Wearable Device to Inhibit Wrist Dorsiflexion for Improving Movement Form in Table Tennis Backhand

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Wearable device to inhibit wrist dorsiflexion for improving movement form in table tennis backhand

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***Abstract*— Proper movement form is crucial in sports. However, novices often struggle to achieve it without proper guidance. While current engineering research has introduced devices to facilitate necessary movements, our research explores the potential of a device that eliminates unnecessary movement. We developed a wearable device to restrict wrist dorsiflexion during table tennis backhand motion. In this study, experiments were conducted to investigate the effect of the device and compare the teaching of movements by the device with verbal instruction. Novice table tennis players were divided into three groups for our experiments: the experimental group used the device, the oral group received verbal instructions to minimize wrist movement, and the control group received neither the device nor verbal guidance. Each group consisted of four participants. Comparative analysis among the groups revealed that three out of four participants in the experimental group tended to suppress their wrist motion and utilize their elbows while using the device. Furthermore, upon removing the device, these three participants also tended to suppress wrist motion and utilize their elbows, indicating enhanced movement form. In contrast, the oral group demonstrated suppressed wrist movement during instruction, yet tended to underutilize elbow movement. Based on these findings, it can be concluded that the use of our device contributed to a proper movement form.**

I. INTRODUCTION

Proper body motion is important in sports for several reasons. Firstly, it helps prevent injury. Take golf as an example, where amateur golfers often experience back injuries due to the excessive strain on their lumbar spine during swings, which contrasts with professionals [1][2]. Improving swing movements has been suggested as a means of preventing such injuries [1]. Secondly, proper body motion impacts performance. In baseball batting, for instance, to enhance accuracy, it is advisable to move the hips widely as force shifts from the back foot to the front foot, while simultaneously minimizing head movement during the swing[3][4].

Novice sports players often do not perform necessary movements, such as twisting the body in baseball or volleyball [5][6]. Moreover, they perform unnecessary movements, such as dorsiflexing the wrist in tennis or table tennis [5][7]. Therefore, it is difficult for novices to acquire the skills needed to master the movement form [8]. Addressing this, recent engineering research has explored various methods to assist body movements in sports.

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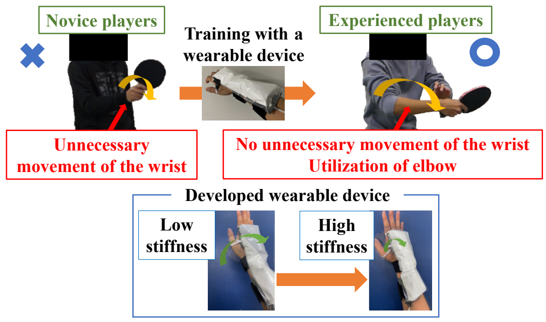


Fig. 1: Objective of this study

Examples of current engineering research on assisting body movements in sports include powered suits to increase the swing speed of baseball [9] and to assist the lower body's twisting motion in table tennis [10]. In addition, research on training with tactile guidance includes training in tennis backhand [11] and snowboarding movements [12]. Moreover, there are visual methods such as learning golf swing movements using models or videos of themselves [13] and learning table tennis movements using virtual reality [14]. In the above research, it is the device that gives or generates the necessary movements. However, a device designed to eliminate unnecessary actions holds promise for enhancing overall body motion.

As an example, we focus on dorsiflexion of the wrist during the table tennis backhand motion which is widely popular among people of all ages and genders [15]. Kinematically, it has been found that novices tend to hit with their wrists more dorsiflexed than experienced players, while experienced players tend to hit while utilizing their upper and forearms instead of dorsiflexing their wrists [7]. In this study, we developed a wearable device to stabilize the wrist during the table tennis backhand motion, thereby eliminating unnecessary wrist dorsiflexion. We conducted experiments with novice participants, having them use the device during table tennis backhand movements to assess its impact on movement form acquisition (Fig. 1).

