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Does distance perception ability of golfers affect their motor control: An attempt to measure individual distance perception using a visual analog scale

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Abstract

To improve sports performance, it is necessary to perceive the environment accurately. Similar to the acquisition of sports skills, the ability to perceive the environment is cultivated through learning. People with higher skill levels can perceive the environment more accurately than those with lower skill levels. However, it has been reported that even if the person is the same person, the person's perception changes dynamically owing to the psychological state. Therefore, a deeper understanding of the relationship between perception and motor control is important in sports science. In this study, two experiments were conducted to examine the relationship between golfers' distance perception and motor control. The first experiment was conducted to investigate whether the visual analog scale（VAS）, which was prepared to measure the golfers' distance perception, could clearly express the differences in task values. It was found that the VAS could be used to measure the distance perception of performers. In the second experiment, 10 professional golfers and 10 high-level amateur golfers participated in putting tasks of different distances from 0.9 m to 3.0 m（a total of 8 distances at 0.3 m intervals）. In each trial, participants answered their distance perception on the VAS and presented various target distances in a random order. The amateur golfers tended to overestimate distances compared to professionals. However, for the peak velocity of the putter head, which was analyzed as a kinematic variable, no significant differences were observed between amateurs and professionals. There was no significant correlation between distance perception and motor control. Although amateurs overestimated the distance perception of the targets, the results of this study did not support the model in which such perceptual distortion influences motor control. The usefulness and limitations of the VAS developed in this study and future research are discussed.

Keywords : Distance perception, peak velocity, variability, expertise, golf putting.

1. INTRODUCTION

It is widely known that even if we see the same object in the same environment, different individuals perceive the object differently in some phenomena. The outcome of acquiring sports skills depends on the learning method (Schmidt et al., 2019); however, the ability to perceive the environment is also cultivated through learning. According to Gibson and Gibson (1955), the ability to differentiate information in an environment is critical for perceptual learning. For example, children's acquisition of knowledge and increasingly complex conceptual sophistication can be attributed to their ability to detect more meaningful aspects of rich stimulation impinging on them (Pick, 1992). Based on this idea and given the problems of perception and movement in sports, it can be assumed that people with higher skills perceive the environment more adequately than those who do not. Golf professionals can perceive subtle differences in inclination compared to intermediate amateurs (Hasegawa et al., 2021).

Furthermore, even if they are the same person, their perceptions of the height of the net, width of the court, and size of the ball in sports differ depending on their psychological state at the time. The environmental perceptions required in sports include spatial, speed, weight, and time perceptions; however, many studies have reported the existence of perceptual distortions in performers that do not match their physical environments (e.g., Witt and Proffitt, 2008; Witt et al., 2008; Lee et al., 2012).

Regarding research findings on the relationship between perception and action, Rossetti (1998) distinguished two general theoretical views: the serial and parallel views. The serial view, which seamlessly fits the traditional Cartesian view, holds that perception enslaves actions. That is, action is based on and controlled by perception, without the necessity of any further transformation. The implication is that any perceptual error owing to suboptimal information-perception relations will be reflected in action (van Lier, Kamp, & Savelsbergh, 2011). By contrast, the parallel view of perception and action posits that they are separate and largely independent functions that exploit different types of information (Milner & Goodale, 1995; 2008). The two-visual pathway model explains that the information-processing pathway is divided into the ventral visual pathway, which is responsible for perception, and the dorsal visual pathway, which is responsible for movement. Therefore, individuals can perform based on physical quantities without being influenced by perceptual distortions (e.g., Michaels, 2000; Milner & Goodale, 1995; 2008; van der Kamp et al., 2003, 2008).

These studies used a perceptual task in which participants evaluated the size or length of illusory figures, and a motor task in which they grasped them. To summarize the results of these studies, in perceptual tasks, individuals perceive physical quantities that deviate from the actual physical quantities owing to the influence of illusions. However, in motor tasks, individuals perform grasping movements appropriately without being affected by illusions.

Conversely, researchers have also reported that when a new condition is added to conventional perceptual and motor tasks using illusory figures, in which the illusory figure disappears immediately after the grasping movement begins, changes in individual perception affect the individual movement (Gentilucci et al., 1996; Westwood and Goodale, 2003). According to the planning/control model (Glover & Dixon, 2002), the initial stage of movement is strongly influenced by the planning of the movement; however, this effect disappears with online corrections in the latter half of the movement (Glover, 2002). That is, planning is susceptible to context-induced illusions, whereas control is not. Many dissociations between perception and action may be better explained by the dissociations between perception and online control (Glover & Dixon, 2002). In other words, movements that are controlled online, such as grasping, are not influenced by perceived size or length; moving without looking at the target during the trial after seeing the target (not controlled online) may be affected by perceptual distortions. Golf putting involves determining the distance and direction to the target in advance and hitting the ball without looking at the target, has been used as a task to examine the relationship between perceptual distortions and planning/control (Ogasa et al., 2016; Wood et al., 2013). Ogasa et al. (2016) used the Müller-Lyer illusion to manipulate participants' distance perception and examined its effects on perception and planning/control. They reported that the putter head velocity of golf beginners increased because of longer depth perception. Incidentally, Ogasa et al. (2016) treated changes in motor control as synonymous with changes in motor planning.

