VR リダイレクションを用いたゴルフスイングトレーニングシステム

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概要.　本論文は、ゴルフのトレーニングにおいて、スイング軌道を修正させるために、仮想現実（VR）技術を用いたボール位置のリダイレクションを提案する。一連のスイング動作の中で、インパクト前にボールを前方に移動させることで、ゴルファーが無意識にボールの移動に反応し、スイング軌道を修正する。このリダイレクションを達成するために、仮想環境（VE）を開発し、高速光学トラッキングデバイスを使用してゴルフクラブのモーションデータを収集し、リアルなシミュレーションを行った。本研究ではリダイレクションのためのボール移動パターンを 3 つ提案し、12 人の被験者を対象としてユーザ実験を行った。この実験により、異なるパターンのトレーニングをしたゴルファーの学習率を評価し、それぞれのパターンの効果を検証した。その結果、ボールの「間欠的な (Interspersedly)」移動が、ゴルファーに無意識にスイング軌道を修正することができ、持続的な学習効果を示した。この手法をトレーニングに取り入れることにより、ユーザの偏ったフォームを改善し、技能レベルを向上させる可能性がある。

1　Introduction

For golf beginners, there is often a high degree of instability in the ball's flying direction when they strike it. This problem also happens to golfers with years of experience playing the round. They often perform a strong bias in their swing path, particularly tend to deflect from outward to inward, causing the ball to veer left of the target. This outward-to-inward path tendency often leads to a series of errors, one of which is commonly known as a "slicing shot"[1]. The slicing shot causes the ball to veer sharply in the opposite direction (right side) and is a challenge for many golfers [8]. There are various reasons for this outward-to-inward bias, most of which can be attributed to an erroneous swing motion called the "over-the-top swing". Seeking guidance from a professional coach is arguably the most efficacious method to rectify these swing inaccuracies. However, the associated costs might deter beginners, particularly those pursuing golf as a mere pastime. A common alternative, self-practice, whether indoors or outdoors, may risk ingraining poor techniques in the absence of proper guidance.

This work proposes a virtual reality (VR) golf training system to help golfers correct inappropriate habits during a swing. We use a spatial distortion technique of VR to change the user's behavior, also called redirection, while the users do not perceive the change of position. In the VR system, we dynamically move the ball position when the users are performing a downswing. When the ball shifts a short distance ahead, the user promptly shifts his downswing path forward, thus correcting his swing path to some extent.

Based on previous research exploring the prolonged aftereffect of visuomotor adaptation to gradually distorted reality in VR[7], we introduce three modes to shift the ball during the downswing. To evaluate the effectiveness of the proposed system, we develop a VR golf simulation system incorporating the three modes above and conduct a user study.

2　RELATED WORK

2.1　Visual/Object redirection

Visual dominance[2][3] can be used to influence the user's experience in the virtual environment and thus achieve specific desired effects, with redirection techniques being one of the most popular. For example, in redirected walking [13], users may perceive themselves as walking in a straight line, although they are walking on a curved path. A non-strict mapping between head rotation and orientation in the real and virtual world achieves this work.

Kasuga et al.[7] had participants wear VR headsets and had them perform the task of repetitive 3D arm reaching for a target on a touchpad in front of them. The target had multiple movement modes. In the abrupt condition, the im-