II. WEARABLE DEVICE

A. Requirements for wearable device

In this study, there are several requirements for the development of a device to suppress the dorsiflexion of the wrist in table tennis backhand motion. The device should have a function that allows the user to freely move the wrist before taking a ready position to fine-tune and keep the wrist still when the user hits in order to achieve the best suppression effect according to the wrist shape and preference of the

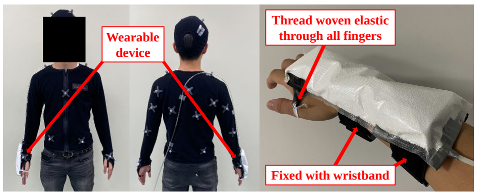


Fig. 2: How to wear the wearable device

individual user. In other words, it is necessary to be able to switch stiffness. In addition, the device should be lightweight so as not to interfere with the user's movement. This will allow the user to maintain natural movement.

To meet the above requirements, we focused on the jamming transition as a mechanism for variable stiffness actuation [16]. Examples of research using the jamming transition include a device that presents viscoelasticity to the fingertips by fixing them to the wrist and torso [17] and a wrist-wearable robot for rehabilitation and injury prevention that uses layer jamming [18].

B. Overview of wearable device

The wearable device was made by sealing a roll dedicated to a vacuum preservation food sealer to 21.0 × 6.5 × 2.0 [cm^3] and filling it with polystyrene foam with a grain size of 1 mm or less. The tube was inserted from one of the short sides. To keep the device attached to the arm, it was attached to the fingers with a woven elastic and to the forearm with two magic bands (Fig. 2). The device is lightweight at 112 g.

A jamming transition occurs when the air inside the device is vacuumed through the tube. In the jamming transition, the rigidity of the device is increased by the loss of fluidity of the powder inside. In one example, the range of motion for dorsiflexion of the wrist goes from 70° to 22°.

C. Control flow of wearable device

Fig. 3 shows a schematic diagram of the flow of controlling the timing of the operation of the device. The sound of a bounding ball being launched at regular intervals from the table tennis machine (Nittaku Co., NB-1150) is sent to the microcomputer (Arduino Co., Arduino Uno R3) via a sound sensor (DFROBOT, DFR0034) to control the timing of the operation of the device when the next ball is launched. During the operation time, a 5 V signal is sent from the microcontroller to the valve drive board with a MOSFET, which is amplified to 24 V by the power supply unit. The solenoid vacuum value (Koganei V112E DC24V) is driven by 24 V and opens at this time. The vacuum valve is connected to a vacuum pump (Mahls LS-90-H-AC100V) and a vacuum jamming device, and the jamming device is in a vacuum state when the valve is opened. A pilot air supply of 200 kPa is used to switch the valve of the solenoid vacuum valve.

Because it takes at least 0.4 s for the device to reach -40 MPa and gain rigidity, it is too late if the device activates after the bounce of the present ball. Thus, the activation time of the device is decided by the bounce timing of the previous ball using the fact that the balls are launched at roughly equal intervals of 1.67 s. The device begins to work 1.35 s after the bounce of the previous ball, approximately when the present ball passes over the net. The device keeps activation until 0.68 s after the bounce of the present ball to provide wrist stiffness during the swing.

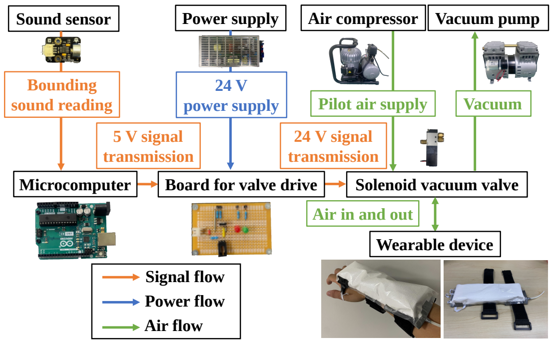


Fig. 3: Control flow of developed wearable device

TABLE I: Participants information (No. 1-4: The experimental group, No. 5-8: The oral group, No. 9-12: The control group)

