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Attempting to incorporate elements of open skills into closed-skill learning: A case study using a golf putting task

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Abstract

In motor learning, how a target skill is learned is important, and performance results vary depending on practice-related factors. Motor skills, which are classified as closed skills, are typically practiced through self-paced repetition. However, learning a target-following task performed alone may be facilitated by intervention from another person. Therefore, we considered an environment with disturbances such as open skills, even for a closed-skill learning activity such as a golf putting task, and expected that learning would be promoted in an environment with high uncertainty. In this study, we developed an idea based on several previous studies, and examined the effects of the practice of "catching and hitting a ball launched from ball launchers." The participants were four golf novices, two of whom practiced a conventional putting style as the control group. The participants practiced 10 times over a month, during which they took a pretest, midterm test, and posttest. Subsequently, the participants were challenged with two tasks. The participants practiced with approximately 1,000 balls during the study. To evaluate their performance, we used a motion capture device to measure the orientation of their body, kinematics of the putter head, and final ball positions. To measure participants' sight lines, we proposed a method that utilizes a local coordinate system to efficiently represent and estimate the movement of points. From the results of the sight line analysis using this method, we understood the problems of novices' alignment (aligning the putter head and body for the target). In addition, we were able to determine how long it takes for golf novices to acquire their approximate movement patterns and the number of days that the absolute error of the final ball position can be kept within 0.2 m ~ 0.4 m. We discuss the impact and future possibilities of incorporating elements of open skills to improve golf-putting skills.

Keywords: Putting practice, unpredictable environment, bodily orientation, alignment, individual differences, learning curve

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1. INTRODUCTION

The predictability of the environment when performing an activity provides a basis for classifying movement skills (Poulton, 1957; Gentile, 2000). Closed skills are performed in a relatively predictable environment (Magill, 1989), and include target-aiming tasks such as darts, bowling, and golf. Typically, when learning a skill classified as closed, people explicitly learn the main points of the skill (e.g., tips on how to grip the tool, posture, and movement). Then, based on knowledge of the tricks to the skill, people repeat the same practice at their own pace. However, some studies have suggested that implicit learning methods lead to better performance under test conditions than explicit learning methods (Zhu et al., 2015). Closed-skill learning is generally learned explicitly and with no time constraints during learning; therefore, the player's attention tends to be focused internally. Masters (1992) suggested that learning to focus on one's own body (i.e., internally) hinders one's ability to perform better in competitions. From such evidence, some studies have shown that people perform better when they focus their attention externally (Bell & Hardy, 2009).

Conversely, open skills are those for which the environment is constantly changing such that the player cannot effectively plan their full movements (e.g., wrestling; Schimdt et al., 2019). Open skills require the player to move while constantly updating information regarding their opponent's movements (Kijima et al., 2012). Thus, the player's attention is less likely to become an internal focus, because it is necessary to respond to various inputs under spatiotemporal constraints. It may also enhance the ability to adjust movements, both consciously and unconsciously, to obtain aiming results from diverse inputs. Therefore, we posit that it would be effective to practice closed skills in a high-uncertainty environment like that for open skills. Several previous studies have examined the effectiveness of constant or varied practice (e.g., Shea & Kohl, 1990, 1991), and the effects of context interference (e.g., Magill & Hall, 1990), using various motor tasks. In motor learning research, the effectiveness of using others (incorporating elements from open skills) in learning closed skills has been suggested (Ganesh et al., 2014); however, no studies have examined this in a sports-skill context. Thus, conducted a case study to incorporate elements of open skills into learning the skill of golf-putting.

The ability to be evaluated differs depending on the skill. Many sports classified as closed skills, such as golf, involve aiming at a target. In the skill, it is important to recognize the orientation of one's own body and the tool, and properly align both with the target (i.e., alignment). Thus, setting up is an important skill. Novices in particular may have low sensitivity to the orientation of their bodies and tools (Hasegawa et al., 2021, 2022). Line of sight is particularly related to optical information acquisition, and a lawful relation exists between optical information and movement (van Lier et al., 2011). Thus, we posit that when learning to putt in golf, it is necessary to incorporate practice that increases sensitivity to the orientation of one's body and tools. Although it is clear from classical motor learning research that providing variety when practicing is a key element for skill improvement, the relationship between a player's posture and movement and its development is poorly understood. Putting in golf requires sensing slight differences in the environment, changing aims accordingly, and making subtle adjustments to force. Golf putting is suitable for investigating the dynamics of skill improvement during target-aiming movements.

We also know that the presence of others effectively facilitates closed-skill learning. In a previous study, using a haptic interface, two beginners connected their fingers to a virtual spring and performed the motor task of following a rotating cursor target. Participants could better control the cursor when connected to others than when performing the task alone (Ganesh et al., 2014). This suggests that, even for a closed skill task, adding the open skill element of following others as a constraint may help improve the player's skills. Even with closed skills, incorporating disturbances into the practice situation for learners to expand the extent of their exploration may lead to them recognizing the "correctness" or "wrongness" of their alignment. Therefore, more varied practice routines are needed rather than consistent ones. Furthermore, variation in open situations that involve external input or disturbances may have a greater learning effect than variation in closed situations that simply change the putting distance. We posit that intentionally creating an unstable learning environment and introducing it in the presence of others will effectively facilitate the acquisition of closed skills.

In sports that use tools, players must treat the tools as if they are part of their own bodies. In addition, players' movements change during practice depending on the task constraints (e.g., Araújo et al., 2004). The practice method used by the experimental group in this study was based on the research of Fujii et al. (2015), conducted in the context of basketball. Their findings demonstrated that the success or failure of a basketball defense is determined by the non-weighted and weighted states during a trial using force plates. They reported that guarding was more successful in the non-weighted state than in the weighted state. This suggests that a well-balanced preparatory body state leads to better movement when playing sports. Therefore, we hypothesized that the task of receiving an incoming ball and immediately hitting it would foster a well-balanced preparatory body state, promote easy movement, and strengthen the learner's awareness of the hitting direction.

