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The effect of table tennis racket design on wrist motion

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The effect of table tennis racket design on wrist motion

by

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ABSTRACT

Unnatural postures have been identified as risk factors for hand/wrist injury problems. These postures are usually adopted among table tennis players. In attempt to alleviate wrist discomfort, alternative table tennis rackets have been designed to reduce awkward postures. Tenaly racket and Brodmann racket are the most representative rackets and are both currently available in the market. Additionally, a new horizontal racket was designed for this study, aiming to reduce wrist motion in the radial-ulnar plane. In this research, Tenaly racket, Brodmann racket, horizontal racket, together with traditional racket were evaluated in terms of performance, wrist range of motion, muscle activities and subjective rating. Thirty Iowa State University students participated in this study. They were divided into two groups (experienced and novice) based on preliminary test. In the experiment, participants were required to perform three stroke types: forehand drive, backhand drive and service with these four rackets. Hitting rate, wrist range of motion and muscle activities were obtained during the experiment. Participants were asked to fill out a subjective rating form after the experiment. Results from the experiment showed that subjects had best performance with Brodmann racket and worst performance with horizontal racket. Horizontal racket was the least favored racket in both groups. However, preferences of traditional, Tenaly and Brodmann racket differed between the two groups. The experienced group strongly favored traditional and Tenaly racket because they are powerful to speed balls. In the novice group, the subjective ranking scores of these three rackets were not significant. Also, Tenaly racket was proved as the only one that could improve the posture. No significant was found in terms of muscle activities.

CHAPTER 1. Introduction

1.1 Racket Sports

Racket sports have a wide appeal to a large population due to its unique attributes. This type of sports requires players to have strong personal playing skills. Besides, ease of the arrangement, relatively low cost and no age limit make the population have large access to this type of sports. The major racket sports include badminton, squash, table tennis and tennis. In the game of racket sports, players use rackets to hit a missile (ball or shuttle) so that their opponents are unable to return it back. The different types of racket sports are characterized by different sizes and shapes of area, hurdle, missile and racket [1]. In the sport of table tennis, players hit a lightweight, hollow ball back and forth using table tennis rackets. The game takes place on a hard table divided by a net.

The development and increasing popularity of racket sports in recent years has led to more scientific disciplines involved to understand all aspects of racket sports. Sports engineering is a field of engineering that involves the design, development and testing of sports equipment. There are four items of equipment that are important to all racket sports: the racket, the missile (ball or shuttle), the surface and the footwear [1]. Racket characteristics have changed markedly in recent years, largely as a result of the development of new materials [2]. The modern racket can be made lighter, stronger, stiffer and yield greater power than the one manufactured 20 years ago [3]. For table tennis, large amount of attention has been paid on the materials of blades and rubbers. Different types of blades and rubbers could produce various levels of speed, control and spin [4]. However, these improvements only focus on the performance while the prevention of musculoskeletal disoders (MSDs) are ignored.

Ergonomics risk factors are usually found when hand tools are being used. The use of

racket is therefore associated with the development of work-related musculoskeletal disorders among racket sports athletes. Upper extremity cumulative trauma disorders (CTDs) have been largely reported in racket sports players. It has been estimated that 50% of racket sports athletes will sustain wrist injuries, and 25% to 50% of these are from overuse [5]. Among all the racket sports, table tennis athletes are more susceptible to wrist injuries for the reason that many techniques are heavily dependent on the use of wrist. Awkward wrist postures and high repetition, which were both recognized as key ergonomics risk factors for CTDs, are highly involved in table tennis [6]. When the wrist is not in a neutral position, the tendons of these forearm muscles will compress against each other, the carpal bones and the flexor retinaculum. This compression increases inter-structural forces and friction among the tendons, resulting in tendinitis and other wrist injuries [7]. Armstrong and Chaffin found that flexion and extension of the wrist accounted for the high incidence of carpal tunnel syndrome in sewing machine operators [8]. Tanaka et al. found that radial and ulnar deviations were highly associated with carpal tunnel syndrome [9]. In addition to carpal tunnel syndrome, other problems such as De Quervains disease and lateral epicondylistis have also been associated with radial and ulnar wrist deviations [10].

In an attempt to address the impact of awkward postures on work-related MSDs, the tool redesign has been an area of interest to reduce wrist/hand discomfort and injuries [11] [12]. Many alternative table tennis rackets have been designed by the recreational players for personal fit or wrist comfort. Tenaly racket and Brodmann racket are the most representative in these rackets and are currently available in the market as commercial products.

1.2 Table Tennis Rackets

As illustrated in the Figure 1.1, the main feature of Tenaly racket is its bent handle. This design was based on an ergonomics design principle "Bend the tool, not the wrist." It was proposed that the wrist should be kept relatively in line with the handle during gripping, which could minimize the amount of unnatural wrist postures [13]. This principle has been widely applied to tools in industry, such as hammers, files and knives [14] [15] [16]. Also, the idea of bent handles for all tools and sports equipment was recommended by Bennett [17]. To grip this racket, the index finger is extended along the bottom of the racket, with the thumb being relaxed on the rubber. The bottom three fingers are used to grip the handle [4]. Figure 1.2 intuitively suggests that this bent-handle racket would reduce unnatural postures in radial-ulnar plane. However, the lack of symmetry along the axis of the racket may make it hard for players to estimate the ball's landing spot on the racket. This difficulty may lead to reduced performance.

Figure 1.1 Tenaly racket

Figure 1.2 Grip posture of Tenaly racket

Brodmann racket (Figure 1.3) works like a glove worn over either hand. Players could hit balls using this racket as if using their hands for forehand and backhand strokes. As a result, the wrist posture could be more natural with this racket compared to traditional and Tenaly rackets. Additionally, more sensory feedback and intuitive coordination could be gained from this racket, resulting in better performance.

Figure 1.3 Brodmann racket

Besides the above two rackets, another new type - horizontal racket (see Figure 1.4) was specially designed for this study. The handle of this racket is perpendicular to its head. To grip this racket, four fingers wrap around the handle while the thumb hold one of the end, as shown in Figure 1.5.

