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Gaze control ability in esports expert

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1. Introduction

1. 1 Esports

With the proliferation of personal computers, smartphones, and the internet, many people have been able to easily enjoy playing video games. Today it is popular to play a competitive game with other players online; this activity is called electronic sports (esports) [1]. The expansion of esports markets provides more chances for top-level esports players to earn large amounts of money. According to research on the economics of esports, the total value of global esports competition prizes increased from $360 million in 2005 to $7.1 billion in 2015, and the total industry size of esports is expected to reach 1.084 billion dollars in 2021 [2]. Research about esports has started to increase since 2002, and especially after 2015, the number of publications about esports has steeply increased [1, 3]. Different genre of games exists in esports, such as real-time strategy (RTS), action video game (AVG), first-person shooter game, multiplayer online battle arena and role-playing game.

Interestingly, competitive element, acceptance, and recreation make esports within the frame of traditional sports [3]. Esports was introduced as a demonstration event in 2018 Asian Games. It means that esports has the same status as traditional sports. Media studies of esports have focused on live streaming gameplay and mega event of esports [3]. Esports players are often streaming their play scene through live streaming channel (e.g. YouTube and Twitch). It means that esports players not only play the game but also communicate with other esports players. Additionally, in mega event of esports like World Cyber Games (WCG), spectators are not only watching the game but also actively engaging with the community [4].

1. 2 Real-time strategy (RTS) game

Real-time strategy (RTS) game is a genre of games in which players have a battle with opponents, utilizing complex strategies. In RTS, multiple information streams appear simultaneously in different locations on the monitor screen, and players must recognize and select important information. Based on the information obtained, they must judge how to response to the stimuli with appropriately timing. Thus, multitasking ability, to process multiple stimuli at the same time could be the key element for higher performance in RTS. Additionally, Basak et al. found that RTS game training improves task-switching ability [5]. Task-switching ability is defined as ability to switch the target of attention. Multitasking ability and task-switching ability have similar feature because they are needed to change the attention quickly. In order to switch between tasks, it is necessary to accurately perceive stimuli presented on the monitor screen through proper gaze control. RTS players must move their gaze over multiple areas on the monitor. Therefore, RTS players would use saccade more to process multiple stimuli more quickly. Therefore, RTS requires superior gaze movement. However, the characteristics of gaze strategy in RTS players are still unknown.

1. 3 Gaze movement

Gaze movement, which has an important role in sports in general and esports as well, is divided into three categories. First is saccade which means quick jump of gaze as fast as 300-400 deg/sec [6]. Saccade was controlled by the frontal eye fields (FEF) or superior colliculus [7]. Its function is to make it easy to scan unexpected change in the position of a target [8]. Second, fixation is the state that the eyes are fixed on the single point in the visual field. During the fixation, the image on the retina is stabilized to gather the information [9]. Finally, smooth pursuit is defined as eye movement which indicates fixation on a moving stimulation. Smooth pursuit was used to track a stimulus in the task which required attention [10].

1. 4 Cognitive and neurological training effect of esports

The increasing popularity of esports has accelerated further research on the cognitive influence associated with esports and video games [11]. For example, Kowal et al. [12] found that the task-switching ability is higher in action video game (AVG) players than non-AVG players. AVG is a game genre with action-related elements added to video game. Furthermore, top video game players have better cognitive flexibility than novice players [13] to adapt to new and unexpected conditions [14]. In addition, a recent meta-analysis also found that video game practice has positive effects on cognitive function [15] (the mental processing required to obtain information and knowledge [16]). To be specific, first person shooting game reduce the reaction time, and RTS game increase efficiency of cognitive control ability.

Video game can enhance the cognitive function. Li et al. found out that AVG training improves the contrast sensitivity [17], the ability to detect a small movement of visual target [18]. Participants who trained with AVG had higher contrast sensitivity when the task difficulty was increased. To be specific, Oei and Patterson [19] used different type of cognitive task to measure the effect of video game. Each participant played five different kind of video game over four weeks (total 20 hours). As a result, video game increased visual search ability. Anguera et al. found out that video game training improve working memory [20]. Not only AVG players but also FPS players have superior cognitive function too. To be specific, FPS player have superior cognitive flexibility to adapt the change of environment [21]. Moreover, a literature review points out that AVG improves cognitive function, decision making, and reduce reaction time [22]. Thus, esports training can generally improve various higher brain function.