The purpose of this study was to examine the effectiveness of incorporating elements of open skills into closed-skill learning using a golf-putting task. Therefore, to examine the development of players' movements, we used a motion analysis device to examine their alignment and movement. Additionally, based on previous research indicating that sight lines are important for spatial orientation (van Lier et al., 2011), we propose a method that utilizes a local coordinate system to efficiently represent and estimate the movement of points. Therefore, we recorded the positions of five points: right and left forehead, chin, and right and left eyes before putting. In addition, we estimated the position of the players' eyes while they were putting.

2. METHOD

2.1. Participants

The participants were four students (3 female, 1 male) enrolled at XXX University with no golf experience (1st–2nd grade). The sports experience of each participant was basketball (P1), swimming (P2), badminton (P3), and soccer (P4, male). Only one participant (badminton, P3) practiced regularly. All participants were righthanded. Participants were required to be inexperienced golfers and able to perform continuous light exercise for approximately 30 min. All participants provided written informed consent after receiving a thorough explanation of the study protocol.

2.2. Task and apparatus

2.2.1 Task in the tests

The scheduled test and practice dates are shown in Table 1. In all tests (pretest, midterm test, and posttest) and the applied task, the goal for each participant was to stop the ball in the center of a light beam that was the size of an actual hole on a golf course (10.8 cm in diameter) and was projected using an Offilio EB-1776W ceiling-mounted projector (Epson Corporation; Nagano, Japan) onto a single stretched (4.5 m long × 4.5 m wide) layer of artificial turf that was designed for putting practice (Superbent, Newtons Inc.; Kochi, Japan). For the pretest, midterm test, and posttest, the targets were placed at a distance of 2.1 meters and 3.0 meters, and participants putt the ball from two (Figure 1). Two types of tasks were set for the applied test on Day 11. Task 1 was to putt as accurately as possible from one ball-hitting position at two putting distances (1.5 m and 3.3 m) that the participants had not previously experienced at that time (Figure 2A). Task 2 was to putt as accurately as possible from one ball hitting position for two targets on the left and right sides (both distances to the targets were 2.7 m), as shown in Figure 2B. In the pretest, midterm test, and posttest, the participants were to hit 10 balls from each position for each distance in random order, for a total of 40 balls. Similarly, in Task 1 of the applied task, participants played 10 balls each at two distances in random order. In Task 2, participants played 10 balls each, aiming for the targets on the left and right sides in random order. None of the tests included a time limit.

Table 1. Test and practice schedule

day	schedule	number of strokes	running total
1	pretest	40	40
2	practice	80	120
3	practice	80	200
4	practice	80	280
5	practice	100	380
6	practice + midterm test	100 + 40	520
7	practice	100	620
8	practice	100	720
9	practice	100	820
10	practice + posttest	100 + 40	960
11	applied task	40	1000

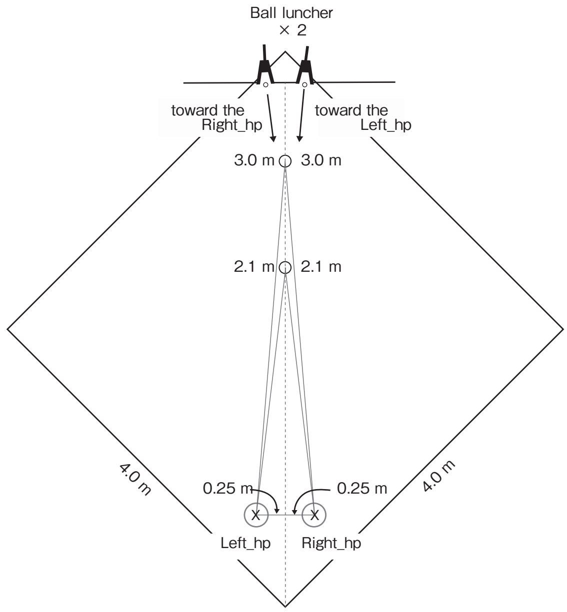

Figure 1. Schematic diagram of the experimental environment from Days 1 to 10. Participants putted from two ball-hitting positions toward the targets. Left_hp indicates the left-side hitting position. Right_hp indicates the right-side hitting position. These were 0.2 m, circular, and shaped by pasting tape onto the artificial grass.

2.2.2 Practice task

During practice on Days 2 to 10, participants in the experimental and control groups practiced aiming the ball toward targets 2.1 m and 3.0 m away from two positions (Figure 1). The learning method for the experimental group (P1 and P3) was similar to catching a baseball. We assumed that by catching an incoming ball and hitting it quickly, participants in the experimental group would be able to develop sensitivity to the direction of the target more accurately (i.e., increased ability to set their body parallel to the hitting line) than participants who practiced normally in the control group (P2 and P4). Countdown audio was played during practice. The countdown during putting at the beginning of training (Days 2–4) was 15 s, and that after Day 5 was 12 s. An experimenter launched the ball using two ball launchers (Figure 3) once every 15 s (or 12 s). The ball launcher (Ball launcher AO-YH02, Applied Office Co., Ltd., Tokyo, Japan) could set five balls for each, which could be launched by pressing a button on the top of the stick. The time from pressing the button on the ball launcher until the ball reached the participant's position was approximately 2 s. The participants practiced in an environment where they did not know beforehand whether the ball would be launched from the left or right side. The following six task constraints were placed on the participants in the experimental group. First, similar to catching in baseball, participants were instructed to attempt to catch the ball that rolled toward them from the machine and hit it back. However, the point of return was a target, not a person. Second, participants were to aim so that the ball stayed within the target. Third, for a catch to be considered good, participants needed to bounce it off their putter and stop it a as close to the putter as possible. Fourth, the important point is to hit it back without shifting from their receiving posture. Fifth, if they did not manage to catch the ball well (i.e., the ball went outside the circle), they needed to return the ball to the circle using the putter within the time limit. They could hit from anywhere within the circle. Sixth, participants were instructed that, once they were accustomed to the task, they should not try to hit the ball back as quickly as possible after receiving it.