This study investigated distance perception and movement of golfers during golf putting. However, instead of using illusory figures, as in previous studies, a regular target (10.8 cm in diameter) was used as a task. Based on Gibson and Gibson (1955), targets of various distances were presented to golfers of different skill levels, and we examined whether there were differences in distance perception depending on the skill level of the golfers. Additionally, the relationship between dynamically changing perceptions and athletic performance was investigated by having golfers hit a ball continuously. Participants included professional golfers and high-level amateur golfers who participated in competitions. Unlike golf novices, their movement variability is thought to be fairly low (Hasegawa et al., 2022; Tanaka & Iwami, 2018), and their relatively stable movements are thought to facilitate our understanding of the relationship between dynamically changing perceptions and actions.

During this study, the most important aspect was how to measure the individuals' perceptions. Previous studies determined the performer's size and height perception by manipulating a miniature model (Witt and Dorsch, 2009), drawing life-sized replicas of the target (Wood et al., 2013), or selecting one of several miniature figures (Lee et al., 2012; Ogasa et al., 2016). Although the participants were asked to verbally express the distance to the target as a numerical value, a visual analog scale (VAS) was used in this study. It is difficult for golfers to express relatively short distances numerically. Additionally, in this study, an answer method with a relatively large number of degrees of freedom was better than an answer format with limited options.

The study aimed to examine dynamically changing distance perception and motor control in two groups of different skill levels; professional golfers and high-level amateur golfers. Hasegawa et al. (2017) reported a significant difference in the resolution of motor control between professional and high-level amateur golfers. High-level amateurs had greater variations in putter head control at low-velocity control (the target distances were less than 3.0 m) than professionals. Based on Gibson and Gibson's (1955) ideas, we hypothesized that amateurs' ability to perceive subtle distance differences would be lower than that of professionals. In addition, because golf putting does not involve looking at a target while hitting the ball, there may be a clear relationship between perceptual and motor variations. Particularly among amateurs, it was assumed that golfers with greater changes in perception would also experience greater changes in movement. Owing to the lower variability in professionals' movements, it was difficult to find such a significant relationship in their performance. The experiments were conducted in two parts. In the first experiment, we investigated whether the VAS forms are useful for measuring distance perception. The second experiment investigated the relationship between distance perception and motor control in golfers.

2. FIRST EXPERIMENT

2.1. Introduction

In the first experiment, we used a VAS with a length of 17.5 cm printed onto B5 paper. We examined whether individuals could accurately represent eight task values (0.3 intervals between 0.9 and 3.0) on a vertical line using the standard (5 cm) presented on the left side of the paper.

2.2. Methods

2.2.1 Participants

The participants were 28 individuals attending sports science classes at XXX University. Their grades ranged from second to fourth. Although this experiment was conducted during sports science classes, students were told to participate based on their own free will, and even if they did not participate, their grades would not be affected.

2.2.2 Task and Apparatus

Participants were asked to visually mark eight task numbers (from 0.9 to 3.0 in 0.3 intervals) on a measurement form (0 at the bottom, see Figure 1), which the experimenter read out in random order every 10 s. That is, the task required participants to express a difference of 0.3 in numerical values, as a difference of 1.5 cm on the VAS. The participants completed 80 trials (10 times for each of the eight task values). The VAS score was measured using a ruler (Stainless Straightedge TZ-1343; Kokuyo Co., Ltd.).

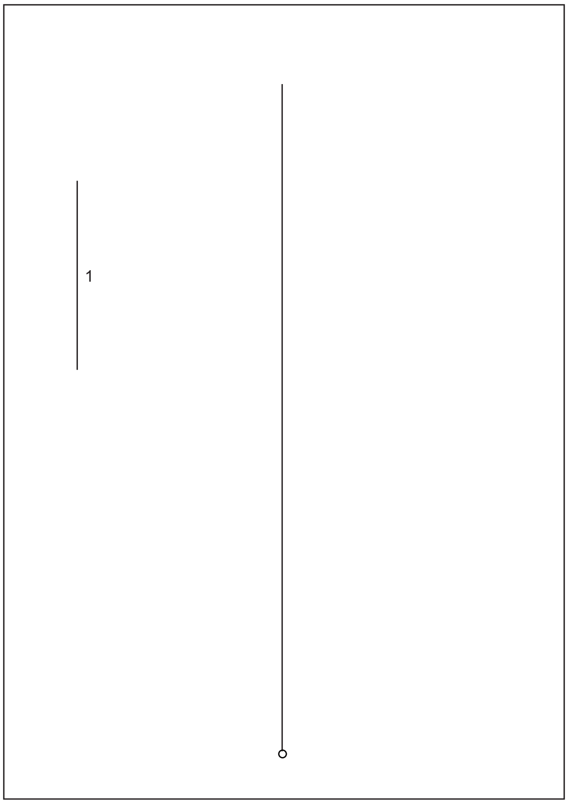

Figure 1. VAS developed in this study.
The total length of the vertical line in the center of the measuring paper is 17.5 cm. The vertical line on the left indicates the reference value, which is 5 cm.