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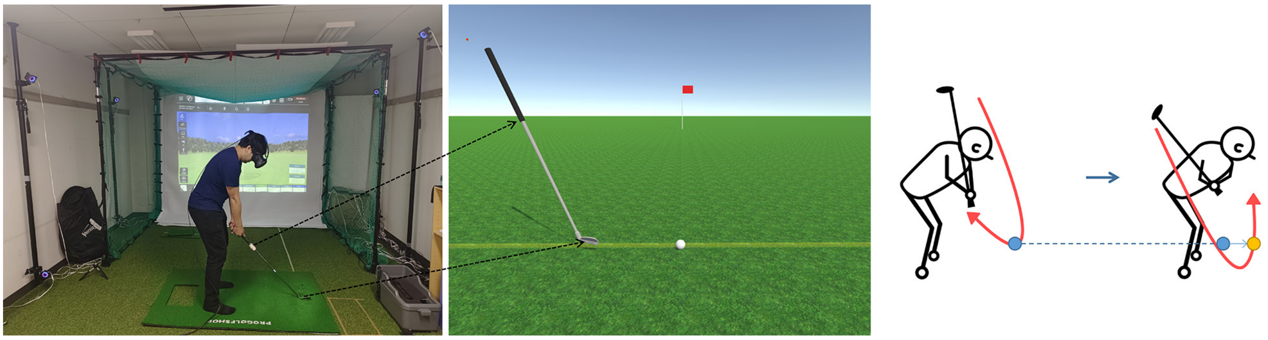

Fig.1. Make the ball shift forward by tracking the golf club while downswing, avoiding "over-the–top"-like motion that can cause outside-to-inside swing path.

ages were rotated by 20°, while in the gradual condition, the rotation was increased stepwise from 0° to 20°. Their results showed that the decay of the aftereffect was slower in the case of slow movement. This research motivated us to design modes in which the user is unaware of the ball's movement. We hypothesize that this type of mode could potentially help users to maintain their training results effectively.

2.2 Golf training in HCI

The application of technology in golf training mainly includes the use of AR [4], VR [9], projection systems [14][5][6], and monitors to aid users to train through various visualizations. Other approaches involve incorporating forms of feedback, such as auditory cues [14][6], haptic feedback achieved by modifying golf clubs [10][11], or external haptic feedback devices [15]. Moreover, research that helps users train by deep learning the swings of skilled players has been actively researched in recent years [12].

In a series of research [14][5][6] focusing on the use of the so-called "Virtual Golf Shadow" for golf training, a skilled golfer's silhouette captured through motion capture technology is projected onto an indoor golf training course. Users can learn and improve their golf swing in real-time by consciously aligning their silhouette with the skilled golfer's. However, this study is only applicable to beginners who need to start learning from posture. Moreover, habits such as "over-the-top swing", caused by many personal preferences and details, are challenging to correct simply by differentiating from experts. Our approach can be used not only for beginners to practice but also for experienced users to correct the swing path.

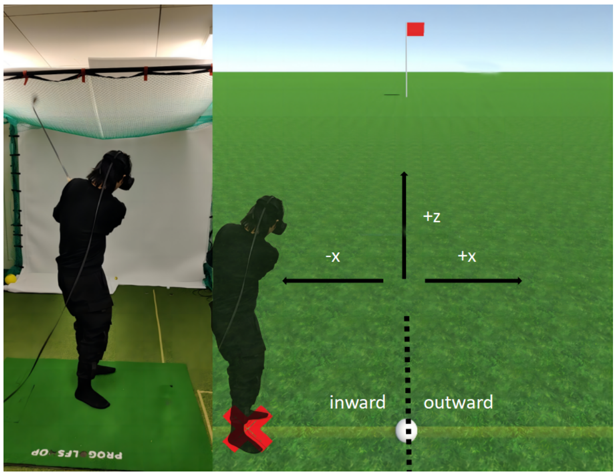

Fig.2. Left: The user takes the HMD for a real swing. Right: the user interface in VR.

3 Design and implementation

The system design is shown in Fig.1. To get accurate motion tracking, we use a high-precision motion capture system (OptiTrack) to track the golf clubs and simulate the outcome of the ball being hit in VR in real time. Finally, we developed three different golf ball shift modes for training using the VR golf setting.

3.1 User interface in VR

The user interface in VR is shown in Fig.2. The user must stand on the yellow line and swing, with the red flag as a target on the user's left side.