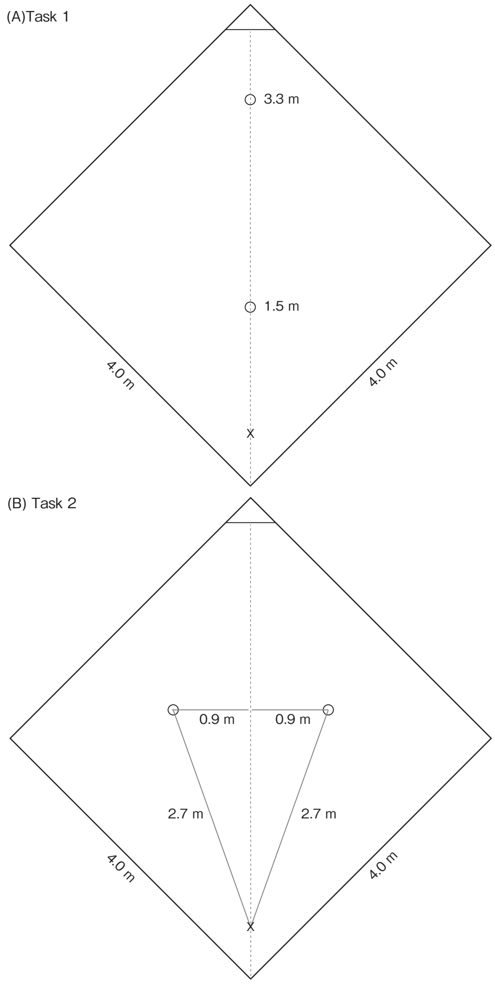

Figure 2. Schematic diagram of an experimental environment for applied tasks conducted on Day 11. Participants putted from one ball hitting position toward different distances in Task 1 and different directions in Task 2.

The learning method for the control groups (P2 and P4) was conventional practice, in which they set up the ball themselves and hit it toward the target. However, similar to the experimental group, an audio countdown was played, and the participants were required to hit the ball within the time limit. The participants in the control group were given four task constraints. First, they were to aim so that the ball remained within the target. Second, they were to position the ball within the circles at their feet, according to the experimenter's "left" and "right" instructions. Third, when placing the ball, they were asked to use points throughout the entire circle. Fourth, once they became accustomed to the task, they were to try to play quickly.

2.2.3 Other apparatus

Various parts of the body (temples, chin, shoulders, and toes), putter heads, and final ball positions (FBPs) were recorded using nine optical motion-capture cameras (OptiTrack Prime13, Acuity Inc.; Tokyo, Japan) operating at 240 Hz. The 12-mm markers were attached to the toe, heel, and neck of the putter head to digitize the positions of the putter. The root-mean-square errors of both the static and dynamic calibrations were < 1 mm during all sessions. All participants used the same putter (SB-01HB; PRGR Corp., Yokohama, Japan) and balls (Srixon Z-Star XV; Dunlop Sports Co., Ltd., Hyogo, Japan).

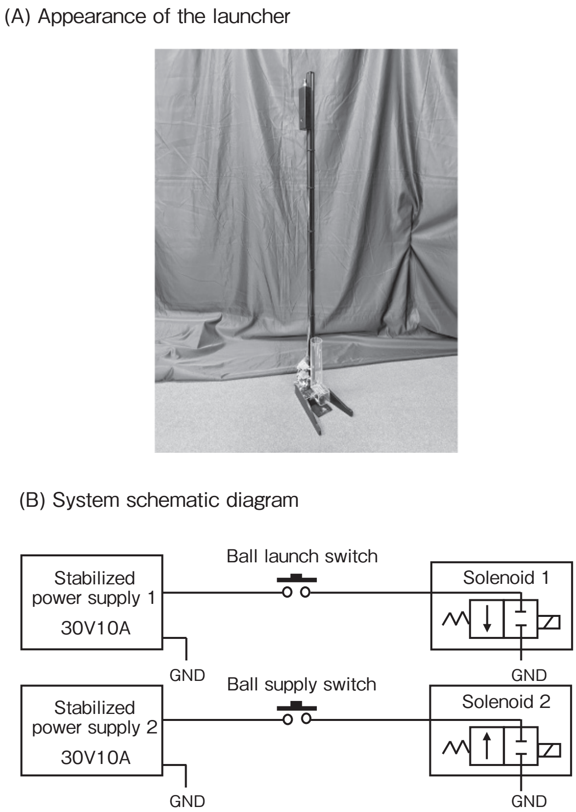

Figure 3. Ball launcher used in this experiment. (A) External view of the ball launcher; (B) Schematic diagram of the system.

2.3. Procedure

The period from the start of the pretest to the end of the posttest was scheduled to be within four weeks, and the participants were asked to visit the laboratory three to four times a week at their convenience.

On the first day, before the start of the pretest, the content of the study was explained to the participants. In particular, participants were informed of the rules, such as refraining from practicing putting or collecting information about putting other than the practice prescribed in the study. Before starting the pretest, the participants watched a video explaining the basics of putting skills. The video was approximately 90 s long, and at the end of the explanation, participants were able to see the stroke of a professional golfer's putt as an example. This explanation can be summarized as follows: 1) grip the putter with both hands; 2) hit the ball around the aiming line of the putter; 3) place the ball in front of their body; 4) align the aiming line of the putter in the direction they wanted to hit the ball; and 5) make sure they moved their body as well as the putter. Participants either practiced or took a test after watching the video (each time). After watching the video, participants also received an explanation of what they should be aware of (six or four task constraints) when practicing (see Section 2.2.2).

