Statistical Analysis of Recent Rule Revision Effects for Tactical and Strategic Elements in Curling

Yutaka Kondo[1][a], Hitoshi Yanagi[3], Michal Ptaszynski[2][b], Shimpei Aihara[4][c] and Fumito Masui[2,4][d]

[1]*Graduate School of Kitami Institute of Technology, 165, Kouen-cho, Kitami, Japan*

[2]*Information Communication Group, Kitami Institute of Technology, 165, Kouen-cho, Kitami, Japan*

[3]*Common Education Group, Kitami Institute of Technology, 165, Kouen-cho, Kitami, Japan*

[4]*Department of Sport Science and Research, Japan Institute of Sport Sciences, Tokyo, Japan*

Keywords: Curling Informatics, Tactics and Strategies, Game Information, Game Score, Scoring Opportunity.

Abstract: In this paper, PCA is performed on a set of tactical elements calculated by scoring opportunity analysis for the men's and women's Japanese Championships 2017, 2022, and 2023 with different rules. Curling is a winter sport called "chess on ice". Curling is considered as a system system consisting of multiple elements, which can be divided into three categories: physical, human and tactical. Among these, strategic and tactical factors are considered to be the most important in top-level competition. In addition, in the curling world, some rules are sometimes changed in order to improve players' skills and tactics. In this study, we analyzed the changes in tactical factors due to the rule changes. As a result, it is considered that the nautical zone rule is not effective in men's competitions. In the women's competitions, scoring points by stealing became more important each time the rules were changed.

1 INTRODUCTION

The official rules of curling were established in Canada in 1838, and in recent years, the sport has been played in 66 countries and regions that are members of the World Curling Federation. Japan is ranked 8th in the men's world and 4th in the women's world and has performed well in world competitions. However, some issues must be solved to maintain the current world ranking.

Considering curling as a system consisting of multiple factors, we can list physical factors (changes in ice conditions), human factors (players' conditions), and tactical factors (knowledge of tactics and strategy). Bradley (Bradley, 2009) points out that strategic and tactical factors are the most important at the top level. Various enhancement programs have been developed to strengthen curling in Japan (Yanagi et al., 2012; Takahashi, 2011; Masui et al., 2012). One example of a method to improve team performance is the informatics approach. In the past few years, many examples of the use of ICT (Information and Communication Technology) to support sports have been reported(Fujimura and Sugihara, 2004; Kagawa, 2006), and curling is one of them (Masui et al., 2012). One example of ICT utilization in baseball is Trackman. It uses optically enhanced radar technology to measure the trajectory of the entire ball.

In this study, as a part of the curling informatics project, game plans in curling are analyzed based on the scoring data. Curling is a highly tactical sport, so much so that it is called "chess on ice." Therefore, it is necessary to collect various tactics-related factors and make a precise tactical plan for each phase of the game. In addition, the first and second turners switch at each end, and only one of the teams can score points. Because of this unique rule structure of curling, it is generally said that the latter team has the advantage. Therefore, players must make end and game plans for their play.

Masui et al. developed the digital scorebook "iCE" to record tactical elements electronically (Masui et al., 2012). Using the "iCE", it is currently possible to provide feedback to players on the direction

[a] https://orcid.org/0009-0008-7432-9999
[b] https://orcid.org/0000-0002-1910-9183
[c] https://orcid.org/0000-0002-8513-0204
[d] https://orcid.org/0000-0001-9979-8734

Kondo, Y., Yanagi, H., Ptaszynski, M., Aihara, S. and Masui, F.
Statistical Analysis of Recent Rule Revision Effects for Tactical and Strategic Elements in Curling.
DOI: 10.5220/0012178800003587
In *Proceedings of the 11th International Conference on Sport Sciences Research and Technology Support (icSPORTS 2023)*, pages 70-81
ISBN: 978-989-758-673-6; ISSN: 2184-3201

of rotation, type, and score (accuracy) of shots in each game. However, research to analyze scoring patterns and consider end and game plans has not progressed, and feedback has not been returned to players.

In addition, there have been two significant rule changes in curling. Players must adapt more quickly to the changed rules and develop their end and game plans. Therefore, it is advantageous to analyze competitions with different rules.

In this paper, we focus on the Opportunities to score and lose points in curling and consider the impact of revising the first-division rules on the tactical elements. Specifically, we analyze scoring opportunities and collect tactical elements considered necessary among top-level players. Next, Principal Component Analysis (PCA) measures the influence of the tactical factors obtained from the scoring opportunities.

PCA is a type of multivariate analysis method, an analytical technique developed in economics. PCA can represent the characteristics of the data by reducing the number of variables without losing the original multivariate data as much as possible.

The outline of this paper is as follows. First, Section 2 introduces related studies. In Section 3, rule changes in curling are introduced. Section 5 describes Goal Scoring Opportunity Analysis and PCA (Principal Component Analysis) analysis methods. Section 6 describes PCA. Section 7 introduces the analysis targets. In Section 8, we interpret the results of PCA. Section 9 discusses the results. Finally, Section 10 concludes the paper.

2 RELATED RESEARCH

As a previous study on support for strengthening tactical elements, there is the curling informatics concept of Masui (Masui et al., 2012). As shown in Fig. 1, it is an attempt to support the top teams in Japan and to contribute to the improvement of the tactical skills of the competitors. For this purpose, we aim to develop technologies and environments for recording, analyzing, visualizing, and sharing match information.

As for tactical and competitive factors, studies on game information analysis in curling have been conducted. Otani (Otani et al., 2016) conducted a correlation analysis between shot accuracy and scoring power at the world's top level and found a positive correlation between shot rate difference and scoring difference. Hirata(Hirata et al., 2016) conducted a correlation analysis of the difference in shot accuracy and the difference in final score by position and found a sexual correlation for the force. However, no correlation was found for positions other than force. Heo(Heo and Kim, 2013) developed a curling simulator that can be used as a training tool to improve performance in real competitions. The realistic curling simulation allows users to set up strategies and tactics while imaginatively training in various situations without being limited by the training space. Sung(Duda et al., 2001) analyzed the game results using binomial logistic regression based on the possession of the first and last stones at each end. The results showed statistical significance between the game results and the control of the last stone from the first end to the tenth end, except for the second end.