According to golf rules, a golf ball's diameter should not be less than 42.7mm. Hence, the diameter of our model ball is set to 43mm. To make it easier for beginners to hit the ball, we let the ball model's collision body diameter be

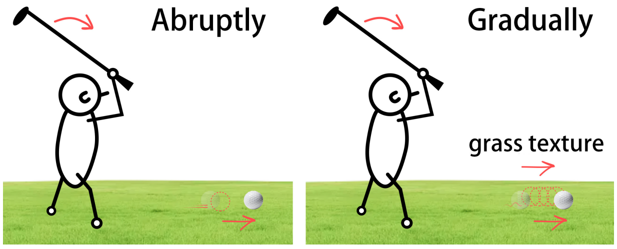

Fig.3. Ball shift sketch for Abruptly and Gradually modes.

1.6 times larger than itself, which is 68mm.

In the VR system, when the user hits the ball with a certain force, the ball flies slightly higher than in reality, while the speed in the x and z directions remains the same as in reality. Our research focuses on the swing path rather than the angle of the golf club face, which allows the user to observe the ball's flight trajectory more comprehensively. The ball's flight trajectory disappears after the ball hits the grass, while a new ball subsequently appears on the ball spawner for the user to continue training.

3.2 Shift of the ball

We developed three shifting modes in which the ball shifts the same distance. The distance of the ball movement is two times the diameter of the ball model, 86mm. The previous study by Kasuga et al.[7] mentioned four modes: abrupt condition, gradual condition, a mixture of abrupt condition and baseline, and a mixture of gradual condition and baseline. Among them, gradual condition and the mixture of gradual condition and baseline are the most effective, with a slower decay of after-effects. In contrast, the mixture of abrupt conditions and baseline mode has the worst effect. To verify whether abrupt and gradual conditions produced similar results in our study, we implemented "Abruptly", "Gradually", and the "Interspersedly" modes for the user study.

Abruptly (A) In this mode, when the user is preparing to hit the ball, the ball suddenly shifts towards the front for a distance (Fig.3 Left).

Gradually (G) This mode makes the ball shift slowly towards the front for a distance and tries not to be noticed by the user. To achieve this, we take advantage of the feature of the tile texture of grass by having the texture move forward with the ball such that the user would lose their frame of reference and be as unaware of the ball's shift as possible(Fig.3 Right).

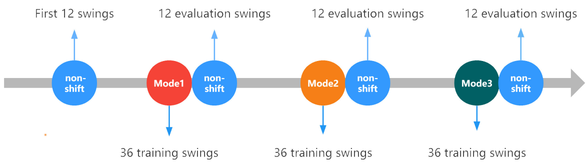

Fig.4. The procedure of user study: Mode 1, Mode 2, and Mode 3 represent the 3 modes in a randomized order.

Interspersedly (I) This mode alternates between the **G** mode and the non-shift mode. We aim to correct the user's habit with the **G** mode swing while preventing over-correction with the "non-shift" mode, allowing the user to learn and verify between the two modes.

4 User Study

To test and verify the hypothesis that shifting the ball during the swing can improve the user's swing path, we conducted a user study involving 12 participants.

4.1 Design and procedure

We first give instructions to the participants on how to swing the golf club properly by having them practice on a real-world indoor golf course. As done in actual training and golfing, we asked the participants to aim at the ball and keep their eyes on it throughout the swing. After we ensure they are familiar with the basic swing by completing a full swing 5 times, we let them train with VR headsets and try to hit the ball in VR. We have all participants use a #7 Iron club, stay in a line throughout the test, and the participant can see the ball's flight path. When the participants hit the ball four times continuously in VR, and it lands in the range of -30° to 30°, we consider that they are ready to train in VR. Then, we give instructions to the user about the experiment, including matters such as the purpose of the study and the three different modes.