The pretest required approximately 60 min, including informed consent and preparation. Each session on the practice day lasted approximately 30 minutes, including preparation (changing shoes and attaching markers). The duration of Days 6 and 10 was 90 min. On Days 6 and 10, there was a 15-minute break between the end of practice and the start of the test. The applied task took 40 min. In addition, participants could take breaks whenever they wanted during practice or testing.

2.4. Evaluation variables

All digitized data were smoothed with a fourth-order Butterworth filter (5 Hz cutoff) based on the root mean square of the residual error between the original and smoothed data (Jackson, 1979; Winter, 1990). To examine how participants orientated their bodies and putter faces relative to the driving line before starting their swing (0.5 seconds from 0.6 seconds to 0.1 seconds before the start of the swing), the direction of both shoulders, eyes, toes, and putter face were calculated as angles. An angle of zero indicated that there was no alignment error. For all angles, negative values indicate the left side of the ball-hole line, and positive values indicate the right side of the ball-hole line.

Visual information is extremely important in golf, and the sight line at the address is one of the variables that should be measured along with face and shoulder directions. However, because it is not possible to attach markers to the eyes while placing them, we propose a method for estimating the positions of eye points in a three-dimensional space. The proposed method utilizes a local coordinate system to efficiently represent and estimate the movement of points. We used the positions of five points: the right and left forehead (p_1, p_2), chin (p_3), and right and left eye (p_4, p_5). Using the method described below, we estimated the position of the eyes during putting (p'_4, p'_5).

(1) Construction of the local coordinate system

First, a local coordinate system was constructed using three points: p_1, p_2, and p_3. The origin was set to p_1, and the x-axis was defined as the normalized vector from p_2 to p_1. The y-axis is defined as the normalized cross-product of the vector from p_3 to p_1 and the x-axis. The z-axis is defined as the cross-product of the x- and y-axes.

(2) Representation of points in the local coordinate system

Next, the coordinates of points p_4 and p_5 in the local coordinate system are calculated. These are expressed by the following equations:

$$p_{4_l} = T(p_4 - O)^{\top},$$
$$p_{5_l} = T(p_5 - O)^{\top}.$$

Here, T is the matrix that consists of the basis vectors of the local coordinate system arranged as column vectors, $\top$ means the transpose, O is the origin, and p_{4_l} and p_{5_l} are the coordinates of p_4 and p_5 in the local coordinate system, respectively.

(3) Position estimation of points in the new time frame

Given the coordinates of three points p_1, p_2, and p_3 in a new time frame, the proposed method utilizes the local coordinate system to estimate the coordinates of the remaining two points p_4 and p_5 in the new time frame. First, we assumed that the local coordinates were the same as in the new time frame and computed the transformation matrix T_N following the same procedure as described in (1). Next, we consider the following equations:

$$p_{4'_l} = T_N(p_{4'} - O_N)^{\top},$$
$$p_{5'_l} = T_N(p_{5'} - O_N)^{\top}.$$

Here, T_N is the matrix that consists of the basis vectors of the local coordinate system in the new time frame arranged as column vectors, O_N is the origin in the new time frame, and $p_{4'_l}$ and $p_{5'_l}$ are the new estimated coordinates of $p_{4'}$ and $p_{5'}$ in the estimated local coordinate system, respectively. Finally, the coordinates of p'_4 and p'_5 in the new time frame are calculated using the following equations:

$$p'_4 = T_N^{\top} p_{4'_l} + O',$$
$$p'_5 = T_N^{\top} p_{5'_l} + O'.$$

The impact velocity is the main variable in the kinematics of placement. In addition, the ball roll distance is highly dependent on the impact velocity (Hume et al., 2005; Mathers & Grealy, 2014), and the midpoint between the toe and heel of the putter head is calculated to analyze the putter head velocity. In particular, at higher skill levels, the peak velocity usually occurs immediately before the ball's impact. Therefore, the peak velocity is often defined as the impact velocity (Hasegawa et al., 2017, 2019, 2020). However, because the participants in this study were novices, we were not necessarily able to observe their ball impact immediately after the peak velocity of the putter head. Therefore, we calculated the positional difference between the putter and ball from the start of the swing and defined the impact velocity as the putter head velocity just before the distance between the putter and ball was less than the radius of the ball (2.1 cm).

We analyzed the final ball positions (FBPs) in the anteroposterior (APD) direction and not in the mediolateral direction. This is because the APD component is highly correlated with the impact velocity. When the ball stopped at the center of the hole, the APD error values were zero. We determined the constant error (CE), the absolute error (AE), and the variable error (VE), values for APD. Additionally, if the was ball hit too hard and went beyond the measurement range, its position immediately before hitting the fence was recorded. The number of balls exiting the bounds was also counted. From Days 1 to 10, the ball was putted from the left and right hitting positions. Because all variables were calculated using the driving line at 0 degrees, we analyzed all variables without considering the difference in hitting position.

