ORIGINAL ARTICLE

Correlation between kinematic features and grade of execution in pair skating throw jumps: A case study at the World Figure Skating Championships

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ABSTRACT

Throw jumps represent a distinctive technical element in pair figure skating; however, the kinematic determinants underlying the grade of execution (GOE) remain unclear. Previous studies in ladies' single skating have demonstrated that greater horizontal distance and higher post-landing skating speed are associated with higher GOE scores. However, throw jumps involve a partner-assisted take-off, suggesting that the factors influencing execution quality may differ from those observed in single skating. This study examined the relationships between GOE and kinematic variables in triple throw jumps performed at the 2023 World Figure Skating Championships. Twenty-three jumps that received non-negative GOE scores from all nine judges were analysed. Vertical height, horizontal distance, take-off speed, and skating speed after landing were quantified using a broadcast-based tracking system, and GOE values were calculated as a trimmed mean. Across all jumps, GOE demonstrated significant positive correlations with vertical height and skating speed after landing. In edge-type jumps, vertical height showed a strong association with GOE, whereas no significant relationships were observed for toe-type jumps. These findings provide quantitative evidence that judges' GOE scores in competition reflect specific kinematic indicators, advancing the objective understanding of subjective evaluation in pair skating.

Keywords: Performance analysis, Sports performance, Artistic sports, Judged sports, Performance evaluation, Tracking system, Sports analytics.

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INTRODUCTION

Figure skating comprises three disciplines: singles, pairs, and ice dance. Among these, jumps represent a fundamental technical element in singles and pairs, whereas they are prohibited in ice dance (Vescovi & VanHeest, 2018). In pair skating, skaters perform side-by-side jumps where partners execute the same jump simultaneously, and throw jumps, in which the male skater launches the female partner into the air (Madsen et al., 2024). Throw jumps are a distinctive and essential element unique to pair skating and play a critical role in competitive performance.

The scoring system for figure skating was revised following a judging scandal at the 2002 Salt Lake City Olympics, leading to the introduction of the International Skating Union (ISU) Judging System (IJS) in 2004. In the previous 6.0 system, technical performance was evaluated relatively based on the overall impression, and skaters were scored on a scale ranging from 0.0 to 6.0 in 0.1-point increments. In contrast, under the IJS, each element is assigned a predefined base value according to its difficulty, and execution quality is quantified through the Grade of Execution (GOE) (Zitzewitz, 2006, 2014). In the current system, GOE is evaluated using an 11-point scale ranging from −5 to +5. The final GOE is calculated using a trimmed mean by excluding the highest and lowest scores awarded by nine judges.

Similar to single skating, the criteria for a positive GOE in throw jumps emphasise kinematic features such as height and distance, as well as creativity and musicality (Table 1). Even in the criteria related to the kinematic aspect, subjective terms such as “*good*” are used, allowing for individual judge interpretation. Therefore, clarifying the kinematic characteristics that contribute to higher GOE scores would provide valuable insights for skaters and coaches.

Rauer et al., (2022) reported a significant upward trend in the average total scores of the top five pair teams at the Olympics, World Championships, and European Championships since 2005. While the number of triple side-by-side jumps performed at the World Championships has increased over time, the number of rotations in throw jumps has remained relatively unchanged. This indicates that executing higher-quality throw jumps at the elite level, reflected in higher GOE, even when the difficulty level remains constant, has become an increasingly important factor for distinguishing performance among top pairs.

Previous studies on pair skating have primarily focused on injury incidence and characteristics (Dubravcic-Simunjak et al., 2003; Kowalczyk et al., 2021; Madsen et al., 2024; Smith & Ludington, 1989) as well as off-ice physical capacities such as power (Sands et al., 2012) and balance ability (Colby et al. 2023). In contrast, studies focusing on technical performance unique to pair skating remain limited. For example, research on twist lifts has shown that rotational speed is a more critical factor than jump height in increasing the number of revolutions. (D. L. King et al., 2008).