In neurological study, long-term AVG training induces changes in the gray matter volume in the dorsolateral prefrontal cortex, hippocampus, and cerebellum [23]. The change of the gray matter volume of each area depends on the level of cognitive functions. For example, dorsolateral prefrontal cortex is related to working memory, future planning and cerebellum is related to motor control. For RTS, players show greater activity in inferior frontal gyrus and anterior cingulate cortex than non-RTS players during the texture discrimination task [24]. Not only single case study but also the recent literature review also pointed out that AVG has positive effect on neural network and function (e.g. AVG has positive effect on central executive network which is connected with working memory) [25].

1. 5 Gaze control ability in sports

According to studies of cognitive and neurological training effect of esports, esports players ha d superior cognitive function than that of non-esports players who did not play any esports (section 1. 4). For the excellent cognition of presented stimuli, esports players have to first check the stimuli through the eyes. Indeed, they have faster saccade (rapid gaze movement, 1-3) reaction time than that of non-esports players [26]. Thus, superior cognitive and neurological characteristics of esports players might be related to gaze control ability rather than the good signal processing in the central nervous system. However, gaze control ability has not been verified for esports players.

To achieve a high performance level in general sports like soccer and baseball, not only higher cognitive function but also variety type of gaze control ability which related to the sports is important because, it is necessary to recognize a visual object before using the cognitive function [27]. In soccer, the study comparing experienced soccer players with non-experienced soccer players showed that experienced soccer players significantly did not stop their gaze movement on the one position when they watching the soccer defense scene [28]. This is advantageous in predicting the opponent's next movement. In baseball, top level batters significantly delay their saccade movement from the fixation on the ball to obtain more visual information, because it can increase the time to watch the ball [29]. In basketball, quiet eye training (training method to fix the gaze position on the target) can improves accuracy in basketball field goal shooting [30]. Thus, the gaze control ability would have important roles in sports, and different kind of gaze control strategy is required for different sports. It is interesting whether or not esports players can show specific gaze control abilities.

1. 6 Purpose of the current study

In elderly people training with RTS games improved multitasking ability [5]. This could be accompanied by or based on improving gaze control ability which RTS games require; that is, for smooth multitasking in RTS games, it would be necessary to quickly process multiple visual stimulation. In light of this background, the current study aimed to clarify how RTS players control their gaze while playing a game. I adopted a popular RTS game, StarCraft, as the model task. Moreover, since task difficulty (i.e., number of tasks among which players have to switch) would be a critical factor for gaze control, it is necessary to clarify whether or not gaze control depends on task difficulty of the game played. Thus, we set test games with three different levels of difficulty. Considering the characteristics of StarCraft that requires players to quickly move their gaze over multiple areas on the monitor, and the fact that long-term training in RTS games improves task-switching ability [5], elite StarCraft players would use saccade more to quickly process multiple stimuli. Thus, we hypothesized that RTS experts would show superior gaze control (dispersed and fast saccadic gaze movement) during playing games compared to the novices. We tested this hypothesis by measuring gaze distribution and saccadic movements.

2. Methods

2. 1 StarCraft

In the present study StarCraft was utilized as a model game to study multitasking ability. StarCraft is a strategy simulation game developed by Blizzard Entertainment in 1999 (https://starcraft.com/en-us/). After the original was released in 1999, "StarCraft: Remastered" featuring some graphics changes was released in 2017.