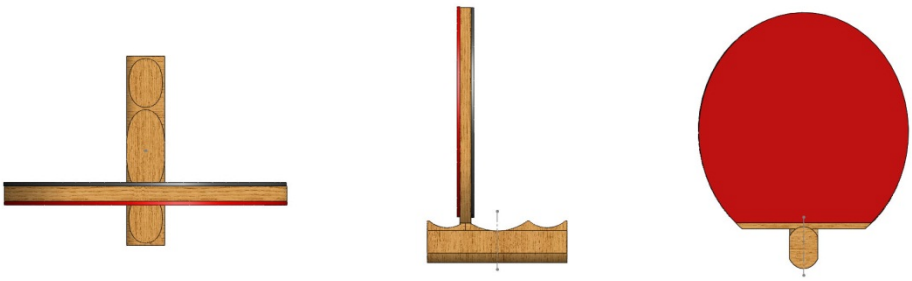

Figure 1.4 Hotizontal racket

Figure 1.5 Grip posture of hotizontal racket

The basic purposes of wrist usage in table tennis include: (1) speeding the ball, (2) spinning the ball, and (3) using last moment changes in wrist angle to deceptively change the direction of the ball. The wrist motions in flexion-extension plane and radial-ulnar plane have different purposes when using different rackets, as summarized in Table 1.1. For the traditional and Tenaly rackets, the wrist motions in both plane are involved to speed and spin balls (combination style). For this newly designed racket, the purpose of the wrist motion in flexion-extension plane and radial-ulnar plane is to spin the ball and speed the ball, respectively. The purpose of wrist motion in the two planes of Brodmann racket is opposite to that of horizontal racket. However, speeding the ball is heavily dependent on the snapping of arm rather than wrist motion. Therefore, the wrist motion in radial-ulnar plane could be highly reduced when using horizontal racket to speed the ball. Also, it is not involved when using this racket to spin the ball. As a result, the awkward posture (typically radial deviation) could be reduced.

Table 1.1 Wrist motion analysis for different rackets

Racket Type	add speed	add spin
Traditional	combination	combination
Tenaly	combination	combination
Brodmann	flexion-extension plane	radial-ulnar plane
Horizontal	radial-ulnar plane	flexion-extension plane

1.3 Research Hypothesis

As of today, no scientific study examines the effects of these redesigned rackets on the reduction of awkward postures. Moreover, their effects on experienced players and novice players might be different. For this purpose, this study is to investigate the effects of different rackets on wrist motions, hitting rate, muscle activities and subjective rating in both experienced group and novice group. The specific research hypotheses for this study are as following:

1. Brodmann, Tenaly and horizontal rackets are significantly better than traditional racket in terms of ergonomics benefits, specifically, wrist motion.

2. The hitting rate of Brodmann racket is significantly higher than that of the other three rackets while the hitting rate of Tenaly racket is significantly lower than that of the other three rackets.

3. Rackets preference between novice players and experienced players are significantly different. The novice players prefer the Brodmann racket while the experienced players prefer the traditional racket.

CHAPTER 2. Methodology

2.1 Participants

Thirty individuals (students of Iowa State University) with no wrist injuries histories participated in this study. Their ages ranged from 19 to 30 years, with a mean of 22.83 years. The participants were divided into two groups (novice group and experienced group) based on the preliminary test. The novice group was consisted of fifteen individuals. There were four males and eleven females in this group. One of them was left handed. The experienced group was consisted of fifteen individuals. There were twelve males and three females in this group. Three of them were left handed.

2.2 Apparatus

2.2.1 Rackets

The traditional racket used in this study was a Stiga Aspire table tennis racket with 5 ply blade, 1.5 mm sponge and inverted rubber. The non-traditional rackets used in this experiment were made from three traditional rackets. For the Tenaly racket, the original handle was cut off and replaced with a new one. The degree between the head and the new handle was 30 degree. For the Horizontal racket, the original handle was replaced with a new one which was perpendicular to the head. The Brodmann racket was composed of two traditional heads for forehand stroke and backhand stroke respectively. There were two pieces of wood in between and one of them with a hole was intended for holding thumb. Except for handles, all the materials of the four rackets were the same. The four rackets can be seen in Figure 2.1.

Figure 2.1 Four rackets used in this study

2.2.2 Robot Pong

A Robot Pong (Figure 2.2 Left) was used as the server to feed balls for participants in this study. The speed and frequency of balls served by this machine could be adjusted through the control box (Figure 2.2 Right). In this experiment, the speed and frequency were both set to 5 at which level novice players felt comfortable to adapt.

Figure 2.2 Robot pong and control box

2.3 Experimental Design

2.3.1 Independent Variables

The independent variables in this study were group, stroke type and racket type. There were two levels of group:

(1) Experienced group

(2) Novice group

There were three types of stroke:

(1) forehand drive

(2) backhand drive

(3) basic service

There were four types of racket:

(1) traditional racket

(2) Tenaly racket

(3) Brodmann racket

(4) horizontal racket

2.3.2 Dependent Variables

The dependent variables were

(1) wrist range of motion (ROM)

(2) muscle activities

(3) hitting rate

(4) subjective rating

2.3.3 Measurements

Two goniometers were used to measure the wrist ROM that a participant travelled through when striking balls. One of the goniometers was positioned on the top of the wrist to measure wrist ROM in flexion-extension plane and the other one on the outside of the wrist for radial-ulnar plane.

The muscle activities were measured by surface electromyography (sEMG). According to the literatures and pilot study, extensor digitorum and flexor carpi ulnaris were identified to be the major muscles used when hitting balls [18]. For this measurement, electrodes were placed on participants'forearms and in directions which were parallel with the fibers of these two muscles[19] [20].

Both the bend sensors and sEMG sensors were connected to a FlexComp Infinity encoder. This encoder recorded raw data and saved it to the BioGraph Infinity Software. This software has the ability to rectify and filter raw data. The sEMG data passed through two filters after being rectified: a notch filter which removes noise caused by electronic devices, and an IIR filter which removes additional artifacts such as heart rate and wire movement.

The hitting rate was calculated by the following equation:

$$\text{hitting rate} = \frac{\text{the number of successful hit}}{\text{the total number of balls}} \tag{2.1}$$

A video camera was used to record the total number of balls and the number of successful hit. For forehand and backhand drives, the strike was counted as successful hit if it passed over the net and hit the opponent's side of table. For the service, the strike was counted as successful hit if the ball first hit the server's end of table, then passed over the net and hit the opponent's side of table finally.