Most technical performance studies in figure skating have focused on jumps performed by single skaters. D. L. King et al. (1994) stated that theoretically, jumping as high as possible while rotating as quickly as possible is the best technique to maximise the number of revolutions completed in the air. However, in practice, several studies have reported that skaters achieve difficult jumps primarily by increasing rotational speed rather than jump height (Arnold et al., 1994; D. L. King et al., 1994; Albert & Miller, 1996;D. King et al., 2004; Mazurkiewicz et al., 2018). Based on these findings, Ridge et al., (2022) examined the effectiveness of weighted gloves in enhancing rotational speed. However, studies focusing on skaters attempting high-difficulty jumps with few successful examples suggest that greater jump height may be essential for skill acquisition (Aleshinsky et al., 1988; Hirosawa, 2025; D. King et al., 2004) indicating that the required kinematic characteristics may vary depending on the level of jump proficiency. Research comparing jump types has shown that top-level female skaters achieved greater jump height during toe jumps (Lutz, Flip, and Toe loop) than during edge jumps (Salchow and Loop), likely because toe-tapping at take-off allows the kinetic energy of preparatory skating to be utilised more effectively.(Sakurai et al., 1999). Furthermore, a recent review suggested sex-related differences in jump characteristics, with male skaters more commonly performing higher-rotation jumps and female skaters tending to show greater angular velocity and flexibility(Sperlich et al., 2026).

Regarding GOE, previous studies focusing on single skating have shown that, in women's double Axel jumps, greater horizontal distance and skating speed after landing are associated with higher GOE (Hirosawa, 2025; Hirosawa et al., 2022). These findings suggest that, in single skating, judges may place greater emphasis on post-take-off displacement and post-landing flow than on vertical height alone when evaluating execution quality. Furthermore, it has been reported that models predicting GOE based on kinematic characteristics (Hirosawa, 2025) achieve higher accuracy than GOE assessments made by novice-level judges (Hirosawa et al., 2025, 2023). This finding highlights the potential utility of kinematic data as an objective framework to complement the inherently subjective nature of execution evaluation in judged sports. Recent scoping reviews have also highlighted the growing use of wearable sensors, marker less computer vision, and pose-based deep learning in figure skating performance analysis.(Drazdova, 2026) However, competition-based kinematic evidence on pair-specific elements such as throw jumps remains scarce.

Given the partner-assisted nature of the take-off in throw jumps, these relationships may differ from those reported in single skating. According to the ISU criteria for positive GOE (Table 1), throw jumps are evaluated based on elements such as "*very good height and distance*" and "*good speed, flow, and control on release and landing*." In line with these evaluation criteria, the present study hypothesized that multiple kinematic variables, including vertical height, horizontal distance, take-off speed, and landing speed, would each show positive associations with GOE in pair throw jumps.

Therefore, the purpose of this study was to examine the relationships between kinematic characteristics and GOE in triple throw jumps performed in the pair skating discipline at the 2023 World Figure Skating Championships, treating GOE as a case study and treating GOE as a competition-relevant performance indicator.

Table 1. Criteria for the positive aspects of grade of execution (GOE) (International Skating Union, 2022).

Pair skating (throw jumps)	Single skating (jump elements)
Very good height and very good distance	Very good height and very good length
Good speed, flow, and control on release and landing	Good take-off and landing
Effortless throughout	Effortless throughout
Difficult, unexpected, or creative entry	Steps before the jump; unexpected or creative entry
Very good air position	Very good body position from take-off to landing
Element matches the music	Element matches the music

Note. FOR + 1: one bullet, FOR + 2: two bullets, FOR + 3: three bullets, FOR + 4: four bullets, FOR + 5: five or more bullets. FOR + 4 and +5, the first three bullets must be present.