2. 2 Participants

We performed a power analysis to estimate the required sample size (G*Power version 3.1). The G*Power was calculated using the Hard Task performance level (described in the Sample games section) of experts (Expert, $n = 4$) and the performance of players with lower skills (Low Skill, $n = 4$) in a preliminary experiment (Cohen's d: 1.91; α level: 0.05; power (1-β error probability): 0.8). Effect size was calculated according to Cohen [31]. According to the result of this power analysis, five participants in each groups were required. Finally, after considering the possibility of each participant's data loss, nineteen participants (18 male, 1 female; 9 Expert, 10 Low Skill; mean age, 22.4 years; age range, 18-28 years) with experience playing StarCraft participated in the present study. Participants were recruited through the Waseda University school bulletin board. Subjects had no record of visual disorders. Subjects were divided into two groups, the Expert group and the Low Skill group, according to the history and official ranking of StarCraft game players. Expert is defined as those who play StarCraft more than three times a week for at least six months, or who are in the top 10% of the official StarCraft ranking (rankings by Blizzard Entertainment, developer of StarCraft). Low Skill players had not played StarCraft for more than six months, or their official ranking was in the bottom 50% of players. Before the experiment, we verbally provided information about the contents and concepts of this research along with the instruction documents. After that, we obtained verbal informed consent from all subjects. The research was approved by the Human Research Ethics Committee of Waseda University, Japan (2019-342).

2. 3 Experimental procedure

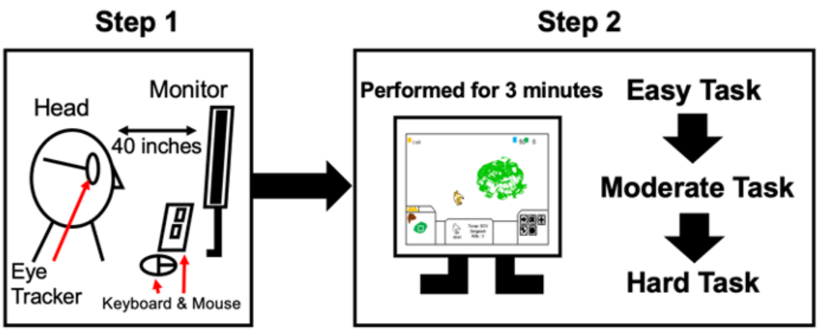

Figure 1. Overall flow of the task. Each step shows the overall flow of the task.

Before the experiment, we measured the distance at 40 inches between the subject's head and the monitor and asked subjects to maintain the position during the task. Each task was performed for 3 minutes. When the participant failed to play the task for 3 minutes, the task was restarted. Additionally, any task which was not played for 3 minutes was excluded from the analysis. During each task, gaze movement was recorded by an eye tracker (Pupil Core, Pupil Labs). The tasks proceeded in the following order: Easy Task, Moderate Task, and Hard Task. When a task was performed for 3 minutes, the task was over.