Subjective rating was administered in the form of questionnaire after the experiment. The participants were required to rate the characteristics of the four rackets. Also, participants were required to rank the four rackets for each stroke (See Appendix B).

Figure 2.3 shows the experiment settings.

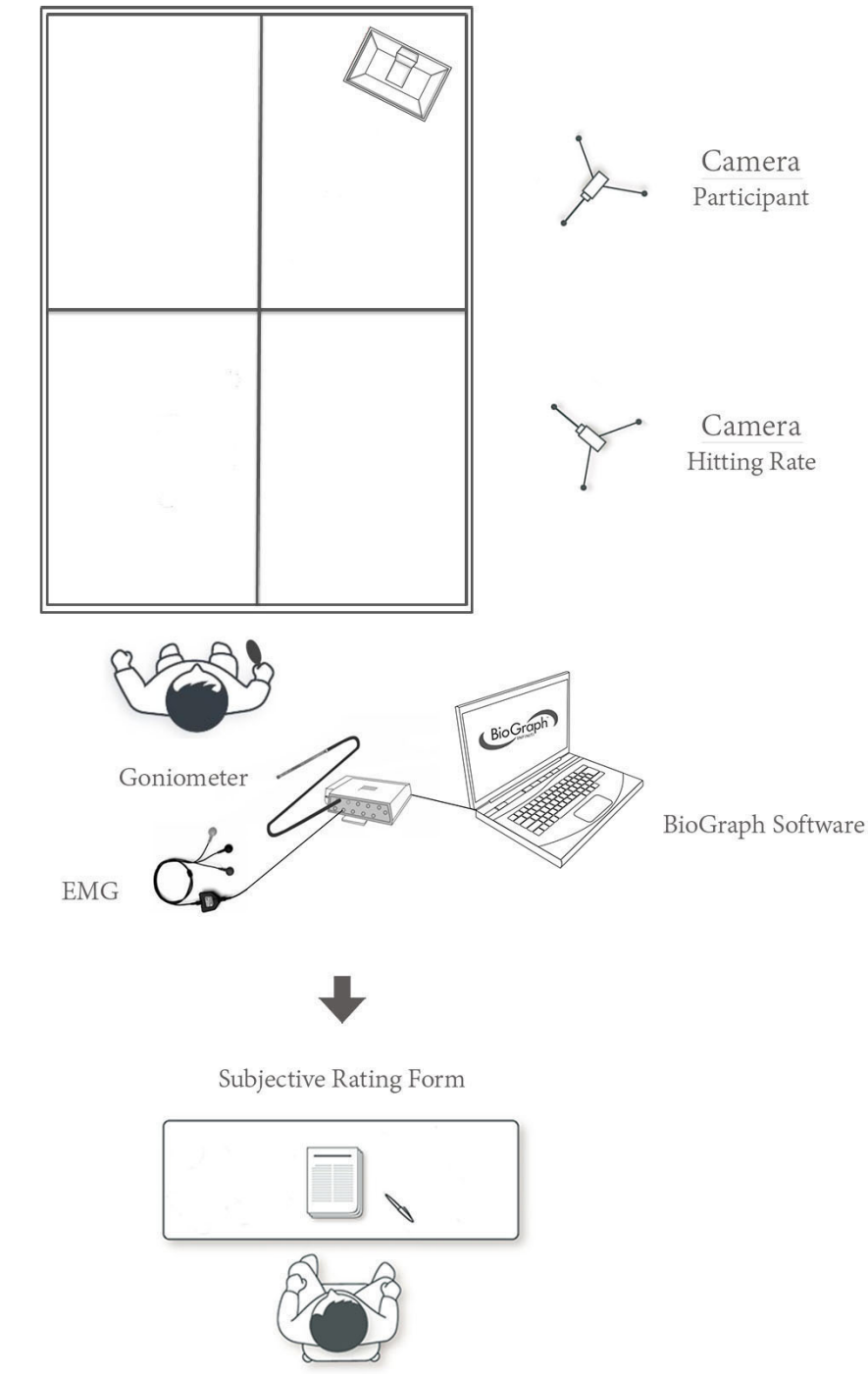

Figure 2.3 Experiment settings

2.4 Experimental Process

Before the experiment, each subject was required to fill out a consent form approved by Iowa State University Institutional Review Board. The anthropometric information and maximum voluntary contractions (MVC) of each subject were gathered. The MVC values were used to normalize the data to determine the level of exertion of the muscles.

Subjects were then demonstrated how to perform forehand drive, backhand drive and basic service using each racket. The ball's route and the participant's standing position of each stroke type are shown in the Figure 2.4.

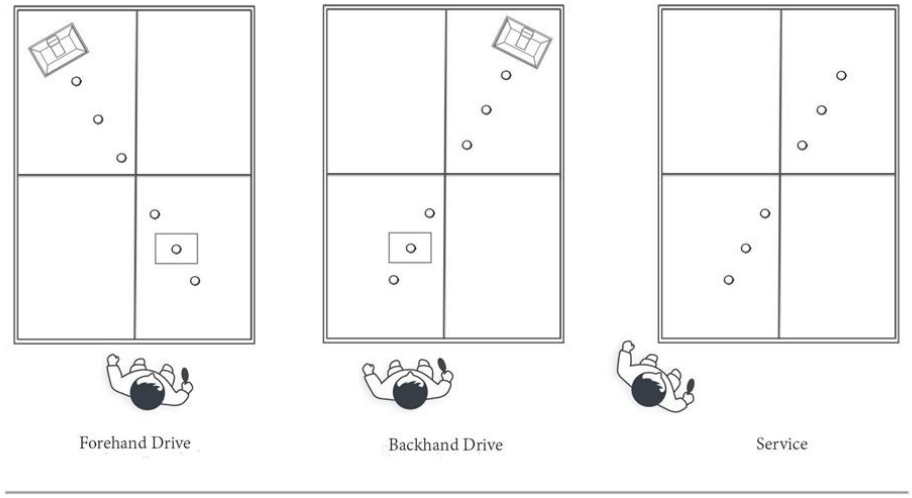

Figure 2.4 The routs of balls and standing position

After the demo session, participants were asked to have preliminary test. In the test, they were required to perform forehand drive, backhand drive and basic service using traditional racket. Participants were assigned to the corresponding group (experienced group or novice group) based on the test results (See Appendix A).

