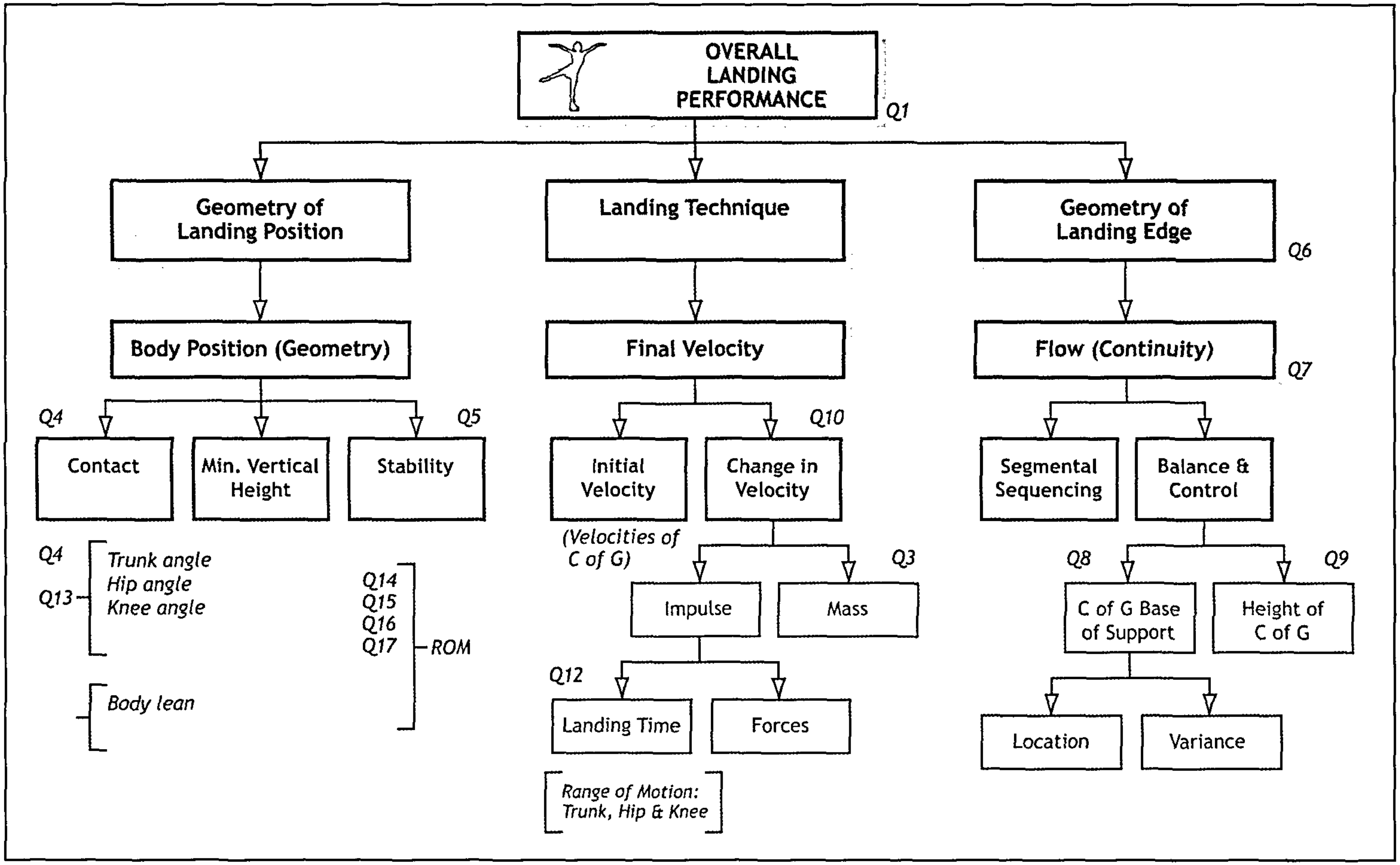

Figure 2 Combined model of relationships between perceptual and biomechanical variables.

