

Analyzing the Improvement Process of Table Tennis Using the Game Refinement Theory

Li JIANGZHOU^{1*}, Anggina PRIMANITA^{1,2}, Mohd Nor Akmal KHALID¹, and
 Hiroyuki IIDA¹

¹*School of Information Science, Japan Advanced Institute of Science and Technology, 1-1 Asahidai, Nomi, 923-1211, Ishikawa, Japan*

²*Informatics Department, Universitas Sriwijaya, Indonesia*

*Corresponding author: lijiangzhou19@gmail.com

Abstract

Table tennis is one of the most popular sports in the world. With a history of just over 100 years, table tennis has slowly become the seventh-largest sport in the world. However, it is unclear whether the improvement actually makes the game better or worst. As such, a consistent quantification approach is needed. In this paper, game refinement (GR) theory was adopted to measure the attractiveness of table tennis and study the change of the GR value when the game is improved. The improvement observed in this study includes physical plays such as ball diameters, the game rules, set numbers, and score limits are analyzed. In addition, in comparison with real Table Tennis Olympic matches are also conducted to further verify the benefits of such improvements. The finding of the study proves that the continuous improvement of table tennis is beneficial.

Keywords: *sports, table tennis, game refinement theory, improvement process*

Introduction

Game problems are everywhere in today's life. Game theory is widely used in finance, securities, biology, economics, international relations, computer science, political science, military strategy, and many other disciplines [1]. However, little is known about the mathematical theory from the designer's point of view. It is interesting to know the theoretical aspects of the game that enable us to increase the attractiveness of games and their sophistication. Early work in this direction had been conducted by the construction of the logistical model under the theoretical framework of game refinement (GR) theory [2]. Such theory was applied to the board and sports games such as Chess and its variants, Mahjong, Football, Basketball, and other time-limited games and scoring games such as Tennis and Badminton [3] [4] [5].

Table tennis is a popular sport all over the world, but it has only been around for less than 150 years. The sport has observed several improvements over the years which makes it the seventh-largest sport in the world [6]. How did Table tennis develop into such an interesting and popular sport game today?

While several iterations of the game revision seem to make the game better and better over the years, there is no consistent way of measuring such improvements. How much does it make the game better (or worst) and in what way the game changes? In this paper, we will apply GR theory to compare the differences between the data before and after the improvement of table tennis and analyze whether such improvement of table tennis is conducive to the development process of table tennis.

Literature Review

Sports are the games we are most familiar with and existed almost everywhere and in any cultures. Many modern sports have a long history, where some have decades or even millennium of development. Their observations in score-limit game have a similar value of game refinement. Table tennis is not a new sport. It has been improved many times. In previous studies, a mathematical model based on this model was proposed, which focused on the uncertainty of game outcome in terms of game process and game information model. The value of game optimization comes from the progress model of game information. Its second derivative, which is acceleration, gives us a whole new way to measure a game or a motion in a dynamic sense [7]. In this article, we will consider the application of GR theory to the rule changes of table tennis. The effect of rule change on GR value was also studied. In previous studies, it has been confirmed that several table tennis reforms from 1988 to the present are beneficial to the development of table tennis [5].

Table tennis originated in England. At the end of the 19th century, tennis was popular in Europe, but due to the restrictions of the court and the weather, some college students in Britain moved the tennis to the indoor table, using the table as a table, the book as a net, with parchment as a racket, playing on the table [8]. In 1890, several British naval officers stationed in India stumbled upon the excitement of playing tennis on a small platform. Later they use solid rubber instead of elastic solid ball, then changed to hollow plastic ball, and board instead of the net, on the

Table for this novel “tennis”, this is the origin of Table tennis named. Soon after its appearance, table tennis became a popular sport [9]. At that time, there were no uniform rules for table tennis. There were 10 points, 50 points and 100 points in one game.

With the growing popularity of table tennis, the international table tennis association was founded in 1926 [10]. The rules are set at 21 points per set. The table is 146.4mm wide, the net is 17mm high and the ball is made of soft material. And the first world table tennis championships began. Under the rules, the table was narrower than it is today, the net was higher and the ball was soft. At that time, table tennis was still in its infancy. These conditions make table tennis more defensive-styled game playing.

Because table tennis was new, table tennis was very simple. Because the offensive approach is prone to errors, so each player has adopted a defensive approach. There have been many long matches under these circumstances. In the 10th world championships of table tennis, it took two hours and 20 minutes to fight for a point whereas seven and a half hours for the men singles match. Obviously, this situation is unfavorable for the development of table tennis [11]. So the table tennis association improved its rules by widening the table (146.4mm - 152.5mm), reduces the height of the net (17mm to 15.25mm), and limits the time of the game. Long games were avoided.