3. RESULTS AND DISCUSSION

Figure 4 shows the body orientation of each participant at their addresses (immediately before the start of the backswing) in each test. It is clear from Figure 4 that all participants turned their eyes (i.e., sight line) to the left before starting their swings in the pretest. Thus, to visually confirm the target, the participants faced their sight line to the left and looked at it. Figure 5A shows that after identifying the target, P1's sight line does not return parallel

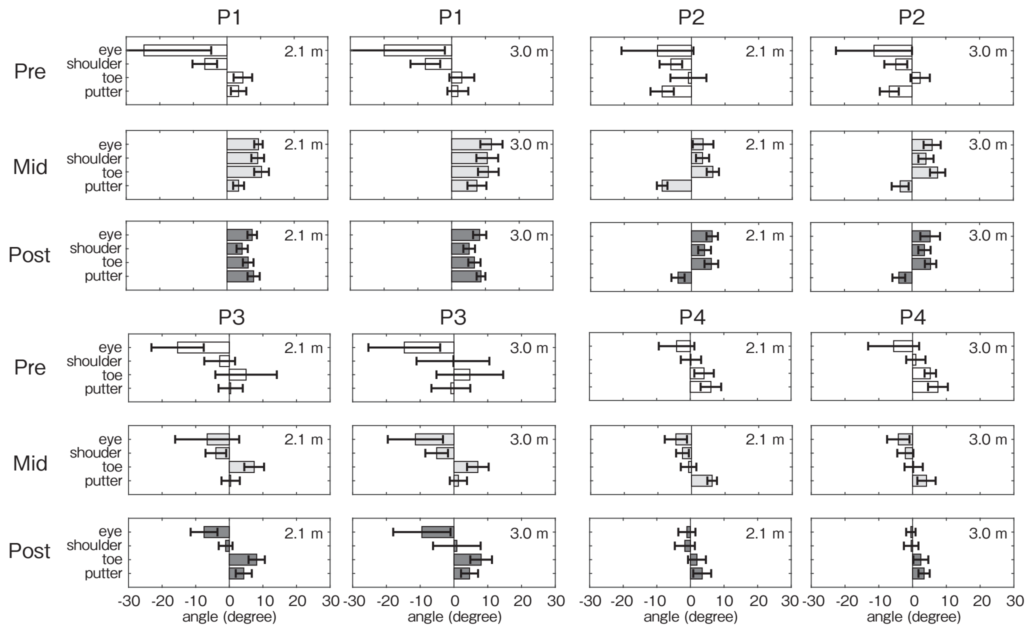

Figure 4. Alignment of putter and body to the ball-hole line at address in the pretest, midterm, and posttest. The orientation of each body part during address is shown for all participants. Different bar colors represent different tests, and error bars indicate ±1 SD. For all angles, negative values indicate the left side of the ball-hole line, and positive values indicate the right side of the ball-hole line. Pre, Mid, and Post are the pretest, midterm, and posttest, respective.

to the ball-hole line at the start of the swing. We can also see that P1's sight and shoulder lines move in the direction where the putter moves on the backswing (i.e., facing right) before the putter head moves. This is a remarkable example when setting up the pretest, and we found that looking at the target and keeping their sight line across the ball-hole line is a characteristic of novices.

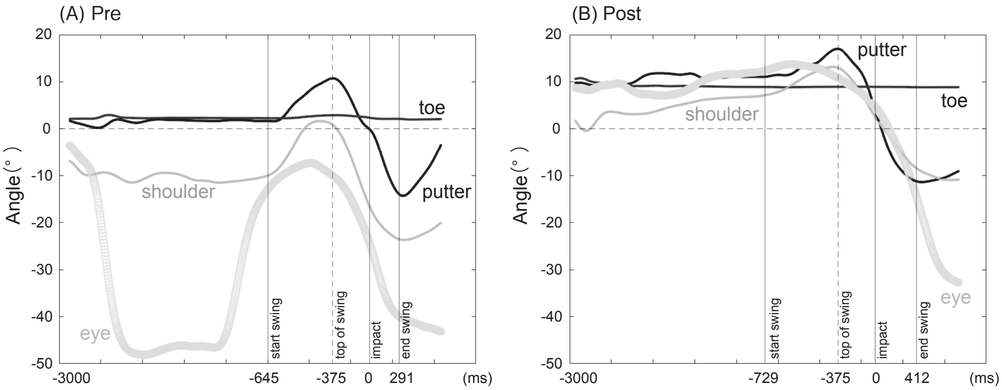

Figure 5. An example of P1's angle during setup and swing in the pretest and posttest. Negative values indicate to the left of the target, positive values indicate to the right of the target.

Furthermore, Figure 4 shows that, unlike the orientation of the upper body, the toe line and the direction of the putter are to the right side of the target, and the upper and lower bodies face different directions. In this study, the participants were not specifically advised about the position of the head (e.g., keeping the head parallel). However, Figure 4 and Figure 5B show that the twisted upper and lower bodies almost disappeared in the posttest. This indicates that all participants' skills improved toward the characteristics of golf experts' addresses (Pelz, 1989). However, P3's learning progressed without the ability to remove the twisted upper and lower body. We think the reason for this is the practice of "catching the balls that come rolling" practiced by the experimental group. When the sight line crosses the ball-hole line, such as P3, the right side of the body is likely to be forward or high. We speculate that this style makes it difficult to initiate a backswing, resulting in a novice-like movement of the head in the same direction as the putter (i.e., novices' heads sway from side to side during a swing; Lee et al., 2008). However, no such trend was observed for P1 in the posttest.

In this study, we expected that taking elements of open skills into consideration would improve players' ability to orient their bodies parallel to the driving line compared to a control group. Normal golf practice is a constant style in which the player repeatedly practices from the same position with little movement. The idea behind the experimental group's practice method in this study was based on the results of Fujii et al. (2015). Their research demonstrated that the success or failure of basketball defense is determined by the non-weighted and weighted states during a trial using force plates. They reported that guarding was more successful in the non-weighted state than in the weighted state. This suggests that a well-balanced preparatory body state leads to better movements during sports activities. Therefore, we hypothesized that receiving an incoming ball and immediately hitting it would foster a well-balanced preparatory body state, promote easy movement, and strengthen a player's awareness of the hitting direction. However, we could not confirm that the alignment of the experimental group in this study was more parallel to the line of the ball hole than that of the control group. As Figure 4 shows, the alignment of the putter's face and body exhibited considerable individual differences.