2. 4 Sample games

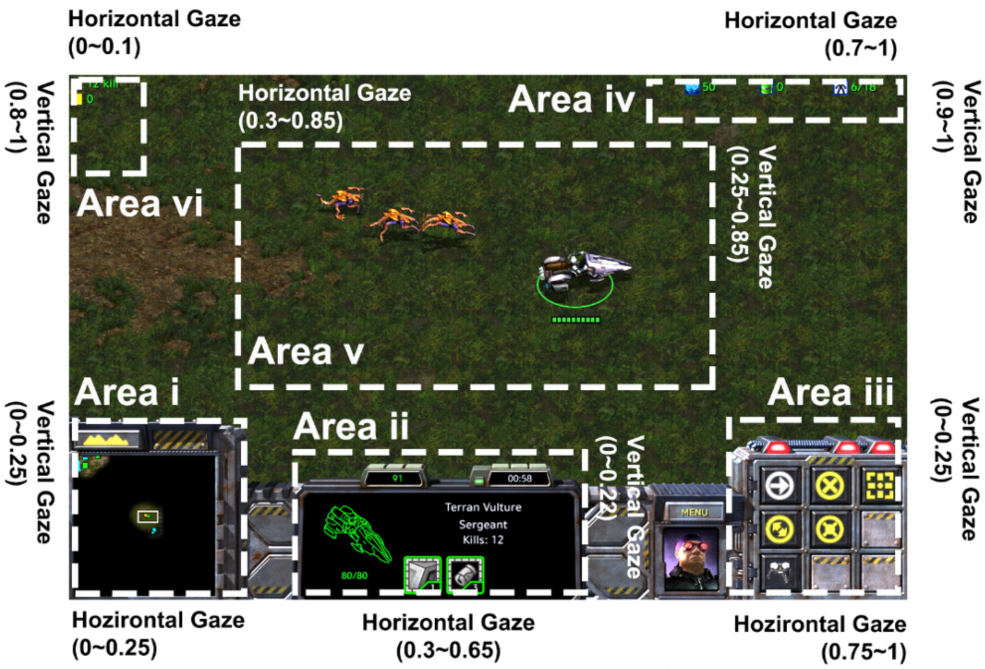

Figure 2. StarCraft main play screen in which different information is displayed. Dashed lines overlaid on the screen indicate six areas. Values in parentheses show the relative coordinates of each area normalized to monitor size, 0 to 1 in both horizontal and vertical directions. Area i: a mini-map which shows a bird's-eye view of all play Zones. When a critical event such as an attack from the enemy occurs in a certain Zone, the Zone blinks to inform the player about the event. Area ii: information about the number of destroyed enemy units, and remaining strength of the commander unit which is operated by the player. Area iii: the function(s) of a selected unit or building. Area iv: the number of resources. Area v: the play area which is a part of the selected Zone. Area vi: the total score amassed thus far by destroying enemy units.

In the game the player must construct as many buildings and produce as many product units (described later) as possible from resources (virtual commodities), and at the same time escape from and destroy enemies.

Four different types of unit exist in the task; commander unit, enemy unit, labor unit, and product unit. There are three Zones in which different jobs are performed. Specific features of units and locations of Zones are shown in Figure 3,4 and 5. Zone 1: one commander unit controlled by the player and three enemy units exist. Enemy units are avatars which are operated by the computer system. The commander unit fights with or escapes from enemy units that attack the commander unit. When all three enemy units are destroyed, three new enemy units reappear in Zone 1. Zone 2: labor units, product units, and buildings exist. Zone 2 is used to collect resources, construct buildings, and produce product units. Though there are multiple labor units, they move together as a group to collect resources, and to construct buildings. Once the game starts, the group of labor units automatically collects resources at a constant rate. Product units are produced by the player, consuming resources. Zone 3: buildings and product units exist. Zone 3 is used only to produce product units. All units, including individual units (commander, ememy, product) and the group of labor units, can move in any direction but cannot get out of their zones. The player must accomplish necessary jobs by switching the Zone that appears in Area v. In this process a high level of multitasking ability is required to perform all these jobs simultaneously.

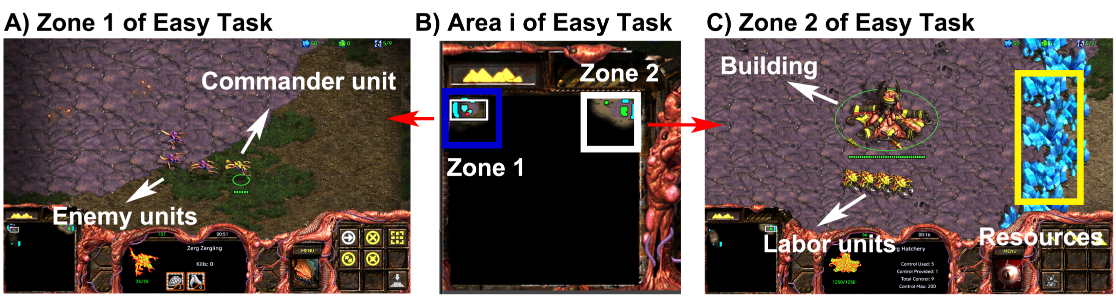

Figure 3. Feature of the Easy Task. The meaning of each box is as follows. white boxes: Collecting resources and constructing buildings are done in these zones (Zone 2). Blue box: The battle between the commander unit and enemy units occurs in this zone (Zone 1). Yellow box: resources.

In the Easy Task, the player must accomplish three jobs; enable the commander unit to escape from enemy units in Zone 1, while at the same time in Zone 2 producing product units and constructing buildings from resources collected by four labor units.