2.2.3 Procedure

When the experimenter explained the task, the participants were told not to look back at the VAS after completing the task. In addition, if participants were unable to respond on time, they were told not to respond and to report to the experimenter about it and respond after completing all responses. After completing 40 trials, there was a 5-min break. After completing 80 trials, the completed form was measured by two participants using a ruler, unlike the person who filled it out. A third participant was assessed only when there was a discrepancy between the measurement results of the two participants.

2.2.4 Dependent Variables and Statistics

For the VAS, the average and coefficient of variation (CV) were calculated. In addition, the constant error (CE) and absolute error (AE) for each trial were calculated, and the average value for every 10 trials was calculated for each numerical value of the task, which were taken as representative values (average CE, average AE). To examine whether the eight task values were accurately expressed differently, a one-way analysis of variance (ANOVA) with a within-subject design for the average VAS, VAS CV, average CE, and average AE was conducted. Multiple comparisons were made using the Bonferroni method. The "f" values were calculated as effect-size indices for the ANOVAs (Faul et al., 2007). According to Cohen's (1988) conventions, small ($f = 0.10$), medium ($f = 0.25$), and large ($f = 0.40$) effect sizes were reported. All data were analyzed using PASW Statistics (ver. 18.0; IBM Japan Ltd., Tokyo, Japan). The alpha level of significance was set at $p < .05$; however, statistical results with effect sizes greater than medium were also mentioned.

2.3 Results and Discussion

Figure 2A shows the VAS results. The results of the one-way ANOVA were significant ($F_{7,189} = 833.79$, $p = 2.08 \times 10^{-138}$, $f = 5.56$), and as a result of multiple comparisons, it was confirmed that all task values were significantly expressed differently. Regarding average CV (Figure 2B), the result of one-way ANOVA was significant ($F_{7,189} = 11.09$, $p = 1.00 \times 10^{-11}$, f

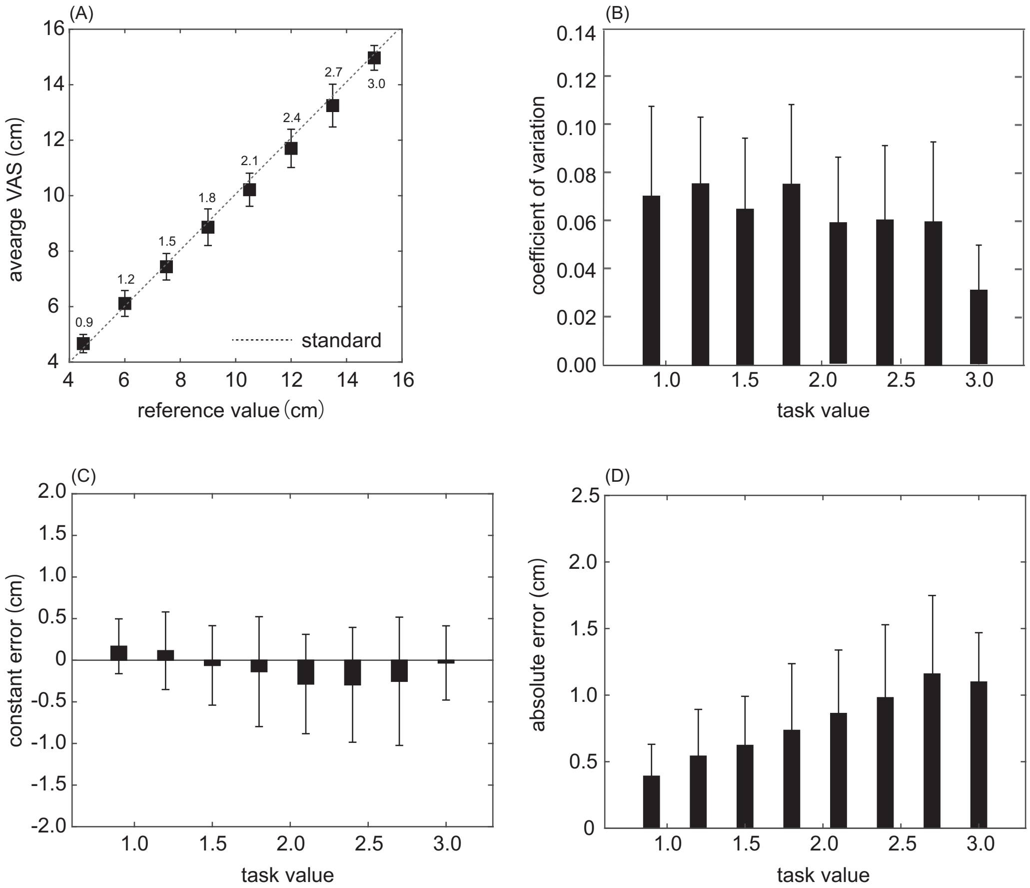

Figure 2. Results of the VAS completed by 28 participants in the first experiment.