However, we obtained important results regarding how early in the learning stage an individual's motor patterns were shaped. Figure 6 shows the body orientation in the first (novel distances) and second (novel angles) tasks of the applied task. The results seen in Tasks 1 and 2 show almost the same pattern as the results in the posttest of Figure 4, except for P1. P1 kept both eyes facing the target when she was faced with the applied task (novel task), as in the early learning stage (i.e., pretest). No such motions were observed in the control group. Therefore, we assessed whether the task constraints of the experimental group prepared for this study were inferior to conventional putting practices in terms of adjusting body orientation, especially the sight line. Furthermore, in P4, the twisting of the upper and lower bodies almost disappeared from the midterm test to the posttest. Moreover, the twisted state almost disappeared during the tasks. Therefore, we assumed that golf-putting learners would acquire an approximate putting model by practicing 500 balls at the earliest and 1000 balls at the latest. This knowledge will be useful when conducting motor learning research using golf-putting tasks in the future.

Figure 7 shows the impact velocity of each participant in all the tests. Participants' impact velocities were the highest in the pretest and approached the values required for each target distance toward the posttest. However, the impact velocity control of P1 was somewhat unstable, even in the posttest. Similar results were observed in the CE FBP results. Figures 8–10 show the changes over the study period in CE, AE, and VE of the FBPs, respectively. Table 2 lists the number of balls that reached outside of the measurement range because they were hit hard. Although the individual learning curves varied, an error analysis of the FBPs revealed that the errors indicated that all participants' skills improved.

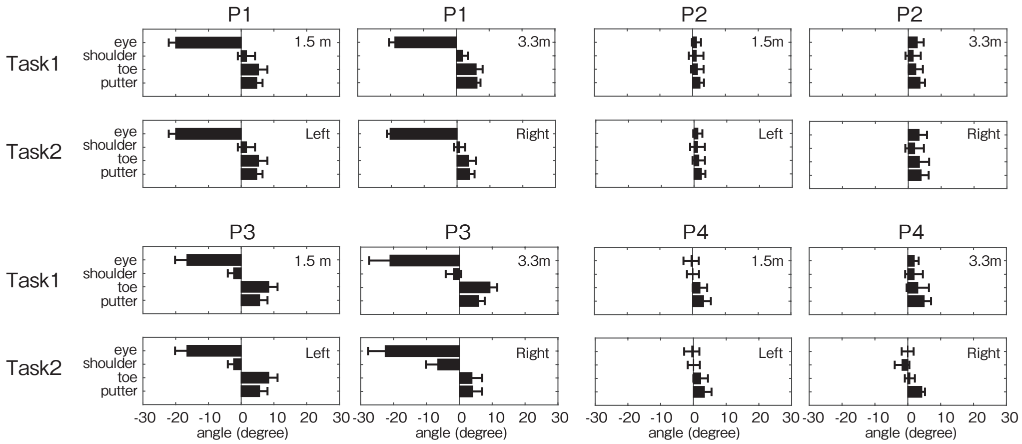

Figure 6. Alignment of putter and body to the ball-hole line at address in applied task. Error bars indicate ± 1 SD. For all angles, negative values indicate the left side of the ball-hole line, and positive values indicate the right side of the ball-hole line.

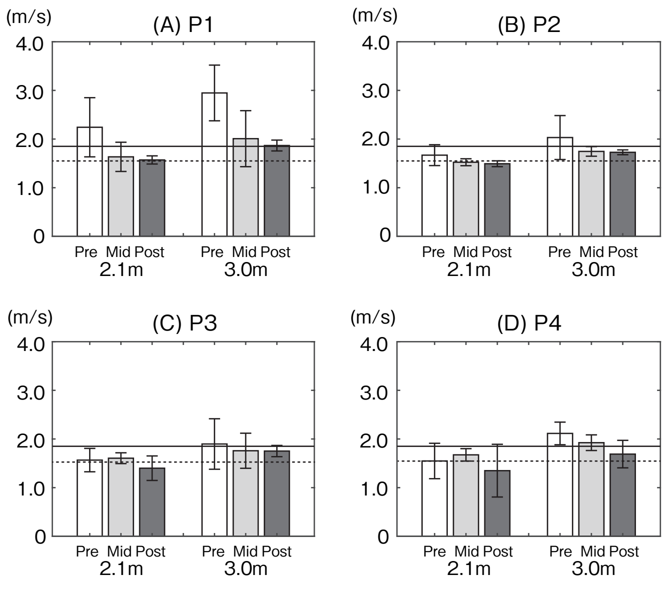

Figure 7. Impact velocities in pretest, midterm, and posttest. The solid (3.0 m) and dotted lines (2.1 m) drawn parallel to the horizontal axis in the figure are the average value of 10 putts in which the ball was brought to a stop in the target zone by one professional. Error bars indicate ±1 SD. Pre, Mid, and Post are the pretest, midterm, and posttest, respective.