In the training session, the subjects of experienced group practiced each stroke with three non-traditional rackets while the subjects of novice group with all the rackets. The training setups of two groups are shown in the Table 2.1 and Table 2.2.

After the training session, participants began the formal test. Each participant used the four rackets to perform the three strokes respectively and the setup is shown in Table 2.3. The

Table 2.1 Training setup of novice group (Unit: hit)

Racket Type	FH	BH	Service
Traditional	60	60	30
Tenaly	60	60	30
Brodmann	60	60	30
Horizontal	60	60	30

Table 2.2 Training setup of experienced group (Unit: hit)

Racket Type	FH	BH	Service
Tenaly	30	30	15
Brodmann	30	30	15
Horizontal	30	30	15

order of the rackets was randomized for each participant. After the test, participants were asked to finish the subjective rating forms.

2.5 Data Analysis

All the data collected from the EMG sensors and bend sensors were normalized first. To normalize the EMG data, all EMG data points were divided by MVC, allowing a comparison across individuals. The wrist angle data was also normalized in the same fashion using the maximum values gathered from anthropometric measurement.

Then analysis of variance (ANOVA) was conducted to determine the effects of different rackets on the wrist motion, EMG activities, hitting rate and subjective rating score. A significant level of 0.05 was adopted.

Table 2.3 Experiment setup (Unit: hit)

Racket Type	FH	BH	Service
Traditional	30	30	20
Tenaly	30	30	20
Brodmann	30	30	20
Horizontal	30	30	20

CHAPTER 3. Results

3.1 Overall Performance

Prior to analysis, the hitting rate of service was Sin and square root transformed to meet the equal variance assumption of ANOVA. As Table 3.1 showed, the interaction effect between racket type and stroke type was significant. Therefore, the simple main effects of racket at each stroke type were examined.

Table 3.1 ANOVA results of hitting rate

Source	F Ratio	Prob >F
Group	18.6532	<0.001*
Stroke Type	7.8933	0.0004*
Racket Type	7.9387	<0.0001*
Group * Racket Type	2.5838	0.0532
Group * Stroke Type	5.2332	0.0058*
Racket Type * Stroke Type	6.6103	<0.0001*
Group * Stroke Type * Racket Type	0.7723	0.5922

Figure 3.1 compared the hitting rates of different rackets for all three strokes. This figure showed that:

1. The obvious difference of hitting rate only existed at the forehand drive level.

2. For the forehand drive, the hitting rate of Brodmann racket was the highest while that of horizontal racket was the lowest.

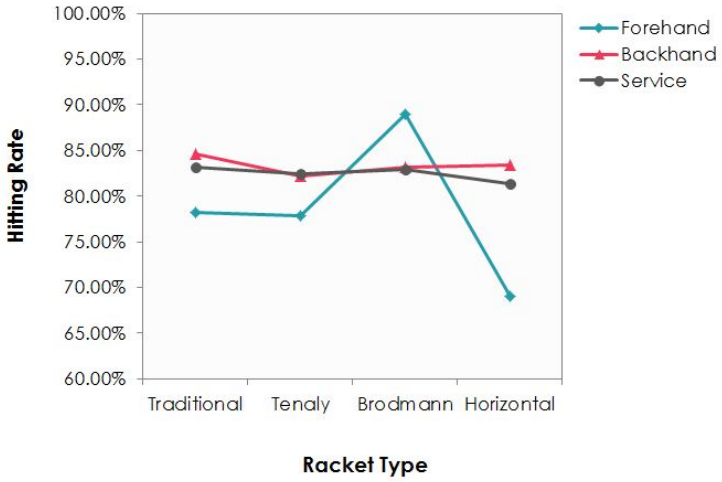

Figure 3.1 Means of hitting rate

The post hoc test was conducted to further explore the results. For the forehand drive, the hitting rate of Brodmann racket was higher than those of all other three rackets and the differences were significant ($p < 0.05$) or highly significant ($p < 0.01$), as shown in Table 3.2. Also, the hitting rates of traditional racket and Tenaly racket were significantly higher than that of horizontal racket. For the backhand drive and service, no significant difference was found.

Table 3.2 Post Hoc Test results of hitting rate of forehand drive

	Mean Difference	Lower CL	Upper CL	p Value
Brodmann-Horizontal	19.99%	11.41%	28.57%	<0.0001*
Brodmann-Tenaly	11.18%	2.63%	19.46%	0.0051*
Brodmann-Traditional	10.85%	2.41%	19.42%	0.0070*
Traditional-Horizontal	9.14%	0.56%	17.77%	0.0320*
Tenaly-Horizontal	8.81%	0.23%	17.39%	0.0417*
Traditional-Tenaly	3.3%	-8.24%	8.90%	0.9996

3.2 Overall Preferences

After the experiment, participants were asked to rank the four rackets (1 represented the least preferred one and 4 represented the most preferred one) for each stroke type. As Table 3.3 presented, there existed the interaction effect between group and racket type.

Table 3.3 ANOVA results of subjective ranking

Source	F Ratio	Prob >F
Group	0.0584	0.8092
Stroke Type	0.0255	0.9748
Racket Type	76.1788	<0.0001*
Group * Racket Type	8.7238	<0.0001*
Group * Stroke Type	0.0255	0.9748
Racket Type * Stroke Type	0.8813	0.5087
Group * Stroke Type * Racket Type	0.9823	0.4371

Figure 3.2 showed the means of subjective ranking scores of experienced and novice groups. This figure indicated that:

1. The horizontal racket was the least preferred one in both groups.

2. The preferences of traditional racket and Brodmann racket were different between these two groups.

The statistical results proved both of the above points. Table 3.4 and 3.5 presented the Post Hoc Test results of subjective ranking scores of both groups. In the experienced group, the ranking scores of traditional racket and Tenaly racket were higher than those of Brodmann racket and horizontal Racket, all with highly significant differences (P-value <0.0001). And also the ranking score of Brodmann racket was higher than that of horizontal racket (P-value=0.0003). In the novice group, the subjective scores of Brodmann, Tenaly and traditional rackets were significantly higher than that of horizontal racket, all with highly significant differences (P-value <0.0001).