MATERIALS AND METHOD

Data sample

This study focused on triple throw jumps performed during the short program and free skating segments of the pair event at the 2023 World Figure Skating Championships in Saitama, Japan. We included only jumps that received non-negative GOE scores from all nine judges and excluded any jump with a negative score from at least one judge. As part of this case study, the data sample comprised 23 valid triple throw jumps performed by 16 pair teams (male: mean age = 26.44 ± 3.78 years; female: mean age = 22.81 ± 5.71 years): 16 edge jumps (Salchow: 5, Loop: 11) and seven toe jumps (Flip: 2, Lutz: 5). The GOE scores were obtained from the official ISU competition results (International Skating Union, 2023). We calculated the GOE as a trimmed mean by removing the highest and lowest scores from the nine judges' evaluations, which were based on an 11-point scale ranging from −5 to +5. Consequently, the theoretical range of the GOE variable in this analysis is 0 to 5.

The explanatory variables comprised four kinematic features extracted from the broadcast-oriented tracking system Ice Scope: vertical height (m), horizontal distance (m), take-off speed (m/s), and landing speed (m/s). This system was introduced by the Fuji Television Network, which holds broadcasting rights for certain competitions, to help viewers better understand skaters' technical performance. The data obtained from this system are not used for official judging purposes. The system employs two 4K cameras (3840 × 2160 pixels) recording at 30 frames per second (fps), and the cameras are positioned to capture the entire 60 × 30 m skating rink. Using the rink layout, it estimates real-world coordinates for each pixel based on the two-dimensional direct linear transformation method.

- Vertical height (m): The maximum vertical value measured from the frame where the toe-pick leaves the ice at take-off to the frame where it contacts the ice upon landing.
- Horizontal distance (m): The horizontal displacement measured between the frame of toe-pick take-off and the frame of landing contact.
- Take-off speed (m/s): This is calculated from the skating distance covered during the five frames preceding the frame in which the toe-pick fully leaves the ice. Given that the system records at 30 fps, each frame corresponds to approximately 0.033 s. Take-off speed is obtained by dividing the total distance by the elapsed time. This value is not publicly disclosed through media broadcasts and was provided directly to the researchers by the company.
- Landing speed (m/s): This is calculated from the skating distance covered during the five frames following the frame in which the heel edge fully contacts the ice upon landing. As with take-off speed, each frame represents approximately 0.033 s. Landing speed is derived by dividing the measured distance by the elapsed time.

This system is intended for real-time use in broadcast footage and is not a high-precision motion capture system designed for controlled experimental environments. Despite its limitations in measurement accuracy, data obtained from this system have been reported in several peer-reviewed publications (Hirosawa, 2025; Hirosawa et al., 2023, 2022).

Statistical analysis

The normality of each variable was assessed using the Shapiro–Wilk test. For normally distributed variables, Pearson's product-moment correlation coefficients were calculated to examine the relationships between GOE and the kinematic variables. Statistical significance was set at 5%. Given the small sample size, nonparametric bootstrapping was employed to assess the robustness of the correlation estimates. Specifically, for each variable, 1,000 bootstrap samples were generated with replacement, and Pearson's correlation coefficient was computed for each iteration. The 2.5th and 97.5th percentiles of the resulting distribution were used to derive the 95% confidence intervals (CIs). In addition, simple linear regression analyses (ordinary least squares) were performed to quantify the associations between GOE and each kinematic variable. Unstandardized regression coefficients and their 95% confidence intervals were estimated, and the regression lines were visualized with 95% confidence intervals of the mean response.

Analyses were conducted on all jumps combined and separately for edge-type and toe-type jumps. All statistical procedures were performed using Python (version 3.11.13; Python Software Foundation, Wilmington, DE, USA) with the Statsmodels package (version 0.14.4).

RESULTS

Table 2 presents the means, standard deviations, and ranges for throw jumps and result of Shapiro-wilk test. Theoretically, the GOE scores range from 0.000 to 5.000. However, the observed values in this sample ranged from 1.000 to 4.000. None of the variables showed significant deviations from normality at the 5% significance level, indicating that all variables were normally distributed.