No.	Age	Height [cm]	Weight [kg]	Dominant hand	Sport experience
1	22	173	61	Right	None
2	25	178	80	Right	Basketball, kyudo
3	24	166	53	Right	Tennis
4	24	171	72	Right	Baseball
5	24	170	50	Right	Soccer, kyudo
6	24	178	78	Right	Basketball, kyudo
7	24	171	72	Left	Baseball
8	24	168	65	Right	Soft tennis
9	23	165	65	Right	Tennis
10	21	165	60	Right	Soft tennis
11	25	178	61	Left	Soccer, climbing
12	25	170	60	Right	Baseball

III. EXPERIMENT METHODS

A. Overview of the experiment

The purpose of the experiment is to evaluate the effect of the developed wearable device on novices in table tennis backhand motion. The experiment was conducted in three groups: The experimental group, the oral group, and the control group. The experimental group wore the device to evaluate the developed wearable device. In the oral group, the participants were given verbal instructions to move their wrists as little as possible rather than wearing the device to compare device-assisted instruction with verbal instruction. In the control group, no device was worn and no verbal instruction was given to confirm the effect of repeated practice. Each group consisted of four participants, for a total of 12 participants in the experiment. The participant details are shown in Table I. this research is based on a protocol that was submitted to and approved by the Ethics Committee of the Faculty of Engineering, Kyushu University (approval number: 2021-04-1).

In this experiment, a motion capture system (OptiTrack, Natural Point) was used to measure the motion. Eight motion-capture cameras (Prime13W, Natural Point) were placed around the participants to measure wrist and elbow

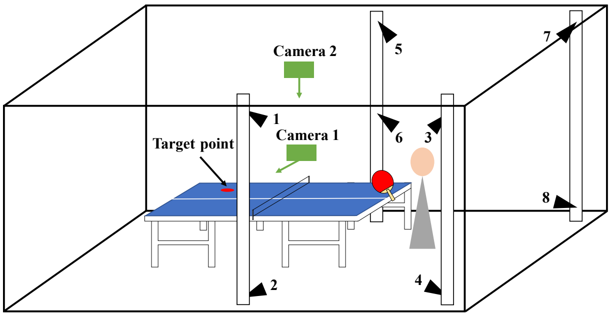


Fig. 4: Camera placement

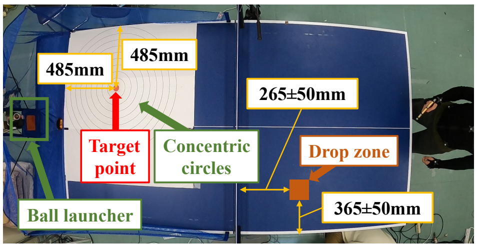


Fig. 5: Target point and drop zone

angle changes during the backhand swing. In addition, two cameras were placed on the ceiling and the side to measure the landing point of the returned balls. Fig. 4 shows the arrangement of these cameras.

B. *Experiment procedure*

In the experimental group, the following (A), (B), (C), and (D) were set as the experimental conditions, and the experiments were conducted in this order.

(A) Not wearing the device.
(B) Wear the device without activating it.
(C) Wear the device by activating it.
(D) Not wearing the device.

In the oral group, the following (A'), (B'), (C'), and (D') were the experimental conditions.

(A') Not given verbal instructions.
(B') Not given verbal instructions.
(C') Given verbal instructions to move their wrists as little as possible.
(D') Not given verbal instructions.