(A) shows the average value of the VAS responses. The dotted line in the figure indicates the standard. (B) is the coefficient of variation of the VAS. These values are the average values across all participants for intra-individual variation, and the error bars indicate inter-individual variation. (C) and (D) show the constant error and absolute error, respectively. Error bars in (A) to (D) all indicate inter-individual variation, which are ±1 SD.

= 0.64); it was found that the CV of 3.0 was smaller than that from 0.9 to 2.7.

Figure 2C shows the average CE. Although the results of the one-factor ANOVA for CE were significant ($F_{7,189}$ = 2.50, p = 0.02, f = 0.30), as were the results of multiple comparisons, no clear difference between the task values was confirmed. Figure 2D shows the results for the average AE. The result of a one-way ANOVA for AE was significant ($F_{7,189}$ = 14.33, p = 6.84×10^{-15}, f = 0.73). The results of multiple comparisons indicated that the AEs were larger for 2.1 to 3.0 than for 0.9, 2.1 to 3.0 for 1.2, 2.4 to 3.0 for 1.5, and 2.7 to 3.0 for 1.8.

Based on the results of the first experiment, it was confirmed that participants were able to use a 17.5 cm long VAS printed on a B5 paper prepared for this study to express the differences in the numerical values given to them. As shown in Figure 2A, the averages compared with the reference values were plotted on the reference line, which showed almost correct answers, although there was a slight downward deviation in the middle values. Furthermore, regarding the CE (Figure 2C), no clear differences were observed in the errors in the numerical values for the tasks.

The developed VAS has two characteristics. First, the CV analysis indicated that the CV of "3," which was the maximum task value, was significantly smaller than that for other task values. The correct answer for the task value "3" was to mark a position 2.5 cm from the top of the 17.5 cm line. The distance from the edge was closer than the minimum value of "0.9" (4.5 cm from the bottom edge); thus, it may be used as a reference when answering. Figure 2B shows that except for task value "3," the variables of the answered VAS remain roughly the same. Therefore, if the upper limit of the task value was greater than "3," this result would not have been obtained. This should also be considered in future studies. Second, regarding the AE results (Figure 2D), the AE was larger for relatively large task values than for relatively small task values. However, this was not evident from the CE results. The CV and AE results indicate that although the variation within individuals for the answer of "3" is smaller than other task values, a larger task value of AEs is larger than a smaller task value of AEs. Despite the above characteristics, the developed VAS could be used to measure performers' distance perception in the second experiment.

3. SECOND EXPERIMENT

3.1 Introduction

In the second experiment, professional golfers and high-level amateur players were recruited. Using the VAS, we investigated whether different characteristics could be observed in distance perception and motor control, and the relationship between them depending on the golfer's skill level.

3.2. Methods

3.2.1 Participants

Ten professional golfers and 10 high-level amateurs with an average age of 34.2 ± 4.9 years (average experience: 19.2 ± 4.1 years) and 40.7 ± 11.6 years (average experience: 14.4 ± 6.4 years), respectively, participated. The amateurs were high-level players with an average handicap of 5.0 ± 1.9; all participated in competitions. All the participants had normal or corrected-to-normal vision. All participants provided a written informed consent after receiving a thorough explanation of the study. The experimental procedures were approved by the Internal Review Board of the Research Centre of Health, Physical Fitness, and Sports at Nagoya University and conformed to the principles of the Declaration of Helsinki.

3.2.2 Task and Apparatus

Participants completed distance perception and putting tasks. The distance to the target (hole) was set in 8 steps (0.3 m intervals) from 0.9 m to 3.0 m and presented to the participants in a random order. Participants were not given explicit information about the distance. The participants placed the ball at a designated location and recorded the distance from the ceiling to the projected target (hole) using a VAS. After completing the VAS, the participants were asked to get the ball within the target range. The participants had to close their eyes immediately after hitting the ball so that they could not see where the ball had stopped. The participants completed 80 perceptual tasks and putts, with 10 strokes at each distance.

The VAS that measured the participants' distance perception was almost the same as the form used in the first experiment (Figure 1), except that the unit "m" was added to the "1" on the standard line displayed on the left side of the measurement form. The target (10.8 cm diameter) was projected onto a ceiling-mounted projector (Offilio EB-1776W; Epson Corporation, Nagano, Japan). An artificial turf manufactured for golf putting (K-80; Kiitos Co., Ltd., Tokyo, Japan) was placed on a flat wooden putting platform (6.00 m long × 1.82 m wide × 0.30 m high). The ball-hitting position was set at the center of the putting table, and the hole was projected in a straight line (parallel to the putting platform, see Figure 3).

Putter head kinematics were recorded using six optical motion capture cameras (Qualysys Oqus 300; Qualisys AB, Gothenburg, Sweden) operating at 250 Hz. We attached 10-mm markers to the toe and heel of the putter head and digitized their positions. The root mean square errors of both the static and dynamic calibrations were < 1.5 mm during all sessions. All the participants used the same balls (Srixon Z-Star XV; Dunlop Sports Co., Ltd., Hyogo, Japan) but their own putters.