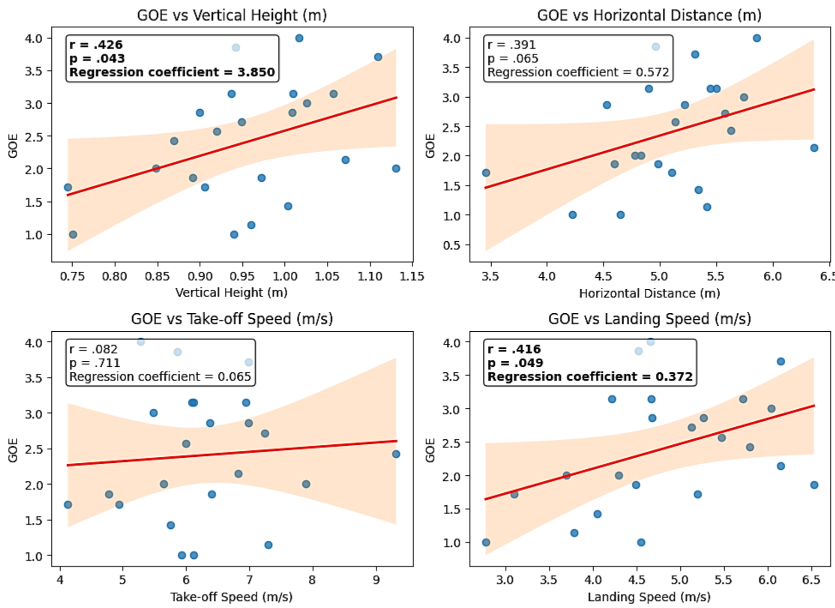
Table 2. Summary of descriptive statistics for throw jumps and result of Shapiro-Wilk test.

Variables	**Mean ± SD**	**Range**	**Shapiro–Wilk test *p*-value**	
Vertical height [m]	0.955 ± 0.098	0.745–1.131	.684	
Horizontal distance [m]	5.111 ± 0.607	3.457–6.364	.711	
Take-off speed [m/s]	6.278 ± 1.108	4.132–9.323	.567	
Landing speed [m/s]	4.820 ± 0.991	2.771–6.527	.821	
GOE	2.404 ± 0.888	1.000–4.000	.493	
	Edge-type jumps (N = 16)		**Toe-type jumps (N = 7)**	
Variables	**Mean ± SD**	**Range**	**Mean ± SD**	**Range**
Vertical height [m]	0.938 ± 0.100	0.745–1.071	0.993 ± 0.088	0.920–1.131
Horizontal distance [m]	5.177 ± 0.711	3.457–6.364	4.960 ± 0.218	4.653–5.310
Take-off speed [m/s]	6.332 ± 1.311	4.132–9.323	6.157 ± 0.432	5.643–6.981
Landing speed [m/s]	4.780 ± 0.890	3.094–6.144	4.912 ± 1.267	2.771–6.527
GOE	2.321 ± 0.832	1.000–4.000	2.592 ± 1.048	1.000–3.857

Table 3. Pearson's correlation coefficients between GOE and kinematic variable for throw jumps.