With the development of science and technology, table tennis technology is developing continuously. In the 1950s, Japan invented sponge rackets and took full advantage of the technology. The invention of the sponge racket improved the speed and rotation of table tennis. From here on, the offensive game playing style has become the mainstream and the pace of the game is accelerated. Then the international table tennis association developed a format for sponge rackets [12]. In 1986, it was stipulated that the front and back of the racket should be easy to distinguish, with black on the top and red on the bottom. The rubber particle height and diameter ratio of the racket is 1 to 1. In addition, table tennis became an official Olympic sport in 1988, which promoted the development of table tennis.

Table tennis has undergone tremendous changes since the 21st century. In 2000, the diameter of the ping-pong ball changed from 38mm to 40mm [11]. As the diameter of the ball increases, the drag increases, and the velocity and rotation decrease. This causes the game improvement such as reduction of players’ mistakes, increase the game aggressiveness, and making the game more exciting. The number of rounds per point increased significantly, making the game more competitive and enjoyable [13]. The 21-point system was changed to an 11-point system in 2001 where the time of each game is shortened and the number of games increases [14].

The International Table Tennis Federation (ITTF) changed the international table tennis competition system from 21 points to 11 points on October 1, 2001. The 11-point system change and the implementation of increased competition results in randomness, reduce the grasp of the best players to win, so as to improve the appreciation of the game, achieve the goal of the development of table tennis sports [15].

METHODOLOGY

Game Refinement Theory. Based on the concepts of game progress and game information progress, a general model of game improvement is proposed. It fills the gap between board games and sports. Game information progress presents the degree of certainty of a game’s results in time or in steps. Let G be the winning player’s score and T the total score of the game. Game progress $x(t)$ will be given as a linear function of time t with $0 \leq t \leq T$ and $0 \leq x(t) \leq G$, as shown in (1).

$$x(t) = \frac{G}{T}t \quad (1)$$

However, the game information progress given by (1) is usually unknown during the in-game period. Hence, the game information progress is reasonably assumed to be exponential. This is because the game outcome is uncertain until the very end of game in many games. Hence, a realistic model of game information progress is given by (2).

$$x(t) = G \left(\frac{t}{T} \right)^n \quad (2)$$

Here n stands for a constant parameter which is given based on the perspective of an observer in the game considered. Then acceleration of game information progress is obtained by deriving (2) twice. Solving it at $t = T$, the equation becomes (3).

$$x^n(T) = \frac{Gn(n-1)}{T^n} t^{n-2} = \frac{G}{T^2} n(n-1) \quad (3)$$

Hence, it is reasonably expected that the larger the value of (3) is, the more the game becomes exciting due to the uncertainty of the game outcome. Thus, we use its root square, given by (4) as a game refinement measure for the game considered.

$$GR = \frac{\sqrt{G}}{T} \quad (4)$$

Analyzing Table Tennis Using The Game Refinement Theory.

Table tennis has been improved several times since it was added to the Olympics in 1988. In 2000, the diameter of the ball was changed from 38mm to 40mm. This change slowed the tempo of table tennis [13]. In 2001, the scoring system was changed from 3 wins in 5 sets (21 points) to 4 wins in 7 sets (11 points, single). The unblocked serve was introduced in 2002. In 2008, the use of inorganic glue was banned. The ban on inorganic glue slows down the rotation of ping-pong balls, making it easier for players to play multiple rounds [16]. It is reasonable to think that these rule improvements are intended to make the game more enjoyable and exciting. In previous studies, it has been proved that GR value tends to be stable at 0.076 since 1988 [5].

To provide a proof of concept, a single match of 21-point scale and the 11-point scale are simulated by assuming that the two sides of the table tennis game are equal in strength and no extra game is allowed. Based on this assumption, the resulting score of each player side (referred as Player A and Player B) are simulated using probability knowledge and mathematical simulation in MATLAB software, where the winning probability of the old system had produced 3 out of 5 sets (11-point) and 2 out of 3 sets (21-point), while the new system produced 4 out of 7 sets of (11-point) and

3 out of 5 sets (21-point single) which adopted for comparative analysis (Table 1). As such, the GR value can be computed as in (5).

Table 1. An example of two table tennis matches.