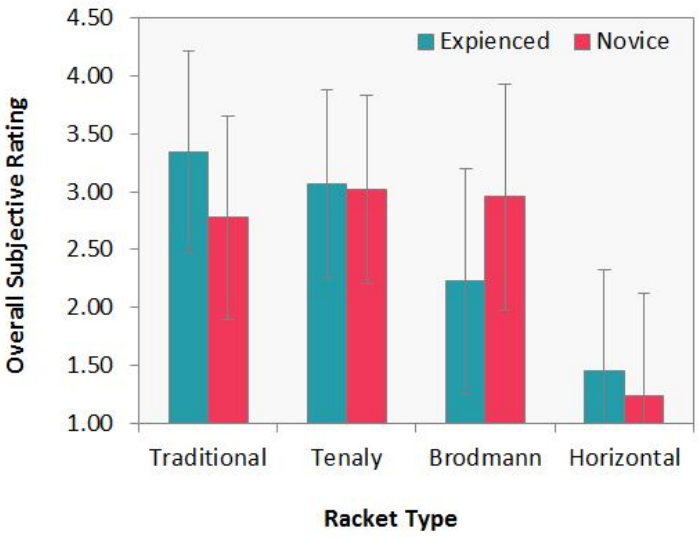

Figure 3.2 Means of subjective ranking

Table 3.4 Post Hoc Test results of subjective ranking (experienced group)

	Mean Difference	Lower CL	Upper CL	p Value
Traditional-Horizontal	1.8864	1.4068	2.3660	<0.0001*
Tenaly-Horizontal	1.6136	1.1340	2.0932	<0.0001*
Traditional-Brodmann	1.1136	1.6340	1.5932	<0.0001*
Tenaly-Brodmann	0.8409	0.3613	1.3205	<0.0001*
Brodmann-Horizontal	0.7727	0.2931	1.2523	0.0003*
Traditional-Tenaly	0.2727	-0.2069	0.7523	0.4547

Table 3.5 Post Hoc Test results of subjective ranking (novice group)

	Mean Difference	Lower CL	Upper CL	p Value
Tenaly-Horizontal	1.7778	1.3097	2.2459	<0.0001*
Brodmann-Horizontal	1.7111	1.2430	2.1792	<0.0001*
Traditional-Horizontal	1.5333	1.0652	2.0014	<0.0001*
Tenaly-Traditional	0.2444	-0.2237	0.7125	0.5296
Brodmann-Traditional	0.1778	-0.2903	0.6459	0.7581
Tenaly-Brodmann	0.0667	-0.4014	0.5348	0.9827

3.3 Wrist Motion

3.3.1 Wrist Range of Motion in Radial-Ulnar Plane

As Table 3.6 presented, there existed the interaction effect between racket type and stroke type. Therefore, the simple main effect of racket type was further examined at each stroke type.

Table 3.6 ANOVA results of wrist range of motion in radial-ulnar plane

Source	F Ratio	Prob >F
Group	3.8796	0.0497*
Stroke Type	3.6402	0.0273*
Racket Type	12.6796	<0.0001*
Group * Racket Type	0.4579	0.7119
Group * Stroke Type	0.5202	0.5949
Racket Type * Stroke Type	2.4519	0.0247*
Group * Stroke Type * Racket Type	0.2554	0.9569

Figure 3.3 showed the means of wrist ROM in radial-ulnar plane. From this figure, we could learn that the wrist ROM of Tenaly racket were the lowest for all the stroke types. Also, the wrist ROM of Brodmann racket was obviously lower than that of traditional and horizontal rackets at the forehand drive level.

The significance of difference was further analyzed by the post hoc test. As shown in Table 3.7 showed, for the forehand drive, the wrist ROM of Tenaly racket and Brodmann rackets were significantly lower than those of the other two rackets. And also, the wrist ROM of Tenaly racket was significant lower than that of Brodmann racket. For the backhand drive, the wrist ROM of Tenaly racket was only significantly lower than that of Brodmann racket, with P value = 0.0366. Finally, for the service, as showed in Table 3.8, the wrist ROM of Tenaly racket was significantly lower than those of traditional and horizontal rackets. Plus, the wrist ROM of Brodmann racket was significantly lower than that of traditional racket.

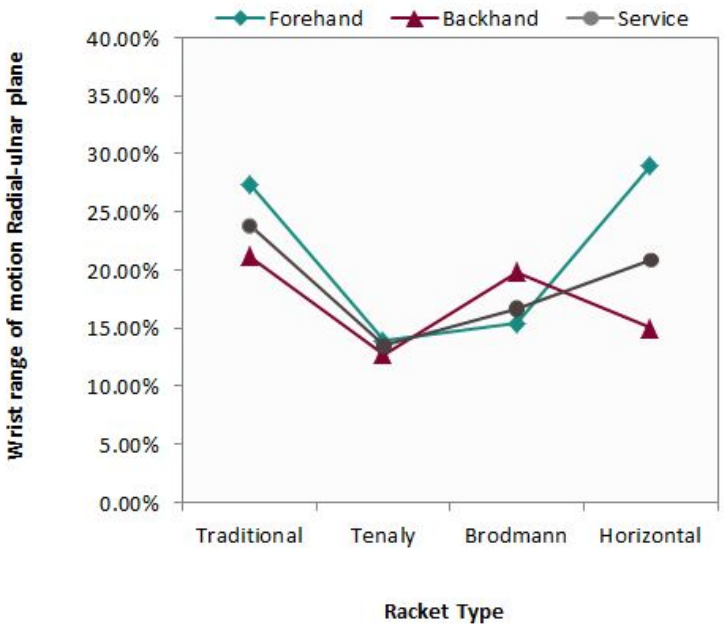

Figure 3.3 Means of wrist ROM in radial-ulnar plane

Table 3.7 Post Hoc Test results of wrist ROM in radial-ulnar Plane of forehand drive

	Mean Difference	Lower CL	Upper CL	p Value
Horizontal-Tenaly	14.13%	4.39%	24.87%	0.0014*
Traditional-Tenaly	13.51%	3.59%	23.42%	0.0031*
Horizontal-Brodmann	11.58%	0.18%	21.32%	0.0128*
Traditional-Brodmann	10.96%	1.04%	20.87%	0.0241*
Brodmann-Tenaly	2.55%	-7.18%	12.29%	0.9031
Horizontal-Traditional	0.62%	-9.28%	10.54%	0.9984

Table 3.8 Post Hoc Test results of wrist ROM in radial-ulnar plane of service

	Mean Difference	Lower CL	Upper CL	p Value
Traditional-Tenaly	10.35%	3.83%	16.86%	0.0004*
Horizontal-Tenaly	7.33%	0.82%	13.84%	0.0207*
Traditional-Brodmann	7.21%	0.58%	13.84%	0.0271*

3.3.2 Wrist Range of Motion in Flexion-Extension Plane

As Table 3.9 presented, interaction effects between stroke and racket were significant. The racket effects for each stroke (forehand, backhand and service) were therefore examined.