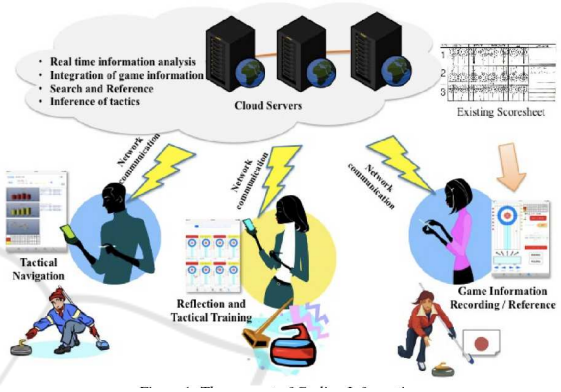

Figure 1: The Concept of Curling Informatics.

3 CHANGE OF COMPETITION RULES

Below are some of the changes in the rules and tactics of curling.

3.1 Rules of Curling

In this section, we will introduce the basic rules of curling and some special rules that vary from age to age.

3.1.1 Basic Rules

Curling is a sport where two teams play against each other in an area called a "sheet" made of ice. Each team takes turns throwing eight stones to score points. Points are awarded only to the team whose stone is closest to the circle's center called the house. One point is awarded to the team that scores a point for each stone inside the nearest stone from the center of the house of the team that failed to score a point.

In the first end, the team with the lowest LSD (Last Stone Draw) is the last team to score a point, and the team with the highest LSD is the first team to score

a point. After the second end, the team that scored in the previous end is the first to attack, and the team that scored in the previous end is the second to strike. A blank end is an end in which neither team scores a point. In this case, the first and second teams do not switch.

3.1.2 Special Rules

Curling has special rules that significantly influence tactics, and the rules have been revised twice so far. The free-guard zone rule has been in effect since 1993. This rule states that if an opponent's stone is directly or indirectly moved out of the playing area before the fifth throw of the end is made, the thrown stone is removed, and the moved stone is returned by the non-offending team to the position it was in before the infraction took place.

This free guard zone rule was amended for the 2018-2019 season to state that if an opponent directly or indirectly moves an opponent's stone out of the playing area before the sixth throw of the second is made, the thrown stone will be removed. The moved stone will be returned by the non-offending team to the position it was in before the violation was committed. The rule is now that the thrown stone is removed, and the moved stone is returned by the non-offending team to its position before the infraction. However, players have started to use tactics to avoid violating the rule by throwing shots (wick) to shift the opponent's stones to the edge of the playing area. Therefore, the No Tick Zone Rule was implemented for the 2022-2023 season. This rule prohibits a player from moving an opponent's stone directly or indirectly in the free guard zone and touching the center line to a position outside the free guard zone or not touching the center line before the sixth throw of the end. The offending team may choose one option: (1) Remove the thrown stones and return all stones to their original position. (2) Leave all stones in place.

3.2 Curling Tactics

It is generally believed that the team with the rear end has the advantage of curling. Therefore, the theory of curling is that the first team should limit the opposing team's score to one point, and the second team should score two or more points. Thus, curling is a sport in which the offensive and defensive tactics are switched between the first and the second team.

The tactics of the first and the second turn, often seen in recent years, are as follows. The first team places a stone called a guard near the center line of the free guard zone in front of the house (the yellow area in Figure2) on the first throw. By filling the center of the house with your team's stones, you can suppress your opponent's scoring. The second team throws a come-around, a shot to hide behind the guard stone thrown on the first throw. The second throw is shot to hide the guard stone behind the guard stone thrown in the first throw. The team attacking from the rear throws a take-out shot to bounce the opponent's rock in the center of the house, creating a space in the center and scoring multiple goals, including the stone thrown in the first throw. From the middle of the end of the game, the game proceeds according to the phase. When the score difference is far, even if your team is the second team, you should not try to score points but rather reduce the risk of losing points. If the team is not expected to score more than two or more goals, the game may be played with a blank end, and the game continues with the following end as a back-placed game. This tactic is intended to reset the stones and start the next end with the back end again.

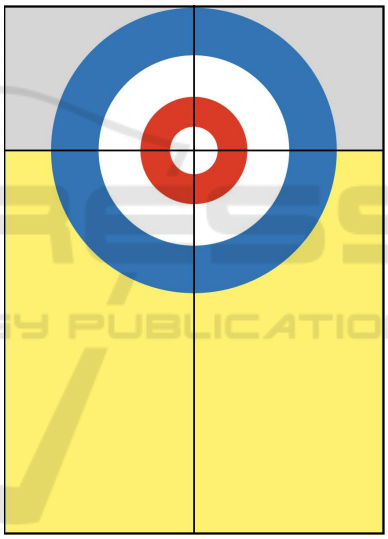

Figure 2: Free gard zone.

4 ANALYTICAL METHOD

In this study, we collect the tactical elements of each team from the analysis of goal-scoring machines and conduct quantitative research on the influence of each tactical element on the tournament using PCA (Principal Component Analysis). Based on the results of PCA, changes in tactical elements due to rule changes are discussed. Section 5 describes the analysis of Opportunities to score and lose points, Section 6 describes the PCA, and Section 7 describes the analysis targets.

5 SCORING OPPORTUNITY ANALYSIS

Curling is a sport in which the tactics differ between the first and the second team, and only one of the teams can score points. Therefore, it is crucial to clarify the pattern of goals scored by the first and second teams.

In the analysis of scoring opportunities, the score of each game is recorded, and the tactical factors are calculated for each tournament. The tactical factors are score(Scorling), lost points(Lost), first turn(First Turn), second turn(Second Turn), first blank end(BECFirst), second blank end(BECSecond), number of steals(Steal), number of steals conceded(Stolen), Last Stone Efficiency(LSEff), and Force Efficiency(FEff). These tactical elements are those emphasized by world-class teams. Section 5.1 describes the collection and recording of game information, and Section 5.2 describes the analysis for each tournament.