Correlations between biomechanical and perceptual data

Spearman rank order correlations were then performed between the biomechanical and perceptual average scores to determine the association between the biomechanical evaluation of landing mechanics and the judge's perception of excellence in landing performances (Figure 2); however, no statistically significant relationships were found. Correlations represented only a small and insignificant overlap that goes beyond the lack of power resulting from a small sample size of jumps assessed. Because of the weak association between biomechanical assessment of quality and the judges' perceptions, we sought to refine the biomechanical ratings for further analysis.

Secondary comparative analysis

On-ice landings can be described as a complex series of dependent movements. Because of the statistical analysis performed, data were treated as isolated, independent entities. An attempt was made to identify a relationship or association between isolated categories of mechanical variables and a score representing perception of performance. Given the dependence of the categories of variables, it was not surprising to find a null relationship. Because of the non-significant results as stated above, a second analysis was explored. From the biomechanical measures computed, six independent, yet complementary, biomechanical variables were selected as key performance indicators. Table 2 outlines the variables and descriptions of their relative optimal performance characteristics.

Using these characteristics, the data were re-grouped to identify biomechanical strategies used by the athletes in executing on-ice landings. For example, the range and sequence of motion among the various joints, such as the ankle, knee and hip, described the strategy, or technique, that was used in the landing phase of the jump to dissipate the impact forces at landing while maintaining balance, control and the aesthetic demands of the sport. Three specific landing strategies were identified as being predominant among the ten landing performances analyzed. Landing strategies were defined by the sequence of movement, as well as the range of motion of the lower extremity joints – the ankle, knee and hip. Figure 3 illustrates the angles assessed. The hip strategy had primarily hip movement with little movement of the support leg during the landing. The knee strategy had more knee movement than hip movement during the landing. Finally, the shared strategy was defined as approximately equal hip and knee movements during the landing. Pearson product moment correlations were conducted between the specific landing strategies and judges' overall performance scores. This analysis revealed significant correlations ($r = 0.818$–0.944, $p < 0.01$). Landing techniques deemed biomechanically proficient or those landings that adopted one of the three strategies were significantly correlated with the judge's perception of excellence or, more simply, specific strategies were identified as being rewarded highly. Jump landings that could not be clearly identified as using one of the three strategies were not evaluated as favourably by the judges. Because of the small number of jumps analyzed ($n = 10$), it was

Table 2 Six biomechanical key performance indicators in on-ice landings.

Biomechanical key performance indicators	*Description of optimal condition*
1. Balance and Control	Values near 0 indicate a stable-controlled landing with little body swaying over the base of support (support foot).
2. Change in Vertical Velocity of Centre of Mass (CoM)	To optimize safety and control, the change in vertical velocity of the CoM should be large during the landing phase. However, this value should also be accompanied by a large landing time.
3. Stability	Dissipating the landing momentum using the hip allows for less variance in the free leg and is aesthetically more appealing.
4. Landing Time	For safe landings, the force needs to be dissipated over a long period.
5. Knee to Hip Time Sequence	This variable relates to segmental sequencing. The shorter the time, the more simultaneous the movement versus a strategy that is more sequential, using a greater time.
6. Body Position Geometry during Landing	Angular positions as related to Body Geometry during the landing phase of the jump (see Figure 3).

impossible to further assess which one of the three strategies was preferred by the judges.

In summary, significant correlations were revealed within the four categories of biomechanical variables (Figure 1) and within the five categories of perceptual variables (Table 1). These results suggested a strong association between related categories within biomechanical and within perceptual categories. Furthermore, a strong agreement existed between the 42 judges' perceived ratings of an isolated jump performance. It appears that the strategy, rather than the isolated mechanical variables, was the most important factor in determining the relationship between mechanics of jump landing and perception of performance. In addition, six biomechanical measures identified as key performance indicators, significantly contributed to the definition of landing strategies (Table 2).

Discussion and Implications

Objectively figure skating judging has been challenged routinely in competition. Accusations of bias have been brought from a variety of sources. Clearly, figure skating must seek remedies to judging bias and score fixing if the sport is to remain as a viable and attractive competitive activity for athletes and spectators.