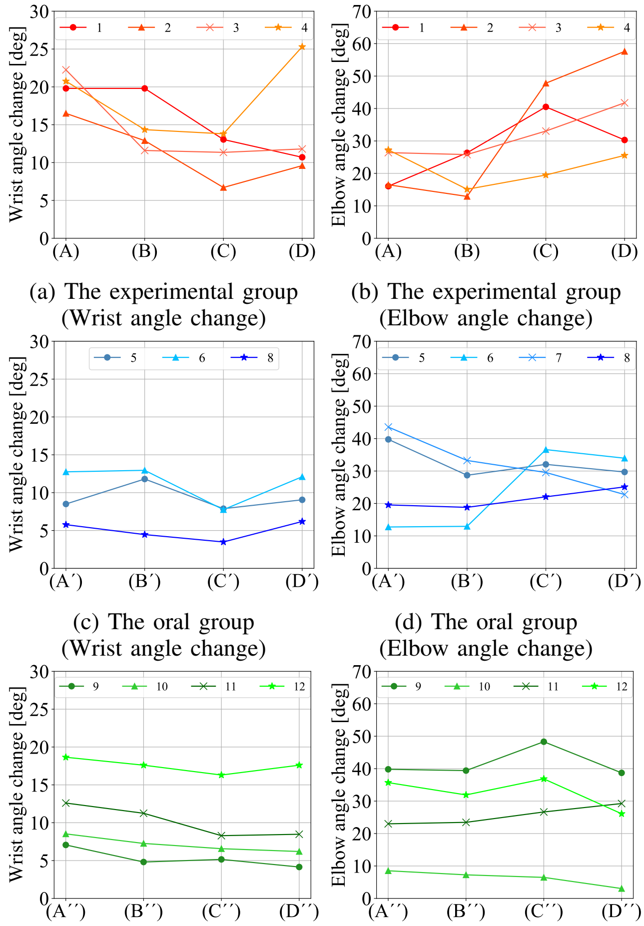
In the control group, (A"), (B"), (C"), and (D") did not wear the device and not are given verbal instructions.

In each condition, 20 balls were launched at a speed of 3.64 m/s and top spin revolutions of 26.7 r/s by a table tennis ball launcher so that each ball landed at a predetermined drop zone (Fig. 5).

C. *Analysis details*

Ten concentric circles were set up to evaluate the accuracy of performance, and the distance between the circles was set to 5 cm. Participants in each group were asked to return the ball to a circle with a diameter of 5 cm, which was the center of the concentric circles, as the target point. The locations of the concentric circles and the center of the target point are shown in Fig. 5. The target point was set at 10 points, and the interval from the target point to the next circle was 9 points, 8 points, ..., 2 points, 1 point, and the ball that did not fall on the concentric circles was 0 points. The average scores and the return rate were calculated for each condition.

For wrist and elbow angle change parameters, statistical tests were conducted on the data among the four conditions for each participant. Normality and equal variances of the data were considered, and the Holm method (Holm) was used when normality could not be considered, the Games-Howell test (GH) was used when normality could be considered but equal variances could not, and the Tukey test (Tukey) was used when both normality and equal variances could be assumed. Here, the Shapiro-Wilk test was used to determine normality.



(a) The experimental group (Wrist angle change)
(b) The experimental group (Elbow angle change)
(c) The oral group (Wrist angle change)
(d) The oral group (Elbow angle change)
(e) The control group (Wrist angle change)
(f) The control group (Elbow angle change)

Fig. 6: Median wrist angle change and elbow angle change results for each condition (the wrist angle changes of Participant 7 are shown separately in Fig. 7 because the values are large)

IV. EXPERIMENT RESULTS

The results of the measured wrist angle changes and elbow angle changes are shown in Fig. 6. The results are plotted for each participant as the median of 20 values per condition. The wrist angle change for Participant 7 is shown in a separate graph because the value was large (Fig. 7). The results of the