5.1 Collecting and Recording Match Information

The scoresheet shown in Fig.1.3 analyzes each game. The team name, LSD (Last Stone Draw), and score are entered on the score sheet. LSD is an abbreviation for Last Stone Draw. Before the game, both teams throw one pitch counterclockwise and clockwise to a circle called a house, and the total distance from the circle's center is recorded. Team names, LSD, and scores are entered manually by referring to the match information on the tournament's official website. The first or the second team is assigned to the first or the second team for each end based on the entered LSD record and the score. HMR(HAMMER) in the first line of Fig. 2 indicates which team was the second in each end. R suggests that team A was the second team, and Y shows that team B was the second team. The number of blank ends, steals, LSEff, and FEff are also tabulated for each game. LSEff is the ratio of the number of ends that scored two or more points in the second round. FEff is the ratio of the number of endpoints in which the opponent scored only one point in the first turn. LSEff and FEff are indices for quantitatively calculating whether the theory of curling is generally followed. The formulas for calculating LSEff and FEff are given below. In the formula, the number of multi-score ends in the 2nd half is given as "Multi-score ends in 2nd half," and the number of defensive ends in the 1st half is given as "Number of defensive ends".

$$LSEff = \frac{\text{Multi-score ends in 2nd half}}{\text{(Steal-BECSecond)}}$$

$$FEff = \frac{\text{Number of defensive ends}}{\text{(First Turn-BECFirst-Steal)}}$$

HMR		R	R	Y	R	Y	R	R	Y	Y	Y					
Session1	LSD	1	2	3	4	5	6	7	8	9	10	EE	合計	Count	LSEff	FEff
Steal									1	1	1		3	3		
A	135.5	0	1	0	2	0	0	1	1	1	1		7		33%	0%
B	156.0	0	0	2	0	2	0	0	0	0	0		4		40%	67%
Steal													0	0		
Blank End		1					1						2			

Figure 3: Match information for one game.

5.2 Analysis of Each Tournament

The information of each match is compiled and analyzed for each tournament. Here, we create a table of average goals scored per end, a graph of the percentage of goals scored, a graph of the rate of goals scored, a table of number of ends with multiple goals scored per end, a table of number of ends with 3 or more goals scored per end, and so on. In this table, ten tactical elements (Scoring, Lost, First Turn, Second Turn, BECFirst, BECSecond, Steal, Stolen, LSEff, FEff) are calculated as the average value per game. The reason for calculating the average per game is that the number of games played in a tournament varies from team to team.

6 PCA(PRINCIPAL COMPONENT ANALYSIS)

The concept of PCA for the case of two variables is shown in Fig.4. PCA is a type of multivariate analysis that compresses the original data into a smaller number of principal components, taking into account the correlation and variance among the variables in the data set. The principal components are chosen such that the variance of the original data is maximized, and the next principal component represents the remaining direction with the largest variance of the original data. A simple method for calculating principal components is described below. See the Appendix for details.

For the entire data set, a d-dimensional mean vector μ and a d × d covariance matrix Σ are computed. Next, eigenvectors and eigenvalues are computed and arranged in decreasing order of eigenvalue. These eigenvectors are called eigenvectore_1 with eigenvalueλ_1, eigenvectore_2 with eigenvalueλ_2,... and select the k eigenvectors with the largest eigenvalues. In many cases, there are only a few large eigenvalues, which means that k is the eigendimension of

the subspace governing the ”signal” and the remaining d-k dimensions generally contain noise. We then form a dxk matrix A with k eigenvectors as columns. The representation of the data in terms of principal components consists of projecting the data onto the k-dimensional subspace as follows (Satomi et al., 2009).

$$x' = F_1(x) = A^t(x-\mu)$$

On the other hand, since the objective of PCA is to represent the original amount of information with as little information as possible, the number of principal components employed is important. As a rule of thumb,(1)the eigenvalue should be greater than 1, and (2)the cumulative contribution rate should be greater than 80However, depending on the interpretation method, principal components may be taken even when the eigenvalues are not greater than 1. The determination of the number of principal components should be considered according to the results of the analysis.

Eigenvalues represent the degree of characteristic variability of the original data through diagonalization (conversion to a diagonal matrix) of the covariance matrix. Specifically, eigenvalues are an important measure of how much directional variation the corresponding eigenvector has in the data, depending on its magnitude. The contribution ratio is a measure of how well each principal component explains the variability in the original data. The cumulative contribution rate is a cumulative measure of the contribution rate, and the larger the value, the more information on the original data is explained. The principal components obtained in PCA are expressed as a linear combination of the original variables. The loadings are coefficients that indicate how much each original variable contributes to the linear combination of its principal components. In order to capture the relationship between the principal components and the original variables, correlation coefficients are computed between the principal components and each variable, which are interpreted as loadings.

7 SUBJECT OF ANALYSIS

The analysis covered men’s and women’s matches of the Japan Championships 2017 (JC2017), the Japan Championships 2022 (JC2022), and the Japan Championships 2023 (JC2023), which were held before the free guard zone rule was revised after the revision, respectively. Table1-6 displays the 10 tactical elements calculated by the goal-scoring opportunity analysis for each team. The columns represent the respective

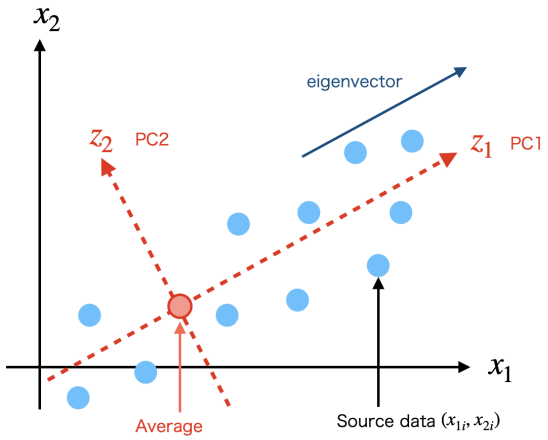

Figure 4: PCA concept.

teams, which are not shown in this paper. The rows represent the following 10 tactical elements. Here, the average score is abbreviated as Sc(Scorling), the average goals scored is abbreviated as Lo(Lost), the number of turns taken by the first team is abbreviated as Ft(First Turn), the number of turns taken by the second team is abbreviated as St(Second Turn), the number of blank ends by the first team is abbreviated as Bf(Blank End for the First Attack), the number of blank ends by the second team is abbreviated as Bs(Blank End for the Second Attack), the number of steals is abbreviated as Stl(Steal), the number of steals suffered is abbreviated as Std(Stealed), LSEff is abbreviated as LS(Last Stone Efficiency), and FEff is abbreviated as FE(Force Efficiency).