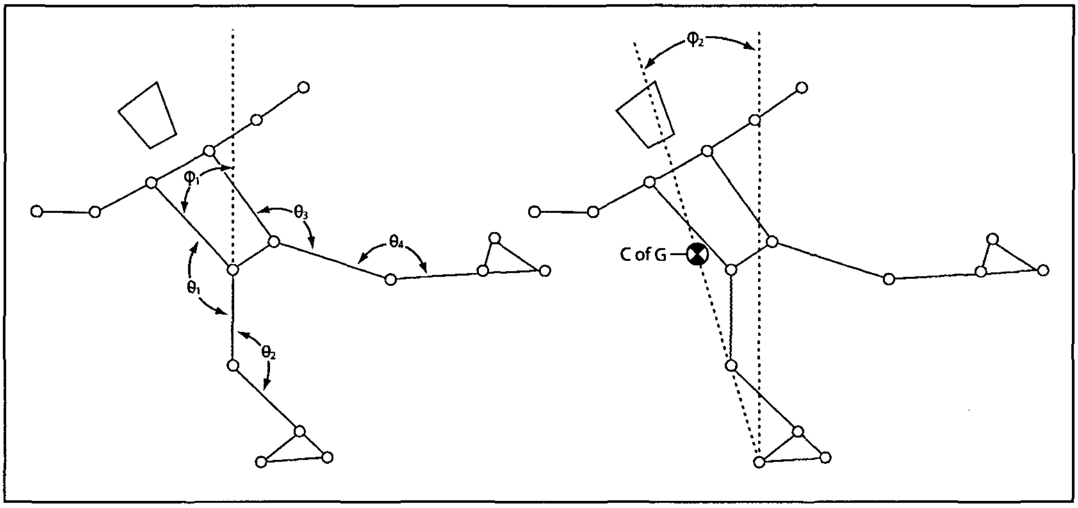

Figure 3 Body Position Geometry (Angular Position): φ_1 Trunk segment angle; φ_2 Body lean angle: θ_1 Support leg hip angle; θ_2 Support leg knee angle; θ_3 Free leg hip angle; θ_4 Free leg knee angle.

One method of resolution is to analyze judges' scores. However, such an assessment is extremely difficult owing to the lack of a sufficient 'gold standard' to compare scores. Therefore, this study was conducted to provide support for the notion that jump landings rated by subjective evaluation are in agreement with empirical evaluations of the same performances. The biomechanical analysis served to provide an empirical 'gold standard' against which perceptual data could be compared. Although on-ice jumps are not evaluated in isolation in competition, technical faults are assigned to jumps as elements of the program. Under the traditional 6.0 based scoring system, the performer starts with a base score from which deductions are made for performance faults. General deductions are made for faults including technical violations, form or positional violations. Major deductions are also taken for landing violations including falls or two foot landings. In the present study, all jumps selected for evaluation and analysis were executed successfully or void of major technical violations, that is without touchdowns or falls. As a result of this study, significant correlations within the perceptual data set provided support for consistency of subjective evaluations performed by accredited judges when analyzing jump landings. Although the biomechanical analyses of landings did not reveal that any one isolated category of mechanical variables was highly related to the judges' perceived rating of landing performance, optimal strategies of proficient on-ice landings were identified. Three specific landing strategies used were in agreement with the judges' perception of 'excellence' of landing performance. Thus, support was revealed for the notion that strategies executed during successful jump landings rated by subjective (judge's perception) evaluations are in agreement with empirical (biomechanical) evaluations of the same performances.

CONCLUSION

The purpose of this study was to compare empirical and perceptive evaluations of figure skating jumps. The correlations between biomechanical landing strategies and judges' evaluations provided a means of support for the subjective method of assessment currently used in the sport of figure skating. Furthermore, understanding the strategies used by successful landing performances is of value to coaches and athletes as both coaching and evaluative tools.

ACKNOWLEDGEMENTS

The authors would like to thank Skate Canada Sport Science Committee for providing partial funding for the project, and the skaters and judges who volunteered their time, skills, and expertise.

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