3.2.3 Procedure

After the participants provided informed consent, they were told that they could hit the ball anytime they wanted, that their goal was to stop the ball at the center of the circle of light, that they had to close their eyes immediately after ball impact (so they could not confirm the final ball position), and that they were to report to an experimenter promptly if

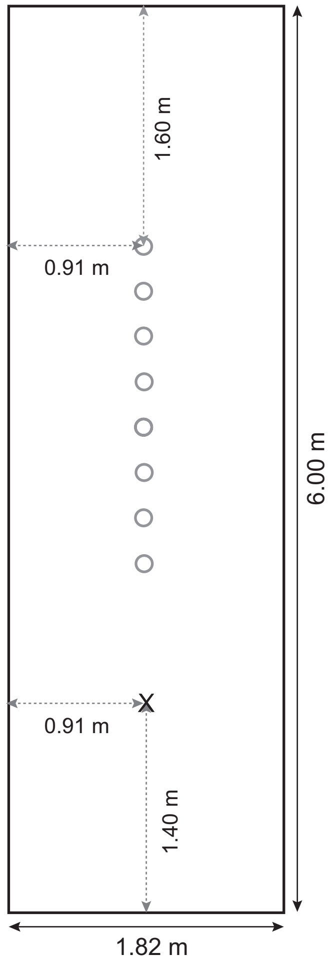

Figure 3. Experimental settings of this study.
X indicates the initial position of the ball. The eight targets indicated by gray circles are not presented simultaneously; they are projected individually onto the artificial turf by a projector from above.

they saw the final ball position. That is, participants did not receive visual feedback on their performance. Additionally, the target circle was turned off immediately after ball impact, and the assessment of movement variability was prioritized.

First, each participant practiced in green, making 24 putts (three for each distance) in a random order (visual confirmation of the final ball position was acceptable). Thereafter, the participants made eight additional putts, one for each distance. At this point, the participants could not confirm their final ball positions. Each participant then underwent testing as described; 5-min breaks were allowed after 20, 40, and 60 putts.

3.2.4 Dependent variables

3.2.4.1 Distance perception

To measure participants' distance perception, two experimenters used rulers (Stainless Straightedge TZ-1343, Kokuyo Co., Ltd.) to measure the distance from the bottom of the VAS to the horizontal line where the participants indicated the center of the hole. Additionally, for trials in which there was a discrepancy between the two experimenters' measurements, the average value was used. The average value and coefficient of variation of 10 trials for individual were calculated.

3.2.4.2 Peak velocity of the putter head

All digitized data were smoothed with a fourth-order Butterworth filter (5-Hz cut-off) based on the root mean square of the residual error between the original and smoothed data (Jackson, 1979; Winter, 1990). The peak velocity of the putter head has a high correlation with the distance the ball rolls (Hasegawa et al., 2019), and is the variable with the highest explanatory rate among the kinematics (Hasegawa et al., 2021). According to previous studies, the impact velocity occurs immediately after the peak velocity; therefore, the peak velocity is sometimes substituted for the impact velocity. However, the measurement frequency in this study was 250 Hz, and the time resolution was insufficient to define the impact velocity; therefore, it was expressed as the peak velocity. Peak velocity is the velocity in the direction of the ball hitting midway between the toe and heel of the putter head (approximately at the center of the putter head) (does not include horizontal and vertical components) and is the average value of 10 trials for everyone. The coefficient of variation (peak velocity CV) was then calculated.

3.2.5 Statistics

A two-factor mixed-design ANOVA was performed to explain the relationship between the two groups (professional and amateur) and the eight putting distances (0.3 m intervals from 0.9 to 3.0 m) for the average VAS, VAS CV, average CE, average AE, peak velocity of the putter head, and peak velocity CV. As the putting distance was a repeated-measures factor, the Bonferroni method was used to accommodate multiple comparison testing. In addition, to examine whether there was a correlation between distance perception and peak velocity and between VAS CV and peak velocity CV, Pearson's correlation analysis was conducted by group and distance. This is performed by distance to eliminate the effect of increasing the values of both variables as the distance to the target increases. The "f" values were calculated as effect-size indices for the ANOVAs (Faul et al., 2007). According to Cohen's (1988) conventions, small ($f = 0.10$), medium ($f = 0.25$), and large ($f = 0.40$) effect sizes were reported. All data were analyzed using PASW Statistics (ver. 18.0; IBM Japan Ltd., Tokyo, Japan). The alpha level of significance was set at $p < .05$; however, statistical results with effect sizes greater than medium were also mentioned.

3.3. Results and Discussion

3.3.1 Distance perception

The ANOVA results for the VAS (Figure 4A) indicated that the interaction was not significant. However, the main effects of the group tended to be significant ($F_{1,18}$ = 3.20, p = 0.09, f = 0.42); amateurs tended to perceive distances as longer than professionals. In addition, the main effects of distance ($F_{7,126}$ = 562.85, p = 8.29×10^{-92}, f = 5.60) were significant; there were significant differences in all eight distances. The ANOVA results for the VAS CV (Figure 4B) indicated that the interaction and main effects of the group were not significant. However, the main effects of distance ($F_{7,126}$ = 14.56, p =8.64×10^{-14}, f = 0.90) were significant. That was, the VAS CVs at 0.9 m and 1.2 m were larger than those at 2.4 m to 3.0 m. The VAS CVs at 1.5 m, 1.8 m, and 2.1 m were larger than those at 2.7 m and 3.0 m. In addition, the VAS CV at 2.4 m was higher than that at 3.0 m.