Table 1: Tactics elements(Japan Championship Men 2017).

	A1	B1	C1	D1	E1	F1	G1	H1	I1
Sc	9.6	7.36	6.82	5.91	5.22	4.88	5.38	5.38	4.88
Lo	4.00	5.64	6.09	6.27	6.44	7.75	7.75	7.88	5.63
Ft	4.60	5.27	4.82	4.73	4.44	3.88	4.63	4.13	4.25
St	3.80	3.91	4.55	5.00	4.56	4.75	4.88	5.13	4.88
Bf	0.70	0.73	0.55	0.36	0.78	0.00	0.38	0.50	1.13
Bs	0.20	0.45	0.55	0.45	1.00	0.63	0.38	1.00	0.63
Stl	1.40	1.27	0.82	1.36	1.00	0.75	0.88	0.75	1.00
Std	0.60	0.55	0.82	1.27	0.89	1.25	1.50	1.25	1.63
LS	0.60	0.48	0.37	0.22	0.27	0.16	0.28	0.33	0.19
FE	0.72	0.66	0.57	0.61	0.60	0.39	0.58	0.43	0.56

Table 2: Tactics elements(Japan Championship Men 2022).

	A2	B2	C2	D2	E2	F2	G2	H2	I2
Sc	8.18	7.90	7.70	6.33	6.50	5.13	5.38	3.25	3.75
Lo	4.82	4.50	5.10	5.89	5.13	6.63	6.88	9.38	8.63
Ft	5.09	4.60	4.00	5.11	4.88	3.63	3.63	3.50	4.38
St	3.91	4.40	4.90	3.78	4.00	5.13	4.88	4.13	4.13
Bf	0.82	0.60	0.10	1.00	0.63	0.38	0.38	0.50	1.00
Bs	0.55	0.80	1.20	0.33	0.75	0.75	0.50	0.25	0.13
Stl	1.36	1.50	0.90	1.00	1.63	0.63	0.38	0.50	0.50
Std	0.27	0.70	0.30	0.56	0.75	1.75	1.50	1.75	1.63
LS	0.66	0.53	0.59	0.41	0.58	0.23	0.20	0.10	0.12
FE	0.60	0.73	0.59	0.61	0.50	0.50	0.45	0.42	0.39

Table 3: Tactics elements(Japan Championship Men 2023).

	A3	B3	C3	D3	E3	F3	G3	H3	I3
Sc	8.60	7.36	7.70	7.33	7.25	6.13	5.13	3.50	3.50
Lo	4.70	4.91	5.30	5.67	5.38	8.38	7.50	9.25	8.13
Ft	4.90	4.82	3.80	4.56	4.25	3.88	4.13	3.63	3.88
St	3.90	4.18	4.70	3.89	4.13	4.50	4.75	3.88	4.25
Bf	0.60	0.55	0.10	0.22	0.75	0.00	0.25	0.25	0.63
Bs	0.40	0.64	0.90	0.00	0.50	0.25	0.50	0.00	0.00
Stl	1.60	1.55	1.00	1.56	0.88	0.38	0.38	0.63	0.38
Std	0.50	0.82	0.90	0.78	0.88	0.88	0.88	1.50	1.88
LS	0.63	0.50	0.59	0.39	0.48	0.40	0.25	0.09	0.15
FE	0.64	0.68	0.61	0.64	0.61	0.39	0.51	0.11	0.35

Table 4: Tactics elements(Japan Championship Women 2017).

	a1	b1	c1	d1	e1	f1	g1	h1	i1
Sc	6.91	8.50	8.00	7.70	6.13	6.38	3.75	3.38	5.00
Lo	4.09	4.50	5.80	5.20	6.63	7.00	7.63	9.25	9.00
Ft	4.91	4.10	4.90	4.60	4.50	3.88	3.38	3.50	4.14
St	3.91	4.50	4.00	3.90	4.63	4.75	4.63	3.63	5.14
Bf	1.00	0.10	0.50	0.50	0.75	0.00	0.25	0.00	0.43
Bs	0.64	0.80	0.20	0.20	0.63	0.50	0.63	0.00	0.14
Stl	1.09	1.30	1.50	1.20	1.00	1.13	0.38	1.13	0.71
Std	0.36	0.50	0.90	0.60	1.25	1.25	1.50	1.88	2.29
LS	0.49	0.48	0.52	0.37	0.28	0.26	0.14	0.08	0.21
FE	0.83	0.60	0.59	0.64	0.40	0.63	0.58	0.32	0.50

Table 5: Tactics elements(Japan Championship Women 2022).

	a2	b2	c2	d2	e2	f2	g2	h2	i2
Sc	7.30	7.91	7.20	7.44	6.00	5.38	6.00	5.50	2.25
Lo	4.40	4.64	4.90	6.22	6.75	5.75	6.75	7.00	11.25
Ft	4.50	4.91	4.10	5.11	3.75	4.25	4.75	4.50	2.75
St	4.70	3.73	4.20	4.11	5.38	4.63	3.88	4.25	4.25
Bf	0.10	0.73	0.40	0.56	0.25	0.38	0.75	0.63	0.00
Bs	0.80	0.36	0.70	0.22	0.38	0.38	0.50	0.25	0.13
Stl	1.80	1.36	1.10	1.56	0.75	1.25	1.00	0.88	0.38
Std	0.60	0.55	0.60	1.11	2.00	1.63	0.63	1.25	2.50
LS	0.44	0.43	0.40	0.40	0.34	0.20	0.29	0.38	0.03
FE	0.76	0.67	0.65	0.60	0.58	0.64	0.49	0.67	0.07

8 ANALYSIS RESULTS

In this section, we present and discuss the PCA results for each conference in the tables7-12. The table lists the eigenvalues, principal component loadings, contribution rates, and cumulative contribution rates for each principal component. The number of principal components to be interpreted is determined with reference to the cumulative contribution rate. For interpretation, the loadings of each component are used as a reference.