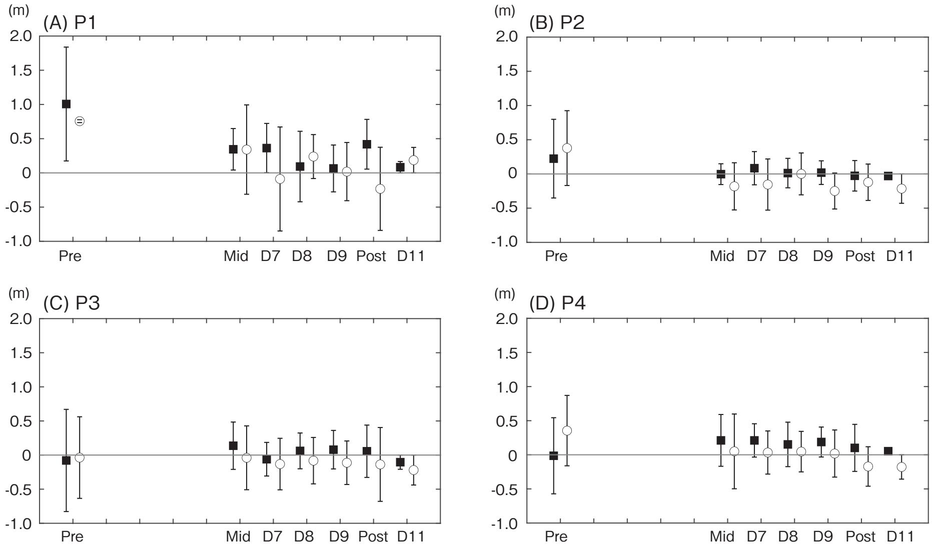

Figure 8. **Constant error of final ball positions.** This figure shows the constant error of the final ball stop positions for the anteroposterior direction from the pretest to the posttest. The black squares indicate results of 2.1 m, and the white circles indicate results of 3.0 m. Error bars indicate ±1 SD. Pre, Mid, and Post are the pretest, midterm, and posttest, respective.

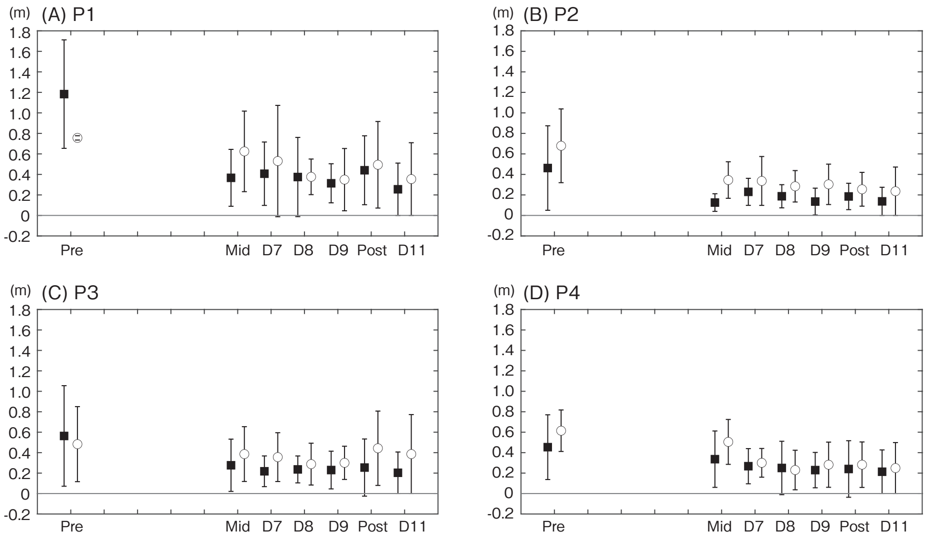

Figure 9. **Absolute error of final ball positions.** This figure shows the absolute error of the final ball stop positions for the anteroposterior direction from pretest to posttest. The black squares indicate results of 2.1 m, and the white circles indicate results of 3.0 m. Error bars indicate ±1 SD. Pre, Mid, and Post are the pretest, midterm, and posttest, respective.

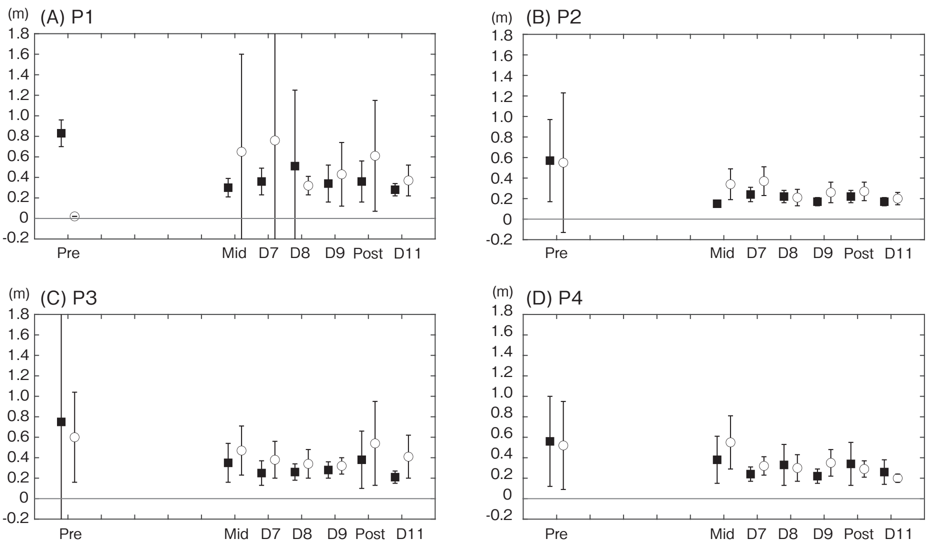

Figure 10. Variable error of final ball positions. This figure shows the variable error of the final ball stop positions for the anteroposterior direction from the pretest to the posttest. The black squares indicate results of 2.1 m, and the white circles indicate results of 3.0 m. Error bars indicate ±1 SD.

Regarding the CE FBP (Figure 8) and Table 2, three participants tended to hit the ball hard in the pretest (especially P1). When putting, the forearm uses approximately 3 % of its maximal voluntary contraction (MVC) force (Tanaka & Sekiya, 2006), and it is difficult for humans to naturally control small amounts of force stably (Enoka et al., 1999). Therefore, the results of hitting the ball harder indicated that novices tended to use more force than necessary. Previous studies have also reported that not only novices but also experienced amateurs tend to hit the ball too hard compared to professionals (Hasegawa et al., 2017; Hasegawa et al., 2022). However, in the posttest, we observed that only one of the participants reached the target of 3.0 m. In other words, the CE FBPs did not converge at approximately 0. This was likely to avoid making mistakes that would result in going out of the measurement range.