During the experiment, we had each participant test all three modes randomly. Before testing the three modes, the user performed 12 swings in the non-shift mode as the baseline. As shown in Fig.4, for the three different modes, such as **A** mode, we let the user perform 36 swings in the

A mode, followed by 12 swings again in the non-shift mode. We mainly use the last 12 swings to evaluate the effective learning rate. Particularly, in the **I** mode, participants first performed 6 swings in non-shift mode, followed by 6 swings in the **G** mode. The participants repeat these two modes until they complete 36 swings and then perform the final 12 swings in the non-shift mode for evaluation. The training is approximately 10 minutes for 48 swings in each condition. We asked the participants to take a 10-minute break between conditions while filling out a questionnaire about this part of the experiment. The whole experiment lasts approximately one hour.

4.2 Participants

We invited a total of 12 participants ($min_{age} = 20$, $max_{age} = 31$, $mean_{age} = 24.25$, $sd_{age} = 3.16$). Eight of them were men, and four were women. Three had no knowledge of golf, six had some knowledge of golf, they may have watched golf videos or practiced swings, and the other three had some golf experience, they frequently engage in indoor golf training or have practical experience playing golf games. Four of them used VR regularly, five of them had VR experience, and three of them had no VR experience at all.

4.3 Questionnaire

We used a customized questionnaire to evaluate the participant's subjective experiences in each mode, which served to support the discussion of the result. We presented four questions for each mode using a 5-point Likert scale questionnaire:

- Q1: How about your experience of this condition?
- Q2: Can you feel the ball shifting when you swing?
- Q3: Do you think the shift of the ball disturbed you?
- Q4: Do you think your swing form changed?

5 Results

5.1 Velocity bias

In our VR environment, the $-x$ direction represents the inward, the $+x$ direction represents the outward, and the $+z$ direction represents the correct direction, i.e., the center(Fig.2). If the x component of the club velocity is negative, the hit will cause the ball to fly to the left and vice versa to the right.

v_x/v_z represents the offset value of the velocity acting on the ball concerning v_x, which we call the **velocity bias**. $\arctan(v_x/v_z)$ represents the offset of the velocity in degrees. When $v_x/v_z = 0.1$, it represents an offset of 5.71°, and 0.2 represents an offset of 11.3°. If v_x/v_z is negative, the swing path swings outward to inward and vice versa. If all other factors are accurate, then v_x/v_z will represent the final deflection of the ball. We want to see a smaller absolute value of velocity bias during training than during the initial measurement. More importantly, we want the absolute value of velocity bias to be as small as possible after training, representing a significant training effect in the normal mode even after training.

We first conducted a two-way repeated-measure ANOVA with turn and mode as variables for the three modes(normally distributed and satisfies the spherical assumption). The results showed that for the three modes, both turn($df = 47$,$f = 1.93$,$p < 0.001$) and v_x/v_z($df = 2$,$f = 39.10$,$p < 0.001$) or the interaction between turn and v_x/v_z ($df = 94$,$f = 1.40$,$p < 0.01$) have significantly differences. We then performed a Tukey-Kramer posthoc test on the three models and found significant differences between (**A**, **I**) and (**G**, **I**) in all three models (both $p < 0.05$). No significant difference occurred between **A** mode and **G** mode($p = 0.09 > 0.05$).

5.2 Average velocity bias

Using the data from the 12 times non-shift mode swing at the beginning, we found that 9 of the 12 participants(P1, P2, P3, P4, P5, P6, P7, P9, P12) were habitually biased from outward to inward, two participants(P10, P11) were between inward and outward, one participant(P8) was habitually biased from inward to outward. Because our ideal target is who is used to playing from the outward bias toward the in-ward, we first averaged the data of these nine participants individually, as shown in Fig.5. From the average data, the velocity bias (v_x/v_z) of these nine participants in the first 12 shots ranged between -0.2 and -0.1, which means that on average, each swing would have a bias of approximately 9°from outward to inward.