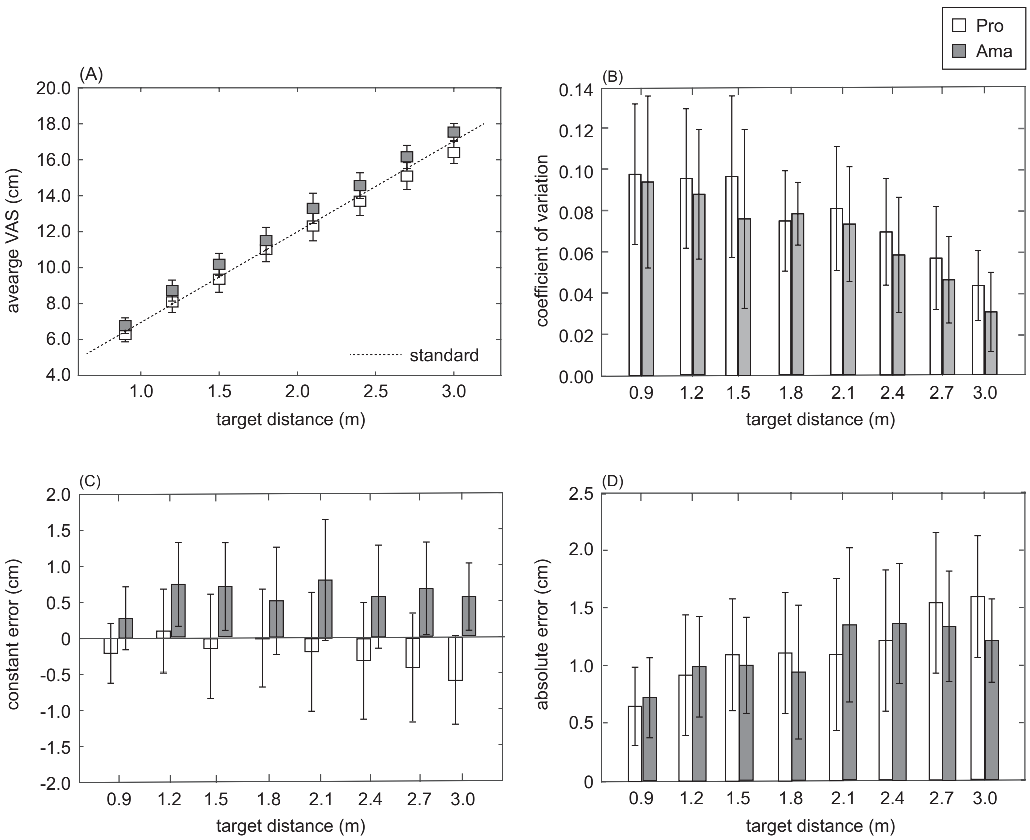

Figure 4. Results of golfers' distance perception were measured using the VAS.

(A) shows the average value of the VAS responses. The dotted line in the figure indicates the standard. (B) is the coefficient of variation of the VAS. These values are the average values across all participants for intra-individual variation, and the error bars indicate inter-individual variation. (C) and (D) show the constant error and absolute error, respectively. Error bars in (A) to (D) indicate inter-individual variation, which are ±1 SD.

The ANOVA results for the average CE of the VAS (Figure 4C) indicated that the interaction and main effects of distance were not significant. However, the main effects of the group tended to be significant ($F_{1,18}$ = 3.20, p = 0.09, f = 0.42); the CE of professionals was smaller than that of amateurs. The ANOVA results for the average AE of the VAS (Figure 4D) indicated that the interaction and main effects of the group were not significant. However, the main effects of distance ($F_{7,126}$ = 7.15, p = 3.41×10^{-7}, f = 0.63) were significant. The AE at 0.9 m was smaller than the AE from 1.8 m to 3.0 m. Additionally, the AE at 1.2 m was smaller than the AE at 2.7 m and 3.0 m.

3.3.2 Peak velocity of the putter head

The ANOVA results for peak velocity (Figure 5) indicated that the interaction was significant ($F_{7,126}$ = 2.25, p = 0.03, f = 0.35). Simple-effects testing indicated that the differences between the groups at each distance were not significant; however, the distances in each group were significant (Pro: $F_{7,126}$ = 789.93, p = 7.94×10^{-101}, f = 6.62, Ama: $F_{7,126}$ = 697.77, p = 1.62×10^{-97}, f = 6.23). The ANOVA results for the peak velocity CV (Table 1) indicated that the interaction and main effects of distance were not significant. However, the main effect of the group was significant ($F_{1,18}$ = 8.75, p = 0.008, f = 0.70), and the peak velocity CV for professionals was smaller than that of amateurs