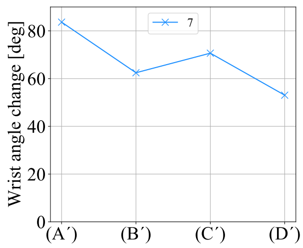
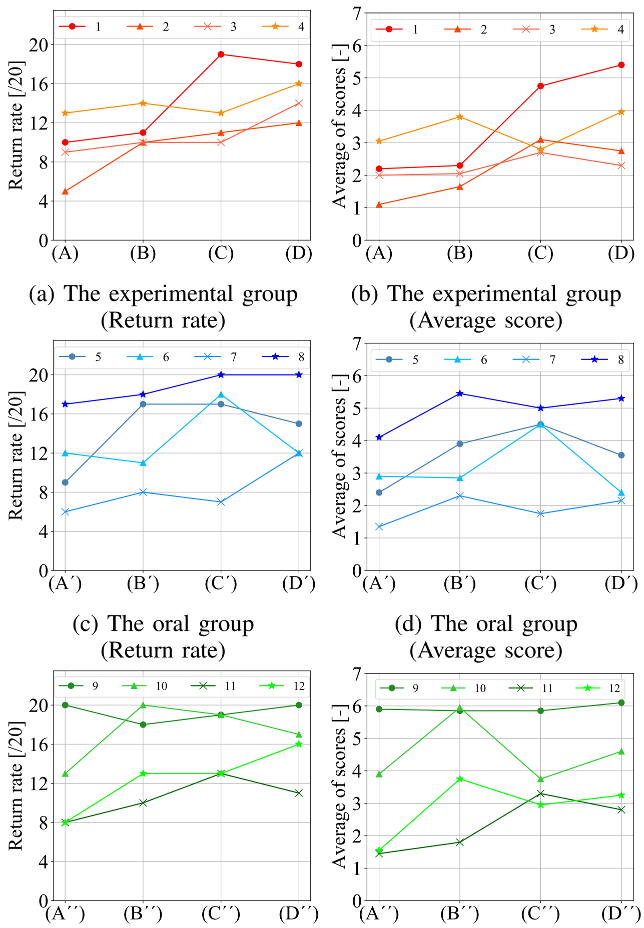


Fig. 7: Median wrist angle change results for each condition in Participant 7

statistic tests for wrist angle change and elbow angle change are shown in Table II, Table III, and Table IV. In addition, the results for the average return rate and score are shown in Fig. 8.



(a) The experimental group (Return rate)

(b) The experimental group (Average score)

(c) The oral group (Return rate)

(d) The oral group (Average score)

(e) The control group (Return rate)

(f) The control group (Average score)

Fig. 8: Success rate and average of score results for each condition

V. DISCUSSIONS

A. *Effects of wearing the device on movement*

The experimental group conditions (A) (without the device) and (B) (with the device and without activation), the oral group conditions (A') and (B') (both are without verbal instruction), and the control group conditions (A") and (B") (both are without the device and instruction) are compared, and the effect of wearing the device on the swing movement is discussed (Table II).

TABLE II: Statistical test methods and significant differences per participants between (A) and (B) (sig.: Significant difference, ↑: A significant increase from (A) to (B), ↓: A significant decrease from (A) to (B))

(A) and (B)	Participant 1			Participant 2		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	0.636	-	Holm	0.601	-
Elbow	Tukey	<0.001	↑	GH	<0.001	↓
	Participant 3			Participant 4		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	GH	<0.001	↓	Holm	0.074	-
Elbow	Holm	0.839	-	GH	<0.001	↓
(A') and (B')	Participant 5			Participant 6		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	0.429	-	Holm	1.00	-
Elbow	Tukey	<0.001	↓	Tukey	0.080	-
	Participant 7			Participant 8		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	<0.001	↓	Holm	0.19	-
Elbow	Holm	<0.001	↓	Holm	0.561	-
(A") and (B")	Participant 9			Participant 10		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	0.033	↓	GH	0.335	-
Elbow	Tukey	0.576	-	Holm	0.288	-
	Participant 11			Participant 12		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	0.135	-	GH	0.625	-
Elbow	Tukey	0.915	-	Tukey	0.829	-

First, we discuss the wrist angle changes. three out of four participants in the experimental group showed no significant difference between (A) and (B), suggesting that wearing the device had little effect on their wrist movements. One participant decreased significantly in (A) and (B), suggesting that the movement may have been restricted by wearing the device. However, one participant in the oral group also decreased significantly in (A') and (B'), and one participant in the control group also decreased significantly in (A") and (B"). This suggests the possibility that the number of trials may have changed the behavior of the participants.