21 point scale			11 point scale		
Player		Total Point	Player		Total Point
A	B		A	B	
21	19	40	11	9	20
19	21	40	11	9	20
21	19	40	9	11	20
			9	11	20
			11	9	20
Total		120	Total		120

*21 point scale = 2 wins in 3 sets;

*11 point scale = 3 wins in 5 sets;

$$GR_1 = \frac{\sqrt{63}}{120} = 0.066 \tag{5}$$

$$GR_2 = \frac{\sqrt{55}}{100} = 0.074$$

$$y = GR^2 x^2 \tag{7}$$

$$y = \frac{\sqrt{1}}{2} x \tag{8}$$

From the calculation, the table tennis competition may have value of $GR \in [0.07, 0.08]$ after the rule change, which is consistent with previous results. If x is the total score and y is the winning score, then (6) can be obtained, which then morphs into (7). Since both sides of the players have the same probability of scoring, then y is half as x which is given as in (8). The intersections of (7) and (8) (see Fig. 1) had showed that the total score of approximately between 78 and 102 is the most reasonable.

$$GR_1 = \frac{\sqrt{y}}{x} \tag{6}$$

Table 2. Game refinement values of the table tennis Olympic matches [5].

Matches	Winner point	Total point	GR value
Pre-2000	57.869	101.530	0.075
Post-2000	54.863	96.465	0.077

Based on Table 1, Table 2, and Table 3, the expected and actual total scores of the two scoring systems are approximately 120 (101.530) and 100 (96.465), respectively. The expected GR value was 0.066 to 0.075 and 0.074 to 0.077 for the actual total points of 120 and 100, respectively. Based on the comparison the simulated total score with the actual total score, the absolute value between the score differences is lower after the rule is improved. In other words, the match reform in 2000 of the Table Tennis showed that the GR value of the real match was much closer with the simulated match.

To further verify the claim made in this paper, application of GR theory to the real game data is also conducted. The data on the Olympics matches from 1988 to present from records had been collected from the ITTF official website ([https:// www. ittf. com](https://www.ittf.com)). The results for both sides of the players and the GR values for the pre-2000 games, post-2000 games, and the new team events [5], are compared and given in Table 2. In addition, a comparison of the GR values on the time-based information on the table tennis rule changes is given as in Table 3.

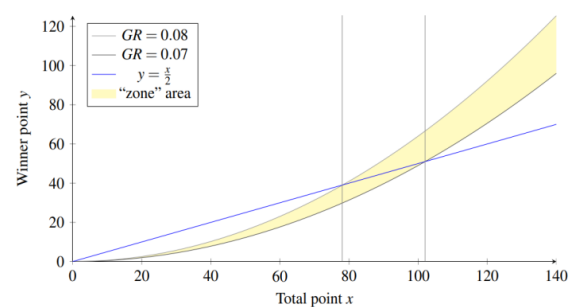


Figure 1. Game refinement values of the most comfortable points for Table Tennis with respect to $GR \in [0.07, 0.08]$ ("zone" area). $GR = 0.07$ and $GR = 0.08$ is the lower bound and upper bound of the game sophistication "zone", respectively. Games that highly dependent on luck (larger win to total score ratio) are situated in area greater than $GR = 0.08$, whereas game that highly dependent on skill (smaller win to total score ratio) are situated in area lesser than $GR = 0.07$.

Table 3. An overview of table tennis regulations: 1889-onward.

Years	Regulations	Expected GR	Player population
1880-1926	<ul style="list-style-type: none"> Table tennis was born with no fixed rules 10, 50, and 100 points 	GR = 0.157 (10pt) GR = 0.072 (50pt) GR = 0.051 (100pt)	200,000 (USA)
1926-1936	<ul style="list-style-type: none"> 2 wins in 3 sets of 21 points system Five server each set Server change after 20 points 	GR < 0.066	Popular in Europe
1936-2000	<ul style="list-style-type: none"> The racket is red on one side and black on the other The rubber particle height and diameter ratio of the racket is 1:1 	GR = 0.066	300 million
2000-onward	<ul style="list-style-type: none"> The diameter of the ball changed from 38mm to 40mm [17] 3 wins in 5 sets of 11 point system 2 balls and 10 ties for each server 	GR = 0.074	The 6 th largest sport in the world [6]

RESULTS AND DISCUSSION

Scoring System and Service Rules. The simulation experiment showed that the GR value of 11-point and 21-point systems is about 0.074 and 0.66, respectively. Meanwhile, the total score of both sides of 11-point and 21-point systems is 100 and 120 points, respectively. In an ideal world, the score of one party is always better than the other in a table tennis game. As such, the total score than the actual score was only slightly lower, which is between 80 and 100 [18]. Comparing the real game data, after the year 2000 format change, the gap between the simulation match score and total score was reduced.