Table 3.9 ANOVA results of wrist range of motion in flexion-extension plane

Source	F Ratio	Prob >F
Group	7.3864	0.0069*
Stroke Type	32.2283	<0.001*
Racket Type	18.1228	<0.001*
Group * Racket Type	1.5240	0.2082
Group * Stroke Type	1.0090	0.3657
Racket Type * Stroke Type	10.2527	<0.001*
Group * Stroke Type * Racket Type	1.0147	0.4156

Figure 3.4 showed the means of wrist ROM in flexion-extension plane. From this figure, we could see that the wrist ROM of Brodmann racket were highest for forehand drive and service. The significance of difference was further analyzed by post hoc test. For the forehand drive, as shown in Table 3.10, the wrist ROM of Brodmann racket was significantly higher than those of all the other three rackets. For the service, these differences were also significant between Brodmann and the other three racket (See Table 3.11). Also, the wrist ROM of traditional racket was significantly higher than that of horizontal racket. No significant difference was found for backhand drive in both groups.

Table 3.10 Post Hoc Test results of wrist ROM in flexion-extension plane of forehand drive

	Mean Difference	Lower CL	Upper CL	p Value
Brodmann-Horizontal	12.01%	6.70%	17.31%	<0.0001*
Brodmann-Tenaly	10.30%	4.94%	15.65%	<0.0001*
Brodmann-Traditional	8.56%	3.26%	13.87%	0.0003*

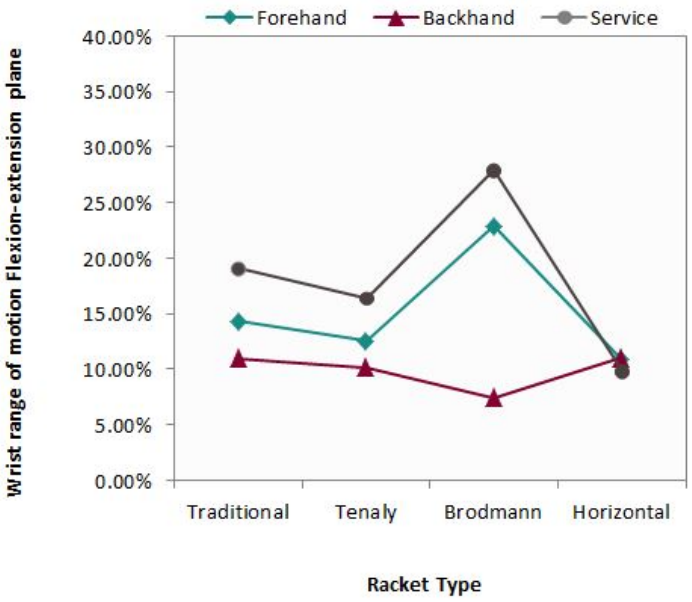

Figure 3.4 Means of wrist ROM in flexion-extension plane

Table 3.11 Post Hoc Test results of wrist ROM in flexion-extension plane of service

	Mean Difference	Lower CL	Upper CL	p Value
Brodmann-Horizontal	18.10%	11.61%	24.59%	<0.0001*
Brodmann-Tenaly	11.49%	5.05%	17.93%	<0.0001*
Traditional-Horizontal	9.25%	2.70%	15.80%	0.0020*
Brodmann-Traditional	8.85%	2.23%	15.40%	0.0415*

3.4 Muscle Activities

Table 3.12 and Table 3.13 revealed that there was no interaction effects in terms of EMG (%MVC) for flexor and extensor. The main effect of racket type was also not significant. Figure 3.5 showed the means of EMG (%MVC) for flexor and extensor.

Table 3.12 ANOVA results of Flexor Activities

Source	F Ratio	Prob >F
Group	0.0575	0.8107
Stroke Type	0.4643	0.6292
Racket Type	0.2445	0.8652
Group * Racket Type	0.2334	0.8731
Group * Stroke Type	3.4057	0.0351*
Racket Type * Stroke Type	0.2151	0.9717
Group * Stroke Type * Racket Type	0.1572	0.9874

Table 3.13 ANOVA results of Extensor Activities

Source	F Ratio	Prob >F
Group	2.7231	0.1003
Stroke Type	2.2335	0.1095
Racket Type	0.4765	0.6989
Group * Racket Type	0.1532	0.9276
Group * Stroke Type	0.0925	0.9117
Racket Type * Stroke Type	0.3735	0.8954
Group * Stroke Type * Racket Type	0.4577	0.8390

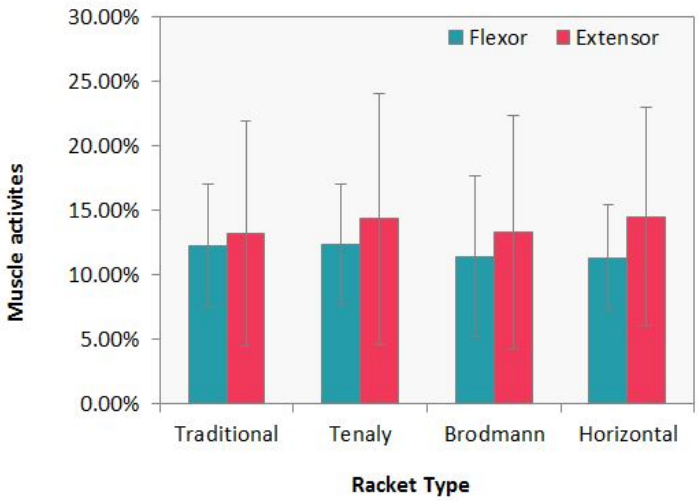

Figure 3.5 Means of muscle activities

CHAPTER 4. Discussion

The purpose of this study is to evaluate the effect of different types of table tennis rackets on players. It was assessed by several aspects: wrist range of motion, muscle activities, hitting rate and subjective ranking. It was proposed that the three non-traditional rackets (Tenaly racket, Brodmann racket and horizontal racket) would significantly reduce wrist motion. Also, it was hypothesized that players would have the best performance when using Brodmann racket while have the worst performance when using Tenaly racket. Finally, when comparing experienced players and novice players, it was hypothesized that the preference of rackets would differ. The results will be discussed in detail in this chapter.