8.1 Japan Championship 2017 Men

Table 7 shows the results of the analysis of the Japan Championship 2017 men's race. This time, we have obtained up to the third principal component whose cumulative contribution rate is 0.8 or more, which is the standard for the number of principal components as described in (2) of 6 chapter. Since the cumulative contribution rate up to the third principal component is 85.9%, we consider that we have effectively processed 10 variables.

Table 6: Tactics elements(Japan Championship Women 2023).

	a3	b3	c3	d3	e3	f3	g3	h3	i3
Sc	9.00	7.18	8.60	8.33	8.50	6.25	5.38	4.38	2.00
Lo	4.80	7.00	5.60	4.78	5.75	7.75	7.13	7.50	11.63
Ft	4.70	4.82	5.00	5.33	4.50	4.50	4.13	3.50	2.63
St	4.20	4.45	4.10	3.11	4.63	4.75	4.50	5.38	4.75
Bf	0.30	0.45	0.30	0.78	0.38	0.13	0.50	0.50	0.13
Bs	0.60	0.36	0.10	0.22	0.63	0.25	0.38	0.88	0.13
Stl	2.00	1.27	2.00	2.44	1.38	1.00	0.63	0.38	0.25
Std	0.60	1.00	1.30	0.78	0.88	1.25	1.38	2.00	3.00
LS	0.49	0.43	0.43	0.57	0.58	0.31	0.33	0.19	0.03
FE	0.28	0.53	0.72	0.69	0.61	0.48	0.69	0.40	0.26

The first principal component is mainly related to the score, with a value of more than 0.3 or -0.3, which can be interpreted as a principal component related to the goals scored. In curling, the team that scores the most points is the first team to attack in the next end, so the loadings on the number of ends for the second team are also large.

The second principal component, BECFirst(Blank End for the First Attack) had a larger value than the other components. BECFirst is considered to have the effect of preventing the first team from preventing the second team from scoring a goal. In other words, the second principal component can be interpreted as a defensive principal component for the first team.

The third principal component, BECSecond(Blank End for the Second) is larger than the other components. BECSecond is considered to be a factor that the rear-angle team choosing the scoring opportunities. In other words, the third principal component can be interpreted as an offensive principal component for the rear-attacking team.

Table 7: Analysis Results(Japan Championship Men 2017).

		PC1	PC2	PC3
Eigenvalue		6.321	1.285	0.986
Load	Scorling	0.366	-0.240	-0.033
	Lost	-0.349	-0.258	-0.052
	First Turn	0.299	0.035	0.079
	Second Turn	-0.361	0.173	0.228
	BECFirst	0.158	0.762	-0.193
	BECSecond	-0.241	0.281	-0.656
	Steal	0.302	0.156	0.371
	Stolen	-0.320	0.234	0.474
	LSEff	0.347	-0.195	-0.279
	FEff	0.356	0.259	0.172
Contribution Rate		63.2%	12.9%	9.9%
Cumulative Contribution Rate		63.2%	76.1%	85.9%

8.2 Japan Championship 2022 Men

Table 8 shows the results of the analysis for the Japan Championships 2022 men. Since the cumulative contribution rate up to the second principal component was 90.5%, we obtained the Load(loadings) up to the second principal component.

In the first principal component, the factors related to the score were high, except for those related to the number of ends. Similarly to the men's Japan Championship 2017, the first principal component can be interpreted as the principal component related to the score.

The second principal component was higher than the other components in terms of Second Turn and BECFirst(Blank End for the First Turn). The first team aims to prevent the second team from scoring by creating blank ends. The second team aims to create scoring opportunities and to score more than two points. Thus, the second principal component can be interpreted as a principal component that represents offense and defense in the end.

Table 8: Analysis Results(Japan Championship Men 2022).

		PC1	PC2
Eigenvalue		6.084	2.968
Load	Scorling	-0.390	0.101
	Lost	0.386	-0.114
	First Turn	-0.294	-0.385
	Second Turn	0.088	0.534
	BECFirst	-0.001	-0.557
	BECSecond	-0.223	0.462
	Steal	-0.364	-0.118
	Stolen	0.378	0.040
	LSEff	-0.396	0.034
	FEff	-0.350	0.055
Contribution Rate		60.8%	29.7%
Cumulative Contribution Rate		60.8%	90.5%

8.3 Japan Championship 2023 Men

Table 9 shows the results of the analysis for the Japan Championship 2023 men. Since the cumulative contribution rate up to the second principal component was 82.5%, we obtained the Load(loadings) up to the second principal component.

The first principal component can be interpreted as the principal component related to the score as in the Japan championship men 2017,2022.

The second principal component is the number of back endings, which is higher than the other components. The second principal component can be interpreted as an offensive principal component for the team that plays in the rear end.

Table 9: Analysis Results(Japan Championship Men 2023).

		PC1	PC2
Eigenvalue		6.115	2.139
Load	Scorling	-0.390	0.078
	Lost	0.391	0.034
	First Turn	-0.332	-0.287
	Second Turn	0.045	0.637
	BECFirst	-0.108	-0.418
	BECSecond	-0.242	0.450
	Steal	-0.337	-0.276
	Stolen	0.342	-0.149
	LSEff	-0.374	0.156
	FEff	-0.376	0.071
Contribution Rate		61.2%	21.4%
Cumulative Contribution Rate		61.2%	82.5%

8.4 Japan Championship 2017 Women

Table 10 shows the results of the analysis for the Japan Championship 2017 women. The loadings up to the third principal component were obtained since the cumulative contribution up to the third principal component was 86.4%.

The first principal component can be interpreted as the principal component related to the score as in the men's competition.

For the second principal component, Second Turn(the number of back-end ends) and BECSecond(Blank End for the Second) were higher than those of the other components. These two components can also be interpreted as offensive principal components of the latter team.

Table 10: Analysis Results(Japan Championship Women 2017).