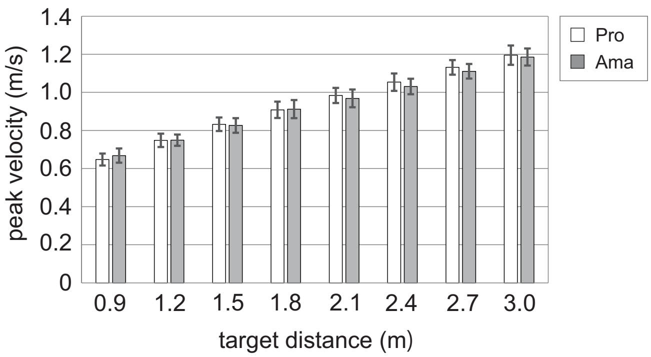

Figure 5. Average putter head peak velocities for each distance in each group.
Error bars indicate inter-individual variation, which are ±1 SD.

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Table 1. Average value of the coefficient of variation of peak velocity for each distance in each group.

		0.9 m	1.2 m	1.5 m	1.8 m	2.1 m	2.4 m	2.7 m	3.0 m
Pro	average	0.043	0.034	0.034	0.036	0.031	0.037	0.035	0.028
	sd	0.017	0.011	0.010	0.010	0.012	0.008	0.009	0.010
Ama	average	0.051	0.049	0.053	0.051	0.049	0.046	0.048	0.048
	sd	0.012	0.013	0.020	0.020	0.026	0.015	0.015	0.017

3.3.3 Relationship between distance perception and peak velocity

To examine the relationship between the VAS and peak velocity of the putter head, correlation analyses were performed by the group and distance, but neither was significant.

However, regarding the correlation analysis conducted in each group for the VAS CV and peak velocity CV, only the results of professionals were significant (r = 0.31, p < .01). A weak correlation was observed (Figure 6A and 6B).

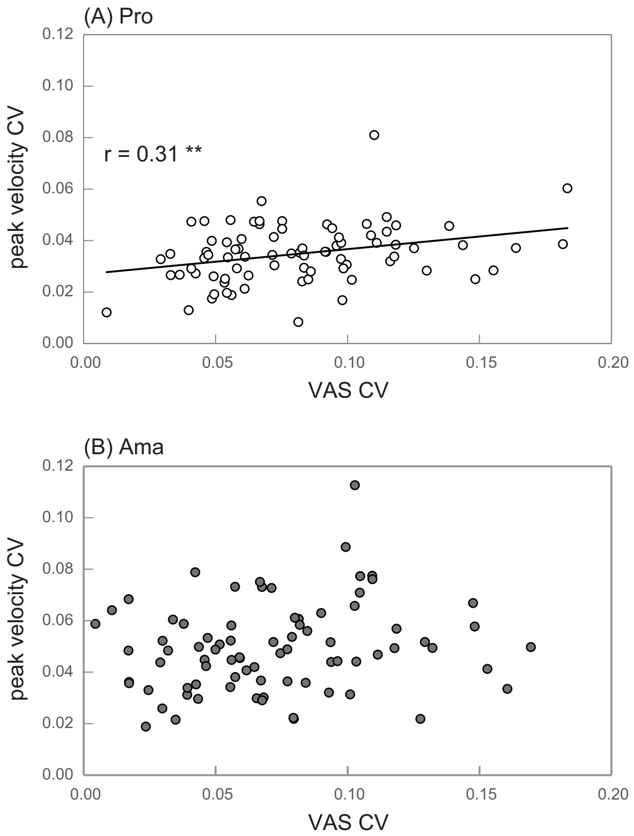

Figure 6. Results of correlation analysis between variation in distance perception and variation in peak velocity for each group.

To summarize the results of the second experiment, for the golfers' distance perception measured using VAS, amateurs tend to perceive longer distances to the target than professionals was found. However, regarding the peak velocity of the putter head, which is the main kinematic variable of the putting motion, the results did not show that the peak velocity of amateurs was higher than that of professionals. Correlation analyses were used to examine the VAS and peak velocity by group and distance; however, none of the analysis results were significant. Therefore, no relationship was observed between the distance perception and motor performance. However, regarding the VAS CV and the peak velocity CV, which was the focus of this study, a weak correlation was observed only in professionals. These results are discussed in the general discussion section.

4. GENERAL DISCUSSION

Two experiments were conducted to examine the relationship between golfers' perceptions of distance and motor control. The first experiment was conducted to investigate whether the VAS (Figure 1), which was developed to measure the golfers' distance perception, could clearly express differences in the task numbers. In the second experiment, ten professional golfers and 10 amateur golfers participated in putting tasks of different distances from 0.9 m to 3.0 m. In each trial, the participants indicated their distance perception on a VAS and placed them for various target distances presented in random order.