4.1 Overall Performance

The experimental results revealed that the significant differences in terms of hitting rate only existed for forehand drive. The hitting rate of Brodmann racket was the highest, next were traditional and Tenaly racket, and horizontal racket was the lowest. Two factors might probably account for the players' better performance when using Brodmann racket.

1. For the forehand drive, players should keep the paddle facing downward at a certain angle when snapping the arm (See Figure 4.1). When the racket is kept at a wrong angle, as shown in Figure 4.2, the ball will fly out. The desired angle could be achieved easily with a neutral wrist posture when using Brodmann racket. However, players had to twist their wrists or even higher their elbows to keep the head facing downward when using horizontal racket.

2. Players hit balls using Brodmann racket as if using their palms, as mentioned in Chapter 1. Consequently, it is much easier to estimate the ball's landing spot on the face and use the central area of the face to hit balls, resulting in higher hitting rate.

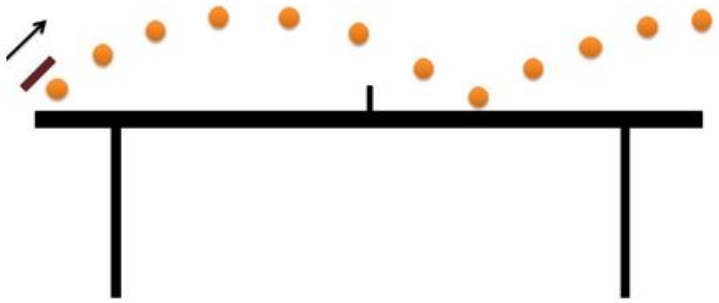

Figure 4.1 Correct racket angle for forehand drive

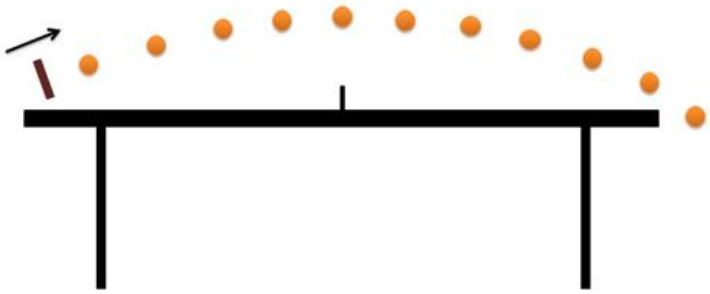

Figure 4.2 Wrong racket angle for forehand drive

Also, the lack of significant difference between traditional and Tenaly racket in terms of hitting rate indicated that the asymmetry axis of Tenaly racket has not detrimental effect on performance.

4.2 Overall Preferences

When looking at the preferences of rackets, it is evident that horizontal racket was the least preferred one in both groups. The main reasons for this were the poor performance and wrist discomfort associated with this racket. The results also indicated that the experienced group strongly favored traditional and Tenaly racket, which is in line with the expectation. Based on the verbal feedback provided, the experienced group preferred these two rackets because they are more powerful when speeding balls. This is due to their longer "lever arms" - handles. For the novice group, despite the significantly better performance when using Brodmann racket,

no significant difference in terms of preference was found among Brodmann, traditional and Tenaly rackets.

4.3 Wrist Motion

Based on the results of wrist ROM, only Tenaly racket has postural advantage, thereby rejecting hypothesis 1. Although the wrist ROM in radial-ulnar plane could be significantly reduced when using Brodmann racket, the wrist ROM in flexion-extension plane was highest with this racket. Finally, it was proved that horizontal racket could not improve posture at all. The wrist motions characteristics of different rackets are discussed as following:

1. Tenaly racket

Tenaly racket was associated with significantly reduced wrist ROM in the radial-ulnar plane. For the forehand drive and backhand drive, extreme ulnar deviation postures are always adopted by players in order to add more spin on the balls (See Figure 4.3). However, such purpose could be achieved with more neutral wrist posture when using Tenaly racket, therefore reducing the wrist ROM.

Figure 4.3 Wrist postures

2. Horizontal racket

For forehand drive, as discussed in the previous section, players must twist their wrists to keep racket face at a correct angle when using horizontal racket. The extreme ulnar deviation posture was involved in this twisting motion. For the backhand drive, the posture of radial deviation had to be adopted in order to keep the face parallel to player's body.

3. Brodmann racket

For the forehand drive and service, the wrist ROM in the flexion-extension plane of Brodmann racket were significantly higher than those of the other rackets. Based on the video, the author found that the players inclined to speed balls using more wrist motions with Brodmann racket. A possible explanation is that, compared to the other rackets, the wrist movement is the least restrictive when using Brodmann racket. For the backhand drive, no significant difference was found. A plausible explanation is that backhand drive is always defensive stroke type in table tennis. Therefore, the speed is not highly required.

4.4 Muscle Activities

No significant difference was found for muscle activities in both groups. Multiple factors such as wrist ROM and grip force could contribute to different levels of muscle exertion. According to the pilot study, it was proved that no large amount of grip force was required to grip rackets' handles. Therefore, the wrist ROM was identified as the major contributor to the muscle activities in this study. The lack of significance regarding muscle activities might be understandable when looking at the experimental results of wrist ROM and EMG (%MVC). The results revealed that all the wrist ROM in radial-ulnar plane were below 30% and all the wrist ROM in flexion-extension plane were below 35%. Additionally, all the EMG (%MVC) of flexor carpi ulnaris and extensor digitorum were below 15%. These results indicated that, in spite of the significant differences in terms of wrist ROM between different rackets were found, the wrist ROM were not large, resulting in low level of muscle activities. Therefore, the difference in terms of muscle activities were not significant.