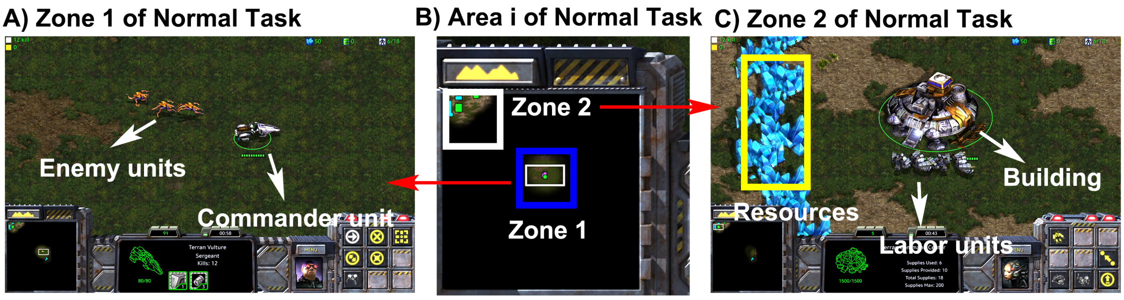

Figure 4. Feature of the Moderate Task. The meaning of each box is as follows. white boxes: Collecting resources and constructing buildings are done in these zones (Zone 2). Blue box: The battle between the commander unit and enemy units occurs in this zone (Zone 1). Yellow box: resources.

In the Moderate Task, the player can destroy enemy units in addition to completing the three jobs of the Easy Task. To destroy three enemy units, the commander unit must land two bombs on each enemy unit, for a total of six bombs used to destroy them all.

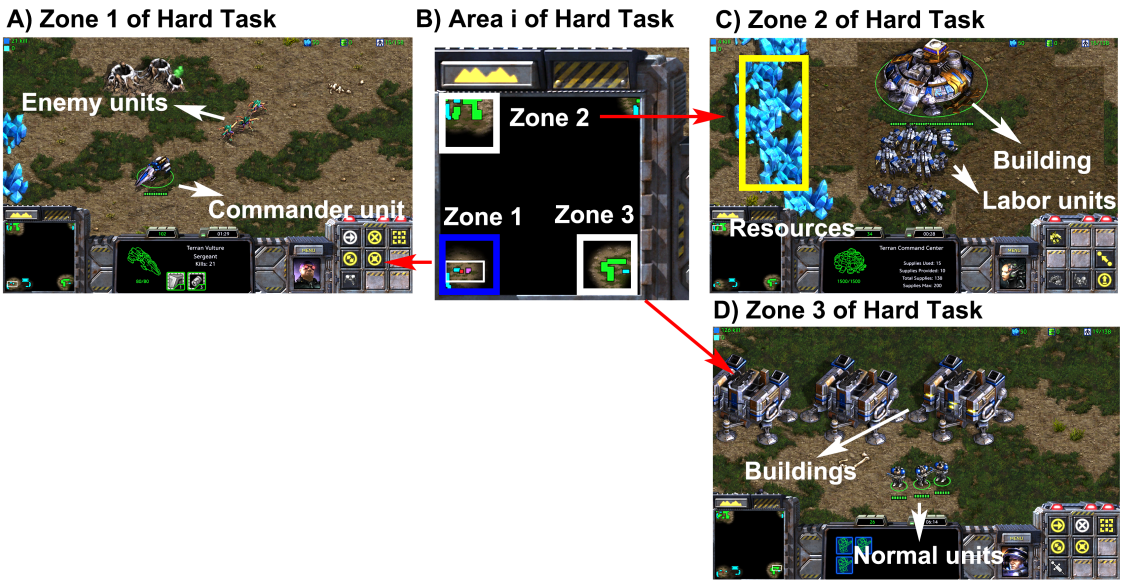

Figure 5. Feature of the Hard Task. The meaning of each box is as follows. white boxes: Collecting resources and constructing buildings are done in these zones (Zone 2 and Zone

3). Blue box: The battle between the commander unit and enemy units occurs in this zone (Zone 1). Yellow box: resources.

In the Hard Task, the player was further required to produce product units in Zone 3. There were six buildings in Zone 3 at the start, and product units were produced in those buildings by the player. In Zone 2, 12 labor units collected resources at a faster rate than the four labor units in the Easy and Moderate Tasks. Zones 2 and 3 were synchronized so that resources did not have to be moved from Zone 2 to Zone 3. Overall task which required in each tasks are listed in Table 1.