		PC1	PC2	PC3
Eigenvalue		5.838	1.670	1.134
Load	Scorling	-0.374	0.0198	0.237
	Lost	0.400	0.125	-0.078
	First Turn	-0.345	0.162	-0.393
	Second Turn	0.132	-0.572	0.065
	BECFirst	-0.218	-0.095	-0.767
	BECSecond	-0.219	-0.547	0.248
	Steal	-0.274	0.483	0.304
	Stolen	0.386	0.039	-0.163
	LSEff	-0.395	0.053	0.045
	FEff	-0.297	-0.290	-0.091
Contribution Rate		58.4%	16.7%	11.3%
Cumulative Contribution Rate		58.4%	75.1%	86.4%

BECFirst(Blank End for the first Attack) was higher in the third principal component when the first attack was made. From this result, the third principal component can be interpreted as a defensive principal component for the first offensive team.

8.5 Japan Championship 2022 Women

Table 11 shows the results of the analysis for the Japan Championship 2022 women. Since the cumulative contribution rate up to the second principal component was 84.0%, we obtained the loadings up to the second principal component.

The first principal component is considered to be the principal component related to the score.

The second principal component was higher than the other factors in the BECFirst(Blank End for the first attack). Therefore, the second principal component is considered to be a defensive principal component in the first turn.

Table 11: Analysis Results(Japan Championship Women 2022).

		PC1	PC2
Eigenvalue		6.580	1.825
Load	Scorling	-0.375	0.038
	Lost	0.371	-0.169
	First Turn	-0.345	-0.258
	Second Turn	0.103	0.621
	BECFirst	-0.216	-0.530
	BECSecond	-0.248	0.400
	Steal	-0.327	0.114
	Stolen	0.355	0.130
	LSEff	-0.357	0.081
	FEff	-0.352	0.202
Contribution Rate		65.8%	18.3%
Cumulative Contribution Rate		65.8%	84.0%

8.6 Japan Championship 2023 Women

Table 12 shows the results of the analysis for the Japan Championship 2023 women. Since the cumulative contribution up to the second principal component was 82.0%, we obtained the Load(loadings) up to the second principal component.

The first principal component can be interpreted as the principal component related to the score.

The second principal component was higher than the other factors in the BECSecond(Blank End for the second attack). BECSecond(Blank End for the second attack) has the effect of increasing the scoring opportunities of the team in the back-offense. Therefore, it can be interpreted as an offensive principal component.

Table 12: Analysis Results(Japan Championship Women 2023).

		PC1	PC2
Eigenvalue		6.637	1.562
Load	Scorling	-0.366	0.105
	Lost	0.365	-0.223
	First Turn	-0.374	-0.031
	Second Turn	0.299	0.413
	BECFirst	-0.228	0.117
	BECSecond	0.020	0.790
	Steal	-0.353	-0.153
	Stolen	0.358	-0.212
	LSEff	-0.373	0.101
	FEff	-0.242	-0.227
Contribution Rate		66.4%	15.6%
Cumulative Contribution Rate		66.4%	82.0%

9 DISCUSSION

In this section, the results of our analysis of the changes in tactical elements due to the revised rules are presented. In order to focus on the changes in the tactical factors obtained from the Opportunities to score and lose points, we use a chart in which the principal component loadings of the three tournaments are superimposed. The principal component loadings of the first principal component are expressed in terms of magnitude, and we focus on the combinations with the highest principal component loadings. In the second principal component, we focus on the changes in the highest component.

9.1 Men's Load Changes

Figure 5 will be an overlay of the principal component loadings of the first principal component for the Japanese Championships 2017, 2022, and 2023 men. Here, each principal component loadings are expressed in absolute values.

The principal component loadings from the Japan Championships 2017 to the Japan Championships 2022 are higher for the four factors of Scorling, Lost, Steal, Stolen, and LSEff(Last Stone Efficiency). These are mainly related to points scored and points lost. We consider that the increase of one more pitching order in which stones in the free guard zone can be thrown out of the playing area has made it easier to score points. Since the principal component loadings of the number of steals have also increased, it can be

seen that scoring in the first end is also important, although it is generally considered that the second end is more advantageous. Two factors, Second Turn and BECSecond(Blank End for the Second), were lower than those of the first endings. This indicates that the number of blank ends is no longer important for the players to win the back end and to win the first end. Therefore, we can consider that the advantage in the back end has decreased, and that the advantage in the first end has slightly increased.

From Japan Championships 2022 to Japan Championships 2023, three factors were slightly higher: First Turn, BECSecond(Blank End for the Second), and FEff(Force Efficiency). Since these factors were slightly higher, we consider that it became more important to limit the opponent's score to one point in the first end. In the back end, it is not necessarily to aim for multiple goals, but to aim at the blank end when it is difficult to score goals, and to aim for multiple goals when it is easy to score goals, which is considered to be an important tactic. The four factors of Second Turn, Steal, Stolen, and the LSEff(Last Stone Efficiency) were lower in the rear end. There was no significant change from the Japan Championship 2022 to the Japan Championship 2023.

Figure 6 shows the principal component loadings of the second principal component of the three competitions.

From the Japan Championship 2017 to the Japan Championship 2022, the highest factor has changed from the BECFirst to the Second Turn. The fact that the influence of the number of back-end turns has increased in curling means that it is important to score more than 2 points in the back end. From Japan Championships 2022 to Japan Championships 2023, the element with the highest principal component loadings did not change in the Second Turn. The introduction of the No Tick Zone Rule does not appear to have changed the tactics of the men's team. It is thought that this is because men can throw a powerful shot called "takeout" that bounces the opponent's stones out of the court, and thus can break the situation where stones are concentrated in or in front of the house.

Thus, there was no change in the men's Japan Championships 2022 to Japan Championships 2023. As mentioned in section 3.1.2, the rule was established to counteract a shot called wick in the Japan Championships 2023. However, since no change was observed, we can say that the wick shot is not an important shot in the men's competitions. In other words, the No Tick Zone Rule is considered to be ineffective in the men's competitions because the wick does not determine the winner.