We analyze the distribution of velocity bias

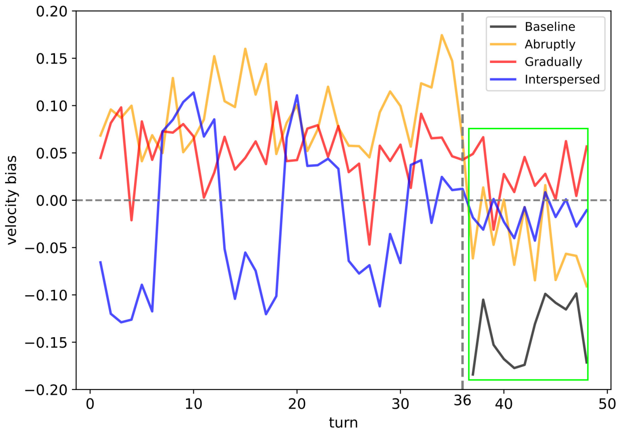

Fig.5. The average Velocity Bias of the 9 out of 12 participants who have a habit of swinging from the outside to the inside.

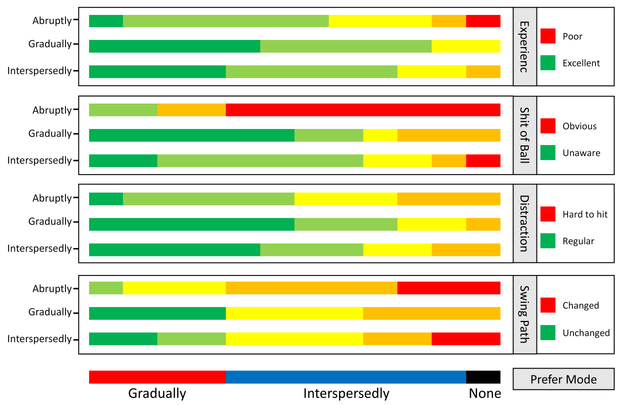

Fig.6. Questionnaire on a 5-point Likert scale for participants' experiences, perception of ball movement, discomfort, and conscious alteration of the downswing path for each mode.

for the first 36 times in all three modes. In the **A** mode, the values were the largest among the three modes most of the time, and the velocity bias was between 0.05 and 0.15 mostly, meaning that the swing path was from inward to outward. In the **G** mode, the velocity bias fluctuated around 0.05, meaning that the average bias angle was close to 3 degrees, and the bias towards either side was not very strong. Intriguing results exist in the **I** mode because it is performed in a cycle of six times in the non-shift mode and six times in the **G** mode. The results of the first 36 times are distributed in positive and negative sides with six as the number of cycles. However, we can observe an overall tendency to converge to 0, and the velocity bias is already close to 0 in the 30th to 36th times in the **G** mode.

5.3 Questionnaire evaluation

11 out of 12 participants thought it was easier to hit a golf ball in VR than in reality, and one thought it was about the same difficulty. Nine people thought golf training using VR was reliable and preferred practicing in a VR environment. The questionnaire results for each mode are depicted in Fig. 6. In terms of the overall experience, ***G*** ($M = 4.25$, $sd = 0.72$) and ***I*** ($M = 4$, $sd = 0.91$) were better than ***A*** ($M = 3.42$, $sd = 1.03$). The majority of participants noticed the movement of the ball in the ***A*** mode ($M = 1.5$, $sd = 0.76$), whereas in the ***G*** ($M = 3.92$, $sd = 1.26$) and ***I*** ($M = 3.58$, $sd = 1.1$) modes, users did not perceive the ball's movement frequently. Additionally, users felt more disrupted and found it more challenging to hit the ball in the ***A*** mode, requiring a conscious effort to modify their downswing path. After conducting all three modes and understanding the purpose of our user study, the majority of participants said they preferred the ***I*** mode for training.

6 Discussion

6.1 Main findings

From the velocity bias, it can be found that all three modes have shown positive effects during the training. ***A*** and ***G*** modes showed the most significant change. Due to its cyclical nature, the ***I*** mode experiences fluctuations over time, but gradually approaches zero. This result is further supported by the questionnaire responses. The questionnaire results indicate users were not aware of the shift of the ball in the ***G*** and ***I*** modes. Therefore, users reported slight discomfort only in the ***A*** mode due to the instantaneous shift of the ball, which made it challenging to make accurate hits.