In addition, according to GR theory, matches that are too long or too short are either noncompetitive or boring, and such matches are less pleasant to watch. The table tennis rule change was designed to solve this problem. In addition, the 21-point system had been changed into an 11-point system to reduce the total score of a single game and increase the number of general offices for competitions. According to (6), the higher the total score is, the longer the duration of the game becomes, resulting in lower GR value which implies that such games are boring [7].

Additionally, by comparing the expected score with the actual score, it can be found that the absolute value of both decreased after the rule improvement in the score system. This affects the ratio of the winning side's score to the total score of the actual game data. While a ratio of 1:2 was adopted in the simulation, if the expected difference between the total score and the actual score is too big, the ratio of the winning team's score to the total score will be larger, changing (8). Such situation induces higher GR value which corresponds to higher score needed from the winning side's score and higher total points, resulting in prolong game and makes the game less interesting to both players and audiences. As depicted in Fig. 2, expecting the absolute value of total points and actual total points to be smaller is more advantageous with table tennis.

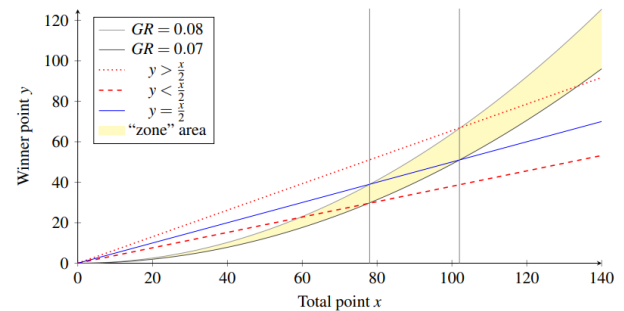


Figure 2. Game refinement values of the most comfortable points for Table Tennis with respect to $GR \in [0.07, 0.08]$ ("zone" area) with different ratios of winner point to the total point of the table tennis game. $GR = 0.07$ and $GR = 0.08$ is the lower bound and upper bound of the game sophistication "zone", respectively. As such, the "zone" area corresponds to the game with comfortable sophistication where appropriate winning and total scores are situated.

Table Tennis Ball Diameter. While the ball diameter changes from 38mm to 40mm (2mm increase) [16], a lot of testing had been conducted and televised for such change. Change of pace in the game was also observed, from the turn of the ball to the audience's reaction. Experimental data had shown that increased in the diameter of the ball can guarantee the viewing quality of the ball game while having little effect on the players.

From the physical standpoint of the game, the increase in the ball diameter had reduced the rotation and speed of the ball which make it easier for the players to catch the ball. Before increasing the ball's diameter, the ball's faster speed and stronger rotation increased the difficulty of players in each round [19]. As a result, every point in the game was scored only in two or three rounds, and sometimes even at the start of serve. Changing the diameter of the ball greatly increases the enjoyment of the game [20], which also justified by increase in the GR value (Table 3). This increases the number of rounds and makes the game more exciting.

Table Tennis Racket. In recent years, with a series of rule reforms by the ITTF, the content of table tennis has undergone great changes. A series of rule changes, such as

the small ball changing into a big ball, the big ball changing into a bigger ball, the implementation of the open service, the prohibition of organic glue and so on, pushes the surface reform of table tennis racket backward. In particular, the use of the new 40mm diameter ball greatly reduces its speed and rotation. While it enhances the enjoyment of table tennis, the attack speed and the threat of the first three rounds of the game are greatly reduced.

With respect to the new rules and keeping the game fresh, the surface of the table tennis racket also corresponds to the further improvement and perfection of better playing power. As such, composite surfaces gradually being adopted and a growing number of the physical properties of the table tennis manufacturers, using new materials and advanced production technology greatly improved the efficiency of the racket surface in terms of hitting effect and power. Butterfly VISCARIA racket is one of the most prominent table tennis rackets in the market, whose internal structure adopts a seven-layer structure, which improves the rebound speed of table tennis ball and enhances the threat of attack while ensuring stability [21].

CONCLUSION

Since the birth of table tennis, the regulations of the table tennis have been constantly updated and improved to meet the requirements of their respective environment. The improvements are threefold. Firstly, the rules of the table tennis had been continuously improved. Secondly, the performance of the table tennis also witnessed continuous improvement. Thirdly, the development and innovation of the competitive equipment is also observed [22]. Table tennis benefits from its changes, which can be verified by the $GR \in [0.07, 0.08]$. According to GR theory, such value is a balance between challenge and skills, so table tennis becomes one of the most popular sports in the world.