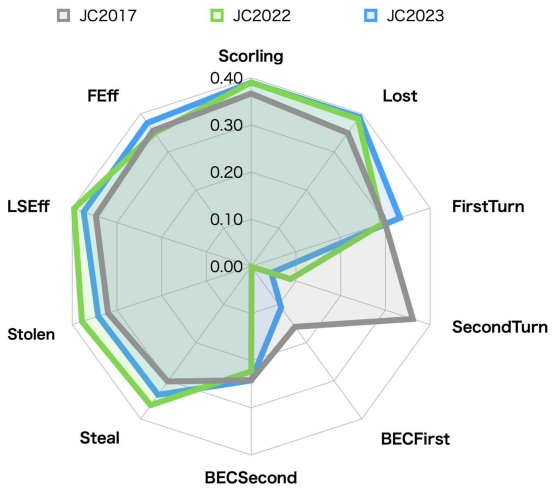

Figure 5: Contribution rate - PC1(Men).

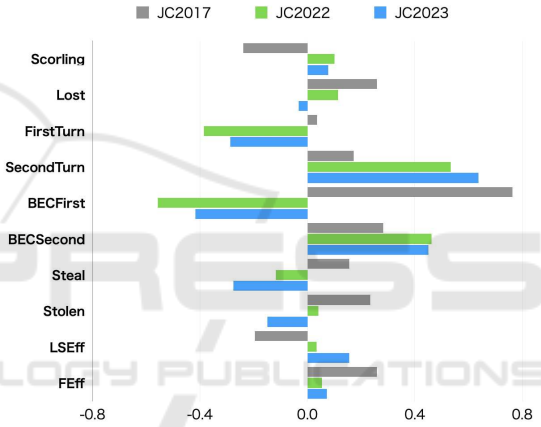

Figure 6: Contribution rate - PC2(Men).

9.2 Women's Load Changes

Figure 7 will be an overlay of the principal component loadings of the first principal component for the Japanese Championships 2017, 2022, and 2023 women. Here, each principal component loadings are expressed in absolute values.

The principal component loadings from the Japan Championship 2017 to the Japan Championship 2022 were higher in the BECSecond(Blank End for the Second), Steal, and FEff(Force Efficiency) for the rear attackers. In addition, three factors, Second Turn, Stolen, and LSEff(Last Stone Efficiency), were lower. All of these three factors are related to the tactics of the second-phase attackers. Therefore, it became important for the first-attackers to aim for steals to gain a scoring advantage, or to limit the opponent's score to one point. The second turner should basically aim for multiple goals, but if he/she cannot aim for multiple goals, it is important to use the tactic of blank

endings.

The First Turn, Second Turn, and Steal were higher from Japanese Championship 2022 to Japanese Championship 2023. The BECSecond(Blank End for the second attack) and FEff(Force Efficiency) of the rear enders became lower. Although the influence of the number of rear ends increased, the influence of the number of blank rear ends decreased considerably, suggesting that the importance of the rear ends may have decreased. In addition, the higher number of steal and the lower FEff may have made it more important to score points in the first end.

Figure8 shows the principal component loadings of the second principal component for the Japanese Championship 2017, 2022, and 2023 women. In the second principal component, we focus on the elements with the highest principal component loadings. From the Japan Championships 2017 to the Japan Championships 2022, the number of steal turns has changed from the highest number of steal turns to the Second Turn. The reason for the change from the number of steals to the number of back-end turns is that the free guard zone rule has been revised so that stones tend to accumulate in the house more often, which makes it easier to score in the back-end turns.

From Japan Championships 2022 to Japan Championships 2023, the factor with the highest principal component loadings changed from the Second Turn to the BECSecond(Blank End for the second attack).The reason for the higher number of blank ends in the back end is considered to be that the creation of blank ends reduces the number of back ends in which the opponent can score points. In addition, although the theory is to aim for two or more points in the rear end, there are many situations in which two or more points cannot be scored, and it is thought that the game plan of the players is to brand intentionally and to start the next end in the rear end as well.

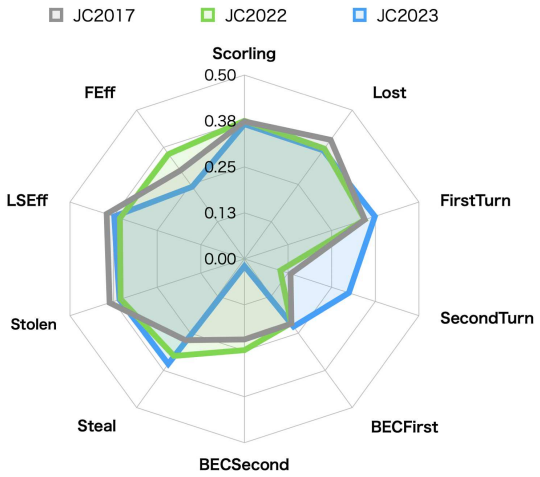

Figure 7: Contribution rate - PC1(Women).

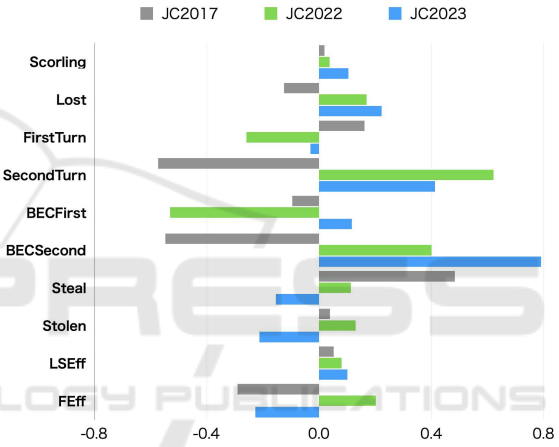

Figure 8: Contribution rate - PC2(Women).

10 CONCLUSIONS

In this paper,the tactical elements obtained from the analysis of opportunities to score goals in the competitions with different rules were performed by PCA.

The change in the men's Japan Championships 2017 to Japan Championships 2022 indicated that scoring points by doing steal are important. There was no significant change from Japan Championships 2022 to Japan Championships 2023. We consider that there was no change in the men' game because they are able to throw the takeout shot more powerfully and thus are able to overcome the situation even in a disadvantageous situation. Therefore, the No Tick Zone Rule was considered to be an ineffective rule in the men's competition.

The changes from Japan Championships 2017 to Japan Championships 2022 for women showed the same importance of scoring by stealing as for men. In addition, the importance of stealing was also increased from Japan Championships 2022 to Japan Championships 2023.