Table 2. Number of hit balls outside the measurement range

	P1		P2		P3		P4	
	2.1m	3.0m	2.1m	3.0m	2.1m	3.0m	2.1m	3.0m
Pre	8	20	1	11	0	3	0	7
Mid	1	5	0	0	0	1	0	1
Post	0	1	0	0	0	0	0	0

Note: Pre, Mid, and Post are the pretest, midterm, and posttest, respective.

Although the AE FBP (Figure 9) of P1 gradually decreased, the CE FBP of P1 continued to fluctuate significantly, even on Day 6, compared to those of the other participants. Furthermore, from the VE FBP of P1's second half of the practice, P1's force control appeared to be unstable compared to the other three participants. Note that the VE FBP (Figure 10) of P1 was close to 0 in the pretest because almost all of her putts to the 3.0 m target were outside the measurement range. However, the CE FBP of P3 score was around 0 in the pretest, but the AE FBP of P3 was about 0.5 m in the pretest, which shows that the error was dispersed between the front of the hole and the back of the hole. The magnitude of P3's FBP error in the pretest was the smallest among the four participants, but the reduction rate of P3's AE FBP in the posttest was the lowest among the four participants. We estimated that the task constraints provided to the experimental group in this study were such that the hit ball could only be reached within 0.4 m and 10 days. Incidentally, for the FBP results of P2 and P4 in the control group, the CE, VE, and AE FBPs decreased relatively steadily from the pretest to the posttest. In particular, the FBP error for P4 decreased significantly after Day 6. This was also evident from the progress of P2. In this study, only two people were placed in each group, and there were individual differences in the FBP error in the pretest. The results for the control group showed a more stable progress over time. However, there were no significant differences between the two groups in the CE FBP results for the applied task (Figure 11). In addition, we also analyzed the FBPs error in the mediolateral direction in the same way but found no noteworthy points in any of the tests.

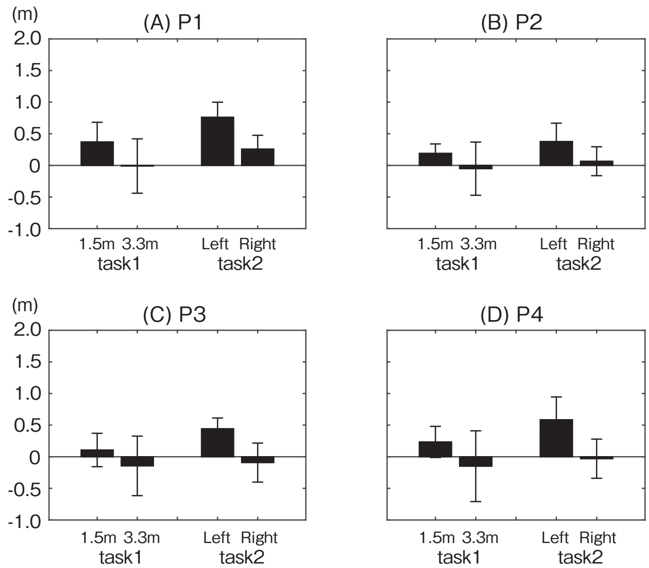

Figure 11. Constant error of final ball positions in the applied tasks. This figure shows the constant error of the final ball stop position for the anteroposterior direction in the applied tasks. Error bars indicate ±1 SD.

It has already been reported that during the motor learning process, individual differences occur in learning speed, performance accuracy (Haibach et al., 2004), movement patterns, and adaptability (Yamamoto et al., 2015, 2018). In the process of learning a novel motor skill task, methods have also been considered to examine changes in task performance during and after learning, considering individual differences (Yamamoto et al., 2021). It is necessary to solve methodological issues, such as how to evaluate measurement variables that have large individual differences, such as golf-putting alignment. Future studies should consider the negative effects of the experimental groups observed in the present study. To counteract these negative effects, it may be effective to shorten the launching interval of the ball launcher or to set tasks that require more force (i.e., far targets). Furthermore, setting up such tasks may prevent players from focusing their attention internally during learning (Masters, 1992; Zhu et al., 2015).

In this study, we used a motion analysis device to measure the progress of the experimental group that incorporated elements of open skills and the control group that practiced conventional putting. The body orientation, putter head kinematics, and final ball position errors were analyzed. In particular, to evaluate participants' sight lines during putting, we proposed a method that utilizes a local coordinate system to efficiently represent and estimate the movement of points. We hypothesized that the experimental group's body orientation at the address would be better (i.e., more parallel) than that of the control group. We also expected the balls hit by the experimental group to be closer to the target than those hit by the control group. However, no such results were obtained. Additionally, one of the two participants in the experimental group crossed her sight line with the hole line at the addresses. In other words, the upper and lower bodies were twisted at the addresses. This may have been a negative effect of catching the rolling ball. However, we determined how many ball novices would need to create their putting model and maintain the final ball position error within 0.4 meters for 3.0 m putting. This is an important finding for future research. Nevertheless, it is not possible to judge from the results of this study alone whether it is appropriate to convert the elements of open skills into closed skills. There are some issues to be solved in motor-learning research, such as those in this study; however, we believe that developing better learning methods is a direction in which motor-learning researchers should aim.

AUTHOR CONTRIBUTIONS

All authors conceived and designed the study. YH and AO conducted the experiments. YH, KY, and KF analyzed the data. All the authors contributed to the study and approved the final manuscript.

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