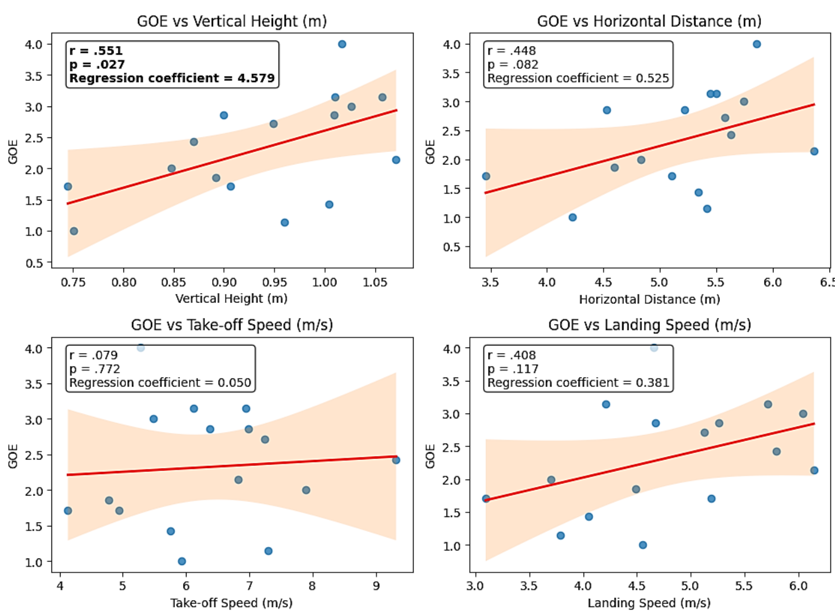
	All throw jumps (N = 23)		
Variables	**Corr.**	***p*-value**	**Bootstrap 95% CI**
Vertical height [m]	.426	.043	0.088 to 0.707
Horizontal distance [m]	.391	.065	0.084 to 0.684
Take-off speed [m/s]	.082	.711	−0.260 to 0.409
Landing speed [m/s]	.416	.049	0.025 to 0.703
	Edge-type jumps (N = 16)		
Variables	**Corr.**	***p*-value**	**Bootstrap 95% CI**
Vertical height [m]	.551	.027	0.184 to 0.834
Horizontal distance [m]	.448	.082	0.074 to 0.745
Take-off speed [m/s]	.079	.772	−0.368 to 0.468
Landing speed [m/s]	.408	.117	0.027 to 0.725
	Toe-type jumps (N = 7)		
Variables	**Corr.**	***p*-value**	**Bootstrap 95% CI**
Vertical height [m]	.098	.834	−0.705 to 0.760
Horizontal distance [m]	.684	.090	−0.089 to 0.998
Take-off speed [m/s]	.262	.571	−0.842 to 0.832
Landing speed [m/s]	.419	.349	−0.748 to 0.968

Table 3 summarises the Pearson correlation coefficients, p-values, and 95% CIs obtained from bootstrapping for the relationships between each kinematic variable and GOE. The corresponding scatterplots with regression lines and 95% confidence intervals of the mean response are shown in Figure 1,2,3. In terms of all throw jumps, moderate and statistically significant positive correlations were observed for vertical height and landing speed. In addition, horizontal distance showed a moderate positive correlation with GOE, but this correlation was not statistically significant in the current sample. Nonetheless, the 95% CI from the bootstrap analysis did not include zero, indicating a potentially meaningful association. No significant correlation was observed between take-off speed and GOE.



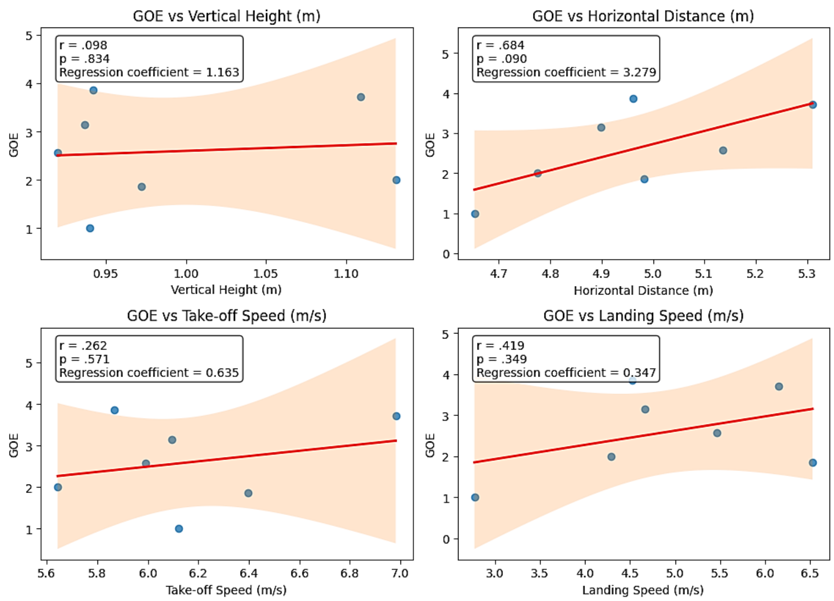
Note. Scatterplots showing the relationships between GOE and each kinematic variable. Solid lines indicate ordinary least squares regression lines, and shaded areas represent the 95% confidence intervals of the mean response.