Regarding distance perception measured using the VAS, amateur golfers tended to overestimate distances compared with professionals (Figure 4A). According to Hasegawa et al. (2017), the resolution of professional motor control was higher than that of amateurs. This is owing to the lower motor variability of professionals. However, the study also suggests that the perceptual resolution of high-level amateurs may be lower than that of professionals. Additionally, Hasegawa et al. (2021) examined golfers' perceptions of slopes and reported that amateurs' poor ability to perceive slopes affected their movement. According to Gibson and Gibson (1955), the ability to differentiate information within an environment is critical to perceptual learning. They explained that individuals become sensitive to certain stimulus inputs and can discriminate between previously indistinguishable inputs (Pick, 1992). An individual can match perceived properties and objects with the physical properties and objects of the environment by learning and distinguishing between previously indistinguishable inputs (Pick, 1992). These perceptions are coupled with actions (Gibson, 1979). This study suggested that high-level amateurs' subjective distance was slightly different from their physical distance.

Because the amateurs who participated in this study had a handicap of 8 or less, it is difficult to understand the phenomenon in which subjective distance deviates from physical distance. For relatively long putts, the distance is measured by the golfer's steps, but golfers rarely count steps for relatively short putts. Therefore, it can be assumed that golfers are unaccustomed to tasks that explicitly process distance. However, if the subject is unfamiliar with the task, certain distortions in far perception may not be observed.

Alternatively, there is another perspective on why amateurs perceive the target as being far away. Amateurs may feel that the tasks are more difficult than those performed by professionals. Such psychological states may affect the perception of the distance to the target. Perceptual distortion in sports is known as action-specific perception (Witt, 2011). In summary, athletes adapt to the conditions of the day and perceive tasks to be easier (e.g., lower net and larger ball) when the conditions are good. Conversely, a bias has been reported in which, under pressure situations where anxiety increases, the task is perceived as more difficult (e.g., higher net or smaller ball). However, because the participants in this study were not under pressure, the results regarding distance perception suggested in this study suggest that motor control ability may influence distance perception.

Conversely, the distance perception of professionals was found to be slightly lower than the physical distance in some cases (Figure 4A), but it was very similar to the VAS results of the first experiment (Figure 2A) and roughly matched the physical distance. Compared with the variability of the VAS in the first experiment (Figure 2B), the variability in the VAS in the second experiment appeared to be slightly larger (Figure 4B). This could be because the task involved determining the distance to the target and making putts in each trial rather than simply expressing numerical values. This result indicates that professionals can accurately perform the unfamiliar task of explicitly expressing short distances. Their ability to perceive the environment appropriately may be one reason why they are professionals.

In this study, amateurs overestimated distance perception; however, the results of the study did not support the idea that such perceptual distortion influences motor control without online-control (Glover & Dixon, 2002). That is, the peak velocity of the putter head was analyzed as a kinematic variable; however, no significant differences were observed between the peak velocities of the amateur and professional putter heads. That is, even if the distance to the target individual was perceived as longer, it did not affect movement. The results of this study differ from those of a previous study that reported that using optical illusion figures, the putter head velocity of golf beginners increased owing to distorted depth perception (i.e., longer; Ogasa et al., 2016). Based on the planning control model (Glover & Dixon, 2002), because golfers do not hit the target while looking at it, the movements planned based on prior distance perception may be affected. Furthermore, as mentioned above, the amateurs in this study were advanced golfers, and their movement variabilities were less than those of beginners (Hasegawa et al., 2023; Tanaka and Iwami, 2018); therefore, the amateurs might execute their planned movements more stably. Therefore, correlation analyses were conducted between distance perception and peak velocity by group and distance. However, none of these analyses were significant.

Regarding the relationship between perceptual and motor variabilities, which was the focus of the present study, a weak correlation was confirmed only among professionals. Considering this result in conjunction with the abovementioned results, no direct relationship was found in which the longer (or shorter) the perceived distance, the larger (or smaller) the motion. In addition, as distance variability increases, movement variability may also increase (or vice versa). Therefore, the ability of professionals with high functional variability (Langdown et al., 2012) is more likely to activate at putting distances where there is a large variation in perception. However, these results differ from those of this study and must be interpreted with caution. This is because there is insufficient evidence to explain why this result was observed in professionals rather than amateurs.

In the second experiment, no difference was observed in the peak velocity CV depending on distance; however, normally, larger movements have greater variability (Schmidt et al, 1979). It was also speculated that the variability in distance perception was similar to that in movement. However, in the VAS developed in this study, the VAS CV for the upper limit of 3 (m) was smaller than that for the other distances in both the first and second experiments. Although it was useful in expressing differences in distance to the target and measuring differences between individuals, it is possible that the VAS may not be sufficiently accurate to measure the variability of distance perception. Therefore, if a VAS is used to measure distance perception in future research, it will be necessary to develop a VAS that covers a wider range than the actual measurement range. Furthermore, it is difficult to imagine that golfers explicitly process putting distance as a numerical value, specifically when putting at relatively short distances; therefore, a measurement method that verbally expresses distance as a numerical value was not chosen in the present study. However, to further investigate the relationship between the perceptual and motor variability observed in the present study, other methods, such as manipulating a miniature model (Witt and Dorsch, 2009) to represent the distance to the target, should be considered. Future research should involve more individuals with different skill levels.

ETHICS STATEMENT

Studies involving human participants were reviewed and approved by Nagoya University. All the participants provided a written informed consent to participate in this study.

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