Next, we discuss the elbow angle changes. Significant differences were found in three out of four participants in the experimental group, with one participant showing a significant increase and two participants showing a decrease. The increase in elbow angle change may be because wearing the device restricted the movement of the wrist, causing the participants to use their elbows instead. On the other hand, the decrease in elbow angle change may be because the tube connected to the device was attached along the elbow, making it more difficult to move the elbow. However, since a significant decrease was observed in two out of four participants in the oral group as well, it is possible that the change occurred as a result of repeated trials in both cases.

Based on these discussions, it is believed that the effects of wearing the device on movement cannot be completely disregarded. In the future, we should make improvements to reduce as much as possible the influence of the wearing.

TABLE III: Statistical test methods and significant differences per participants between (A) and (C) (sig.: Significant difference, ↑: A significant increase from (A) to (C), ↓: A significant decrease from (A) to (C))

(A) and (C)	Participant 1			Participant 2		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	<0.001	↓	Holm	<0.001	↓
Elbow	Tukey	<0.001	↑	GH	0.372	-
	Participant 3			Participant 4		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	GH	<0.001	↓	Holm	0.067	-
Elbow	Holm	0.144	-	GH	<0.001	↓
(A') and (C')	Participant 5			Participant 6		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	0.432	-	Holm	0.006	↓
Elbow	Tukey	<0.001	↓	Tukey	0.018	↓
	Participant 7			Participant 8		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	0.010	↓	Holm	0.008	↓
Elbow	Holm	<0.001	↓	Holm	0.003	↑
(A") and (C")	Participant 9			Participant 10		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	0.011	↓	GH	0.611	-
Elbow	Tukey	<0.001	↑	Holm	0.016	-
	Participant 11			Participant 12		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	<0.001	↓	GH	0.244	-
Elbow	Tukey	0.993	-	Tukey	0.727	-

TABLE IV: Statistical test methods and significant differences per participants between (A) and (D) (sig.: Significant difference, ↑: A significant increase from (A) to (D), ↓: A significant decrease from (A) to (D))

(A) and (D)	Participant 1			Participant 2		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	<0.001	↓	Holm	<0.001	↓
Elbow	Tukey	<0.001	↑	GH	<0.001	↑
	Participant 3			Participant 4		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	GH	<0.001	↓	Holm	<0.001	↑
Elbow	Holm	<0.001	↑	GH	0.895	-
(A') and (D')	Participant 5			Participant 6		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	0.922	-	Holm	1.00	–
Elbow	Tukey	<0.001	↓	Tukey	<0.001	↓
	Participant 7			Participant 8		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	<0.001	↓	Holm	0.620	–
Elbow	Holm	<0.001	↓	Holm	<0.001	↑
(A") and (D")	Participant 9			Participant 10		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	<0.001	↓	GH	0.081	-
Elbow	Tukey	0.944	-	Holm	<0.001	↓
	Participant 11			Participant 12		
	Test	*p*-value	sig.	Test	*p*-value	sig.
Wrist	Holm	<0.001	↓	GH	0.680	-
Elbow	Tukey	0.593	-	Tukey	0.003	↓

B. Effects of activating the device on movement

We compare conditions (A) (without the device) and (C) (with device and operation) in the experimental group, conditions (A') (without verbal instruction) and (C') (with verbal instruction) in the oral group, and conditions (A") and (C") (both are without the device and verbal instruction) in the control group, and discuss the effects of having the device activated and of verbal instruction (Table III).

First, we discuss the wrist angle changes. In the control group, two out of four decreased significantly for (A") and (C"). In the oral group, three out of four decreased significantly for (C') with verbal instructions given for (A'). In the experimental group, three out of four participants showed a significant decrease in (C) with the device on, with respect to (A), and the change was larger than the change in the oral and control groups, where there was a significant difference. These results suggest that both verbal and device teaching suppressed wrist movements. In addition, a comparison of oral and device-based instruction suggests that device-based instruction was more effective in suppressing wrist movements.