CHAPTER 5. Conclusion

This study investigated the ergonomic impact (via posture), performance impact and subjective rating of four different table tennis rackets. The laboratory evaluation results showed that the wrist range of motion (ROM) in radial-ulnar plane were significantly reduced when using Tenaly racket. There was no significant posture improvement with Brodmann racket and horizontal racket. Players had higher hitting rate when using Brodmann racket while the lowest hitting rate when using horizontal racket. There was a difference between experienced players and novice players in preference of rackets. The experienced group strongly favored traditional racket and Tenaly racket because they are more powerful to speed balls. The novice group had no significant preference among Brodmann, traditional and Tenaly rackets. The horizontal racket was the least preferred one in both groups. No significant results was found in terms of muscle activities.

When considering all these factors, Tenaly racket is highly recommended for two reasons:(1) wrist motion in radial-ulnar plane could be significantly reduced, and (2) the asymmetry axis of this racket has not detrimental effect on performance. Although the hitting rate of Brodmann racket was the highest, this racket has no postural advantage. Also, Brodmann rackets is not as powerful as traditional and Tenaly racket to speed/spin balls.

5.1 Limitations

The major limitations of this study are summarized as followed:

1. Although the individuals participated in this study were divided into experienced and novice group, compared to real professional players, all of them were still recreational table tennis players. These varied playing levels might led to the non-standard postures, exerting a negative effect on the wrist motion data collected in the experiment.

2. In this study, the performance was evaluated only based on hitting rate. However, a comprehensive assessment of racket should also consider other factors such as: (1) easiness to speed balls, and (2) easiness to spin balls (topspin, backspin, left/right spin).

3. The stroke types involved in this study are all elementary strokes in table tennis. Other advanced strokes such as smash, chop, push and etc. were not considered.

4. It was believed that different racket designs would have different effects on other body parts, such as elbow, shoulder or even waist. However, in this study, the author just evaluated the effect of different table tennis rackets on the wrist of players.

5.2 Future Work

Designing an improved racket based on the result of this study would be a major area of interest for future work. A study which takes elbow, shoulder and waist into account might allow for more insights of the effect of racket design on players. Finally, this study could be extended to other racket sports, which might help to reduce the chance of repetitive injuries among all racket sports players.

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APPENDIX A. Preliminary Test

- **Test Goal**

  To separate participants into 2 groups (novice and experienced)

- **Test Racket**

  Traditional racket

- **Test Preparation**

  Each participant will have 5 minutes for preparation.

  The aim is: (1) Participants could get an idea of how to return the balls served by a machine. (2) Participants could be familiar with characteristics of the served balls, such as speed, frequency and drop spots on the table, etc.

- **Test Rules**

  Each participant will have 3 groups of balls for each stroke type and there will be 10 balls in each group. Participants who reach the following standards will be separated into experienced group:

  1. The hitting rate averages of all three strike types are above 7.
  2. The rating scale of grip posture is 3.
  3. The rating scale of striking posture is higher than or equal to 2.

Grip posture Rating (Rating Scale: 1-3)

Rating scale3: Correct shake hand grip posture are adopted, which means the index finger is extended along the bottom of the racket, with the thumb being relaxed on the rubber and the bottom three fingers are used to grip the handle.

Rating scale2: Participants adopt such grip postures as (1) all the fingers are used to grip the handle; (2) the position of index finger and thumb are correct but all other fingers are not used to grip the handle.

Rating scale1: Uncommon postures adopted

Striking posture Rating (Rating Scale: 1-3)

Rating scale3: Correct postures adopted for all three strokes

Rating scale2: Correct postures adopted for FH drive and BH drive

Incorrect postures adopted for service

Rating scale1: Uncommon postures adopted

NOTE:

For FH drive and BH drive: strike will be counted as hit if the ball:

(1) pass over the net

(2) hit the opponents end of table; otherwise, it will be counted as miss.

For Service: strike will be counted as hit if the ball:

(1) hit the servers end of table first

(2) pass over the net

(3) hit the opponents end of table; otherwise, it will be counted as miss.

APPENDIX B. Subjective Rating Form

1. Please rate the four rackets you used in the experiment according to your perceived feelings.

Attributes Type I	Racket Type	Rate the racket using the scale below: 1=worst level, 5 =best level
Control	Traditional	1--------2---------3--------4--------5
	Brodmann	1--------2---------3--------4--------5
	Tenaly	1--------2---------3--------4--------5
	Horizontal	1--------2---------3--------4--------5
Ease to exert force	Traditional	1--------2---------3--------4--------5
	Brodmann	1--------2---------3--------4--------5
	Tenaly	1--------2---------3--------4--------5
	Horizontal	1--------2---------3--------4--------5
Wrist Flexibility	Traditional	1--------2---------3--------4--------5
	Brodmann	1--------2---------3--------4--------5
	Tenaly	1--------2---------3--------4--------5
	Horizontal	1--------2---------3--------4--------5
Sensory Feedback	Traditional	1--------2---------3--------4--------5
	Brodmann	1--------2---------3--------4--------5
	Tenaly	1--------2---------3--------4--------5
	Horizontal	1--------2---------3--------4--------5
Attributes Type II	**Racket Type**	**Rate the racket using the scale below: 1=no discomfort, 5 =worst imaginable discomfort**
Wrist Fatigue or Discomfort	Traditional	1--------2---------3--------4--------5
	Brodmann	1--------2---------3--------4--------5
	Tenaly	1--------2---------3--------4--------5
	Horizontal	1--------2---------3--------4--------5
Shoulder Fatigue or Discomfort	Traditional	1--------2---------3--------4--------5
	Brodmann	1--------2---------3--------4--------5
	Tenaly	1--------2---------3--------4--------5
	Horizontal	1--------2---------3--------4--------5

2. In the experiment, three basic strokes are required to finish with each racket. Please rank the rackets for the overall ease or comfort of each stroke. Please use 1-4 to rank the rackets and score: 1 represents the least preferred one while score 4 represents the most preferred one.

Stroke Type	Racket Type			
	Traditional	Brodmann	Tenaly	Horizontal
Service				
FH Drive				
BH Block				

3. Would you purchase/use one of the non-traditional rackets if they are available in the market (all else such as price are equal)?

4. If your answer of question 3 is Yes, which racket do you prefer to choose and why?

5. Do you have other comments or suggestions about these rackets?