Figure 1 Relationship between GOE and kinematic variables in clean triple throw jumps.



Note. Scatterplots showing the relationships between GOE and each kinematic variable. Solid lines indicate ordinary least squares regression lines, and shaded areas represent the 95% confidence intervals of the mean response.

Figure 2 Relationship between GOE and kinematic variables in edge-type triple throw jumps.



Note. Scatterplots showing the relationships between GOE and each kinematic variable. Solid lines indicate ordinary least squares regression lines, and shaded areas represent the 95% confidence intervals of the mean response.

Figure 3. Relationship between GOE and kinematic variables in toe-type triple throw jumps.

In edge jumps, a statistically significant positive correlation with a large effect size was observed for only vertical height. Horizontal distance and landing speed showed moderate positive correlations with GOE; however, these were not statistically significant in the current sample. However, their 95% CIs based on bootstrapping did not include zero, indicating potentially meaningful associations. No correlation was observed between take-off speed and GOE. In toe jumps, none of the kinematic variables were significantly correlated with GOE. Notably, the correlation pattern differed from that of edge jumps: vertical height showed virtually no correlation with GOE, whereas horizontal distance exhibited a relatively stronger association.

DISCUSSION

In this study, we investigated the relationship between kinematic variables obtained from a broadcast-based tracking system and the GOE for throw jumps in pair figure skating. Given the limited sample size, Pearson's correlation analysis and nonparametric bootstrapping were employed to enhance the reliability of our findings.

Across all jumps, vertical height and landing speed exhibited moderate, statistically significant positive correlations with GOE. Horizontal distance showed a moderate correlation with GOE, but this distance was not statistically significant; however, its bootstrap-based CI excluded zero, suggesting a potential association. Take-off speed showed no meaningful correlation with GOE.

The ISU criteria for positive GOE include elements such as "*very good height and very good distance*" and "*good speed, flow, and control on release and landing*;"; however, our findings suggest that judges prioritise vertical height over distance and place greater emphasis on the flow after landing than on the speed before release. Compared to previous findings in women's single skating, where greater horizontal displacement was associated with higher GOE (Hirosawa et al., 2022), throw jumps appear to be more influenced by vertical height. The male partner's assistive throwing action may increase the relevance of jump height when evaluating quality. Horizontal distance was not statistically significant; however, the bootstrap results suggest a possible contribution to GOE, warranting further investigation with a larger sample.

When stratified by jump type, edge jumps showed a significantly strong positive correlation between vertical height and GOE. Horizontal distance and landing speed exhibited moderate correlations, which were not significant, but showed consistent patterns with bootstrap estimates. No significant correlation was observed between take-off speed and GOE, reinforcing the idea that judges emphasise post-landing flow over pre-release velocity. Previous studies in women's singles reported lower jump heights in edge jumps compared to toe jumps, due to inefficiencies in converting horizontal to vertical force (Sakurai et al., 1999). In edge-type throw jumps, the male partner's ability to efficiently convert the female partner's horizontal momentum into vertical lift through the throw becomes a key technical factor. This may explain why vertical height strongly influences GOE, which is subjectively assigned by judges. For horizontal distance and landing speed, the 95% CI based on the bootstrap method did not include zero, suggesting a potential association. Further investigation with a larger sample size is warranted to confirm these trends. In contrast, no clear association was observed for take-off speed, indicating that, at least for edge jumps, judges may place greater emphasis on landing speed than on speed before the release.