This study indicates that the GR value of table tennis gradually tends to be stable where $GR \in [0.07, 0.08]$. The improvement of table tennis rules is conducive to the development of table tennis, making table tennis more popular. However, this study only considers the impact of some rule changes on table tennis. There are other rule changes and factors, such as duration of play, the number of serves per point in table tennis matches, and so on, which might be an appropriate venue for future studies.

REFERENCES

- [1] J. Von Neumann, "On the theory of games of strategy," *Contributions to the Theory of Games*, Bd. 4, pp. 13-42, (1959).
- [2] H. Iida, N. Takeshita and Y. Jin, "A Metric for Entertainment of Boardgames: Its Implication for Evolution of Chess Variants," in *International Workshop on Entertainment Computing: Technologies & Applications*, (2002).
- [3] H. Iida, K. Takahara, J. Nagashima, Y. Kajihara and T. Hashimoto, "An Application of Game-Refinement Theory to Mah Jong," in *Proceedings of Icec Ndhoven*, (2004).
- [4] Z. Long, S. Xiong and H. Iida, "An Analysis of DOTA2 Using Game Refinement Measure," in *International Conference on Entertainment Computing*, (2017).
- [5] N. Nossal and H. Iida, "Game refinement theory and its application to score limit games," *2014 IEEE Games Media Entertainment*, pp. 1-3, (2014).
- [6] S. Das, "Top 10 Most Popular Sports in The World [Updated 2019]," (2019). [Online]. Available: <https://sportsshow.net/top-10-most-popular-sports-in-the-world/>.
- [7] A. P. Sutiono, A. Purwarianti and H. Iida, "A mathematical model of game refinement," in *International Conference on Intelligent Technologies for Interactive Entertainment*, (2014).
- [8] X. Hu, "Research on the development of table tennis," *Contemporary sports technology*, Bd. 4, Nr. 3, pp. 1-7, (2014).
- [9] Q. H. Chen, "Contemplation of the development of world table tennis," *Journal of Physical Education*, (2009).
- [10] L. Tiefeng, "Introduction to the ITTF organization," *Ping pong world*, Nr. 3, pp. 38-39, (1997).
- [11] F. Wei, F. Di and Z. Shouzhong, "Research on the Evolution and Development of Table Tennis Rules," *Journal of Jilin Institute of Physical Education*, Bd. 26, Nr. 5, pp. 62-64, (2010).
- [12] J. Q. Liu, B. Wang, X. Zhao and Y. Dou, "The Application of Rubber Materials on Table Tennis Racket," *Applied Mechanics and Materials*, Bd. 473, pp. 116-120, (2014).
- [13] T. Truscott, Z. Pan and J. Belden, "Why bigger may in fact be better in the context of table tennis," in *Aps Meeting*, (2014).
- [14] L. I. Jin-Liang, X. Zhao and C. H. Zhang, "Influence of New Rules on the Development of Table Tennis Techniques," *Journal of Beijing University of Physical Education*, (2005).
- [15] L. Xingxiang, Z. Yonghua and L. Jiangrong, "Mathematical problems in the table tennis

- system," *Journal of Yan'an University: Natural Science Edition*, Bd. 27, Nr. 3, pp. 16-20, (2008).
- [16] Z. Huiping, "Influence of inorganic glue on the development trend of world table tennis technology," *Journal of Hangzhou Normal University (Natural Science Edition)*, Bd. 9, Nr. 3, pp. 237-240, (2010).
- [17] K. Guo and S. Peng, "CAI teaching design and development for referee scoring of table tennis," in *International Conference on Multimedia Technology*, (2011).
- [18] S. Liu, X. Wu and R. Zhang, "Innovation and Development in Table Tennis," *Journal of Beijing University of Physical Education*, (1995).
- [19] T. Lan, M. A. Li and Q. Zhang, "Research on Tactical Strategies in the Different Phases of Competitive Table Tennis Matches with New Competition Regulations," *Journal of Shenyang Sport University*, (2008).
- [20] X. Li and X. Li, "The Study of the Table Tennis Receiver's Development Rule," in *International Conference on E-education*, (2010).
- [21] M. Dawei, N. Peng, C. Huafu and H. Tao, "Analysis of Equipment Innovation Trend under the Background of Table Tennis Development: Taking the Change of Table Tennis Shooting as an Example," *Sports World (Academic Edition)*, Nr. 11, pp. 48-49, (2017).
- [22] Z. Hao, X. L. Cai, Y. J. Hao, J. J. Zhang and M. L. Hao, "Analysis on Ryu Seungmin's Technique and Tactics in Man's Single Table Tennis Final and Semifinal of the 28th Olympic Games in Athens," *Journal of Beijing Sport University*, (2007).