From these results, it is considered that the rule revision in curling has increased the advantage of the first turn. In curling, it is generally believed that the advantage is in the second turn, but a point scored in the first turn is a big advantage. Therefore, it is concider for the losing team to turn the game around even when there is a large difference in score.

In the future, we plan to conduct a more detailed tactical analysis by dividing tactical elements such as steal and blank end of rear attack, which were shown to be important in this study, into each end, and to

discuss the tactics. In addition, we will develop an application to provide feedback to players based on the analysis of opportunities for goals scored.

ACKNOWLEDGEMENTS

This work was supported by the "Functional Development Project for Resilient Athlete Support" of Japan Sports Agency.

REFERENCES

Bradley, L, J.(2009) The Sports Science of Curling. A Practical Review. Journal of Sports Science and Medicine vol.8, pp.495-500.

Yanagi, H., Miyakoshi, K., Nakajima, Y., Yamamoto, N. Development of Curl- ing Brush for Measuring Force Exerted During Sweeping. Proceedings of the 30 International Conf. on Biomechanics in Sports, pp.354-356 (2012).

Takahashi, S. Support the Japan Women 's Curling National Team by a Trainer. Journal of Training Science for Exercise and Sport 23(1): 7- 12 (in Japanese) (2011).

Masui, F., Hirata, K., Otani, H., Yanagi, H. and Ptaszynski, M. Informatics to Support Tactics and Strategies in Curling. Int J of Automation Technology Vol.10,No.2, pp.244-252 (2016).

Fujimura, A. and Sugihara, K.(2004) Quantitative Evaluation of Sport Teamwork UsingGeneralized Voronoi Diagrams. IEICE Transactions D J87- D2:818-828.

Kagawa, M. Effect of Multimedia Information on Web Pages in Physical Training Class of University. Journal of Japan Society for Educational Technology 29 37-40(2006)

Otani, H., Masui, F., Hirara, K., Yanagi, H., Ptaszynski, M. Analysis of curling team strategy and tactics using curling informatics. In: 4th International Congress on Sport Sciences Research and Technology Support(2016)

Hirata, K., Masui, F., Hiromu, O., Yanagi, H., Ptaszynski, M. Support to strategies and tactics in curling sport utilizing game information database - analysis of characteristics of position based on shot scores. In: Proceedings of the 34th International Conf. on Biomechanics in Sports, P0523433 (2016)

Myeong-Hyeon Heo and Dongho Kim. The development of a curling simulation for performance improvement based on a physics engine. In: 6th Asia-Pacific Congress on Sports Technology (APCST),Procedia Engineering 60(2013) 385-390

Duda, R. O., Hart, P. E., Stork, D. G. (2001). Pattern Classification, 2nd Edition. Wiley-Interscience.

Satomi, T., Sakabukuro, K., Yasukawa, I., Fukagawa, R. (2009). Real-time landslide risk assessment of important cultural heritage sites on back slopes using principal component analysis for rainfall. Journal of Japan ChampionshipsE, Series CC, Vol. 65, No. 2, 564-578.

APPENDIX

PCA(Principal Component Analysis). The concept of PCA is described in section 6. In this section, we describe the specific calculation method of PCA. First, n data ($x_j i$[j=1,2,$\cdots$,m;i=1,2,$\cdots$,n]) for m variables x_1,x_2,$\cdots$,x_m are standardized using equation (1) so that the mean and variance of all data means are zero and one respectively. This is done so that the principal components do not change depending on the unit setting of the data, making it difficult to interpret the results of the analysis.

$$X_{ji} = \frac{x_{ji} - \overline{x_j}}{\sqrt{s_{jj}}} \tag{1}$$

where $\overline{x_j}$ is the mean of the variable x_{ji}, s_{jj} is the variance of the variable x_j, the principal component of the data z_j is expressed as a linear expression as in equation (2), and the variance V(z_i) of this principal component is equation (3).

$$z_j = a_{1j}X_1 + a_{2j}X_2 + \cdots + a_{mj}X_m \tag{2}$$

$$\begin{aligned} V(z_j) &= \frac{1}{n}\sum_{i=1}^{n}(z_{ji} - \overline{z_j})^2 \\ &= s_{11}a_1^2 + s_{12}a_1a_2 + \cdots + s_{mm}a_m^2 \\ &= \sum_{j=1}^{m}\sum_{k=1}^{m} s_{jk}a_ja_k \end{aligned} \tag{3}$$

where a_j are the coefficients of the principal components ($a_j = (a_{1j}, a_{2j}, \cdots,$
$a_{mj}), j = 1,2,\cdots,m$),$X_j(j = 1,2,\cdots,m)$ are the standardized variables in equation (1) and S_{jk} are the variances and covariances. Principal component analysis is an analytical method to determine the coefficients a_j of equation (2) such that the amount of new information obtained is maximized, which must satisfy equation (4) as a constraint condition for the variance v(z_j) in equation (3) not to become infinitely large.

$$a_1^2 + a_2^2 + \cdots + a_m^2 = 1 \tag{4}$$

The present problem, in which the objective is to determine the coefficient a_j when the variance V(z_j) is maximum, using Eq. (4) and the Lagrange undetermined multiplier method, is equivalent to solving the eigenvalue problem in Eq.

$$V_a = \lambda a; V = \begin{bmatrix} s_{11} & b & \cdots & s_{1m} \\ s_{21} & s_{22} & \cdots & s_2 m \\ \vdots & \vdots & \vdots & \vdots \\ s_{m1} & s_{m2} & \cdots & s_{mm} \end{bmatrix}, a = \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_m \end{pmatrix} \tag{5}$$

where λ are the eigenvalues of the covariance matrix V and a is the eigenvector corresponding to the eigenvalue λ. The principal component using the eigenvector corresponding to the largest eigenvalue among the obtained eigenvalues λ is the ”first principal component”, followed by the ”second principal component, ⋯”. Then, the principal component values calculated for each data using equation (2) are called ”principal component scores”. The ”contribution ratio” is an indicator of the degree to which the ith principal component contains the original amount of information, and it means the ratio of the eigenvalues of the ith principal component to the sum of the eigenvalues, and the sum of the contribution ratios up to the 1st i principal components is the ”cumulative contribution rate”. [11]