For toe jumps, none of the kinematic variables correlated significantly with GOE. Notably, vertical height demonstrated almost no association with GOE, while horizontal distance exhibited a stronger correlation compared to edge jumps, indicating a potentially different pattern between the two jump types. As suggested by (Sakurai et al., 1999), toe jumps, where the skater uses the toe pick at take-off, allow for more efficient conversion of horizontal momentum into vertical force, resulting in greater jump heights. The Lutz is considered the most technically demanding toe jump, as it involves rotation in the direction opposite to the take-off edge, thereby requiring greater vertical elevation.

In the present sample, five out of seven toe jumps were Lutz jumps, which are typically associated with higher vertical height. Consequently, the results suggest that in toe-type throw jumps, horizontal distance, rather than vertical height, may play a greater role in determining GOE. Landing speed also exhibited a stronger positive correlation with GOE than in edge jumps, implying that the kinematic features of associated with better execution scores in toe jumps may reflect greater horizontal rather than vertical performance characteristics. However, due to the limited sample size, further investigation with a larger dataset is necessary to validate these trends.

In summary, the results indicate that in triple throw jumps performed in pair skating, vertical height and landing speed showed moderate, statistically significant positive correlations with GOE. This suggests that judges place particular emphasis on jump height and landing flow when evaluating execution. The influence of vertical height was especially pronounced in edge jumps, where a significant positive correlation with GOE was observed. The limited sample size prevents definitive conclusions; however, our findings suggest that the kinematic features associated with higher GOE may differ between edge and toe jumps. Previous studies have noted that pair and ice dance skaters, who perform lifting manoeuvres regularly, tend to possess greater upper-body strength, and strength training programs should specifically target upper-body development (Slater et al., 2016). This may be particularly relevant for enhancing vertical lift in throw jumps, ultimately contributing to improved execution scores.

This study has some limitations. One concerns the accuracy of data acquisition. The tracking system used in this research was designed for media purposes and operates at 30 fps, which is relatively low compared to motion capture systems or high-speed cameras typically used for analysing fast movements in sports.

Collecting data during competitions poses practical challenges, and it would be desirable to use higher-precision equipment with higher sampling frequencies when possible. Another limitation is the sample size. Only 23 jumps were included in the analysis out of a total of 44. Trials were excluded if they received any GOE deductions or were downgraded to double rotations. Even at the level of World Championship competitors, executing triple throw jumps without GOE deductions is not easy. Ongoing data collection from other competitions is necessary to build a more robust dataset.

Despite these limitations, this is the first case study to examine the relationship between kinematic features and the GOE awarded by judges for triple throw jumps performed by world-class pair skaters in actual competitions. The findings suggest that throw jumps in pair skating may have different determinants of GOE compared to double Axel jumps in singles, as reported in previous studies. This research contributes to a more objective understanding of the inherently subjective evaluation in judged sports and may offer valuable insights for coaching and judging guidelines.

CONCLUSION

We examined the relationship between kinematic features derived from tracking data and the GOE awarded by judges for triple throw jumps in pair figure skating. Our findings revealed significant positive correlations between vertical height and GOE as well as between landing speed and GOE, with vertical height playing a particularly important role in edge jumps. In contrast, although not statistically significant, toe jumps tended to show higher correlations between GOE and horizontal distance, suggesting that the kinematic characteristics associated with higher GOE may differ between toe and edge jumps. Future research should aim to improve the generalisability of findings and deepen our understanding by employing higher precision tracking equipment and expanding the sample size.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability. No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy. English editing support was obtained using ChatGPT (OpenAI; San Francisco, CA, USA), which was employed to refine the grammar and readability of the manuscript.

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