Next, we discuss the elbow angle changes. In the control group, there was a significant increase between (A") and (C") in one out of four participants. In the experimental group, there was a significant increase in (A) and (C) in one of the four participants. Two participants tended to utilize their elbows more as the repetitions progressed in (A) and (C), although the difference was insignificant. One participant showed a significant decrease in (A) and (C). On the other hand, in the oral group, one of the four participants showed a significant increase in the angle change in (A') and (C'), while three of the four participants showed a significant decrease.

When the device was activated, the participants tended to limit wrist movement and utilize elbow movement although one participant did not. When verbal instructions were given to the participants to move their wrists as little as possible, wrist movements tended to be restricted, but elbow movements also tended to be inhibited. It is possible that the whole body movement was restrained by the instruction to restrain movement, even though the wrist is a part of the body.

C. Effects of training with the device

The training effects of the device on form improvement are discussed by comparing conditions (A) (before operation without the device) and (D) (after operation without the device) in the experimental group, corresponding conditions (A') (before given verbal instruction) and (D') (after given verbal instruction) in the oral group, and conditions (A") and (D") (without the device and verbal instruction) in the control group (Table IV).

First, we discuss the wrist angle changes. In the experimental group, one of the four participants increased significantly in (A) and (D), but three of the four participants decreased significantly. In the oral group, one of four participants decreased significantly in (A') and (D'). In the control group, two out of four participants decreased significantly in (A") and (D"), and the remaining two participants showed no significant difference.

Next, we discuss the elbow angle change. In the experimental group, three out of four participants showed a significant increase in (A) and (D). On the other hand, in the oral group, four participants decreased significantly in (A') and (D'), and in the control group, two out of four participants decreased significantly in (A") and (D").

From the above, it can be said that the experimental group, in which the device was activated, tended to show the training effect of the target of this research, whereas the oral and control groups did not show the training effect of the target of this research. In the experimental group, one participant (Participant 4) did not show the effects of activating the device and the training. This may be due to the fact that the average time per swing for the other participants was 1.37 s, compared to 0.75 s for the other participants, suggesting that the time to activate the device may not have been appropriate. In addition, a video of this participant during the swing was reviewed, and a greater radial deviation motion was observed (Fig. 9). While dorsiflexion could be inhibited, radial deviation could not be effectively inhibited due to the mechanical challenge of operating the device during large radial deviations. These may have been the reasons for the ineffectiveness of the device, but a definite reason needs to be verified in the future.

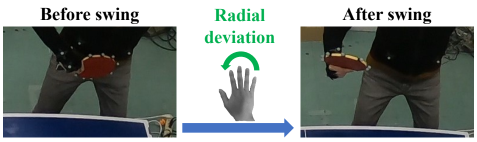


Fig. 9: Radial deviation motion of Participant 4 with no training effect

D. Effect of the device on performance

The effect of the device on performance is discussed in terms of return rate and average score (Fig. 8). In the experimental group, the return rate and average score were higher in (C) and (D) after activating the device than in (A) and (B) before activating the device for 3 out of 4 participants. In the oral group and control group, no such trend was observed.

These results suggest that the use of the device improved the performance of the participants. However, the effects of repeated trials, with or without using the device, were also observed. It is necessary to clarify the effects of the device by increasing the number of participants in the future.

VI. CONCLUSIONS

In this research, we developed a device that suppresses dorsiflexion of the wrist during the table tennis backhand motion for novice players and verified that the device improves movement form. To verify this, the experiment of the device was conducted with the experimental group, oral group, and control group. Each group consisted of four participants.

In the experimental group using the device, three out of four participants tended to swing by suppressing their wrist movements and utilizing their elbows when wearing the device. In addition, when the device was removed, the same three participants tended to suppress their wrist movement and utilize their elbows, indicating an improvement in moving form. On the other hand, in the oral group, who were instructed to move their wrists as little as possible, wrist movement was suppressed when instruction was given, but they tended not to utilize their elbows. From these results, restricting movement with a device may be more effective than verbal instruction in getting them to inhibit movement of only a part of their body.

For one participant, the device was not effective, possibly because his swing was largely different from those of the other participants. It is necessary to design a device that can accommodate a variety of swings in the future.

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