After 36 swings of training, the velocity bias in the ***A*** mode regressed to the baseline level. The ***G*** mode and ***I*** mode maintained the training effects in the short term and showed similar levels. (*RQ 4* is true) The questionnaire also supported the superior overall performance of the ***I*** mode. We believe this is because users can make non-deliberate swing path corrections during training in the ***I*** mode, which allows the user to validate and learn.

6.2 Subjective Feedback

Some participants thought that for golf beginners, training directly with a real ball is challenging to hit and not safe enough. "I like that there was no danger of having to pick up the ball or risk a flying ball."(P6) Hence, golf training using VR is appropriate for beginners. VR golf can help beginners get up to speed rapidly and is very motivating. "It's exciting that you could hit the ball constantly without catching the ball."(P4) Furthermore, visualizing the ball's trajectory, where it lands, and other information in VR can be very beneficial for regular indoor golf training. " it is really fun that I can hit the ball and can see the trajectory of the ball."(P7) "I firstly touch the golf club, but I really enjoyed the golf training in all section, because I can hit the ball. It is useful to beginners to the training to motivate them."(P12)

For perceptions of ball shift in different modes. P6 mentioned: "In the ***A*** mode, the ball position changed so significantly that I felt I needed to consciously adjust my posture. There wasn't much difference between the ***G*** and ***I*** modes because I didn't even notice the change in ball position." P12 commented: "I occasionally feel a sense of space being stretched in the ***G*** and ***I*** modes, but despite this, I don't consciously wonder if this is the ball shifting because the downswing is really fast."

Other comments were concerned with correction, i.e., what was originally an outside-in trend but was corrected to an inside-out trend. Under the distance when we set the ball to shift, the learning result of the ***A*** mode was not effectively retained, and the over-correction phenomenon occurred under the ***G*** mode. At the same time, the ***I*** mode can be contracted to a more reasonable interval by the user's verification during training. However, for user trends that are not outside-in or more exaggerated, it is unsuitable to train directly at this direction and distance of ball shift.

6.3 Limitations and future work

Several participants also indicated that even in the **G** and **I** modes, they were still distracted by the ball's movement. In our user study, 1 of the 12 participants had no significant swing bias, and 2 had an inward-to-outward bias, which might cause poor bias guidance when using our method.

Omnidirectional Redirection For different deflections, including inward-to-outward or outward-to-inward, other users may have different deflections when hitting the ball. Each user has a different bias; therefore, fixed ball shift distance and direction do not suit everyone. We plan to develop an adaptive training system that constantly adjusts to each user's bias. This will not only help users with a significant bias to standardize their swing path but also help users with a smaller bias each time to reduce their bias trend.

Spatial Distortion of Angles Using object position redirection to correct the downswing path may somewhat change the overall swing plane. Our evaluation is mainly based on velocity bias, i.e., angles, so we plan to use spatial distortion of angles as well to allow users to learn unconsciously. We plan to use virtual arrows on the ground to indicate the direction of the user's swing while gradually changing the direction of the arrows during the swing process. This may result in better correction with less discomfort.

7 Conclusion

In this work, we developed a VR method to help users correct their swing path by shifting and redirecting golf balls. We proposed three ball-shifting modes and conducted a user study to compare the advantages and disadvantages of the three modes. Subsequently, we analyzed the three modes' learning rate by visualizing the golf club's speed and swing path during and after the training sessions. Our findings revealed that training with the **I** mode, involving golf ball redirection, was particularly effective in helping individuals with an outward-to-inward swing bias standardize their swing path. In the future, we plan to enhance the system by incorporating other feedback mechanisms and omnidirectional adaptive redirection and conduct further studies on other motor skill training. These future improvements aim to provide many users with further assistance and immersive training experiences.

謝辞

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