Task	**Details**
A) Easy Task	Jobs are done in two different Zones at the same time. Zone 1: escape from enemies Zone 2: collect resources + produce product units + construct buildings
B) Moderate Task	Jobs are done in two different Zones at the same time. Zone 1: escape from enemies + destroy enemy units Zone 2: collect resources + produce product units + construct buildings
C) Hard Task	Jobs are done in three different Zones at the same time. Zone 1: escape from enemies + destroy enemy units Zone 2: collect resources + produce product units + construct buildings Zone 3: produce product units
Common game-over conditions	Amount of resources (minerals, gas) becomes greater than 450 (loss). HP of the commander unit becomes 0 (loss).

Table 1. Three types of multitasking task and common game-over conditions.

For the present study, three sample games (called tasks) with different levels of difficulty, Easy Task, Moderate Task, and Hard Task, were programmed using the StarCraft Campaign Editor (Blizzard Entertainment., U.S.A) (Figure 2). The difficulty of each task depends on how many jobs are required and how many Zones are in play at the same time. When more jobs are required and more Zones are used at the same time, the difficulty of the task increases.

Once the player starts collecting resources, they continuously increase at a rate of 32 resources every 3 sec in the Easy and the Moderate Tasks, and every 1 sec in the Hard Task. There is no limit on the number of buildings and product units produced. Operations utilized in the tasks are listed in Table 2 and the Figure 6 .

A task was played for three minutes. When the task did not last for three minutes because a player lost the game, the player repeated the task until they had played for a total of three minutes. The tasks proceeded in the following order: Easy Task, Moderate Task, and Hard Task. The health point (HP) is defined as the strength of the commander unit against an attack by enemy units. A game ended when the HP became zero due to attack (1st condition causing the game to terminate, the player's loss). The HP decreased by five every time the commander unit was contacted by enemy units. In the Easy Task, the HP started at 35 and decreased by five with each enemy contact, while at the same time automatically increasing by 0.75 per second (the maximum HP is 35). In the Moderate Task and the Hard Task, the HP started at 75. There was no automatic increase of the HP; it recovered to the original level when the commander unit destroyed three enemy units (the maximum amount to which the HP can recover is 75). The number of resources started at 50; if resources were not used they increased by 32 every 3 sec in the Easy and Moderate Tasks, and by 32 every 1 sec in the Hard Task. If the amount of resources reached 450, the game was over (2nd condition causing the game to terminate, player's loss). Thus, participants must use resources, by producing product units or constructing buildings, to ensure that the amount of resources does not reach 450. The above mentioned conditions for game over are summarized in Table 1.

Each Task was original and conducted in response to preliminary investigations measuring gaze movement in esports experts. Participants in our preliminary investigations agreed that a high level of multitasking abilities was required for each task. Additionally, all participants in the preliminary experiment agreed that a high level of multitasking ability was required during the task.

2. 5 Operation method of the task

Figure 6. Detail of operation method. In Figure 6, eight different kinds of operation methods are represented which are required in the task.

To select a unit or building, participants have to use a mouse left click (Figure 6A). To escape from enemy units, select the commander unit by using mouse left click and mouse right click (Figure 6B). The participant can switch zones by using "F2, F3, F4, F5 and spacebar" on the keyboard (Figure 6C). To switch the part of a zone shown in Area v, participants have to use "Arrow keys" on the keyboard or move "Mouse cursor". To destroy enemy units, the participant has to select the commander unit first. Next, "P" on the keyboard and mouse right click are combined to destroy enemy units (Figure 6D). To collect resources, select the labor unit, and mouse left click are combined to start the job (Figure 6E). To produce product units, participants have to select the building first. Next, a mouse left click is required to produce product units (Figure 6F). Finally, select the labor unit and mouse left click on Area iii are required to construct a building (Figure 6G). Overall operation methods are listed in Table 2.

Operation	**Method**
Select a unit or building	Mouse left click
Escape from enemy units	Select the commander unit + mouse right click
Switch Zones	"F2, F3, F4, F5" on the keyboard or "Spacebar" on the keyboard
Switch the part of a Zone shown in Area v	"Arrow keys" on the keyboard or move "Mouse cursor"
Destroy enemy units	Select the commander unit + "P" on the keyboard + mouse right click
Collect resources	Select the labor unit + mouse left click on resources (this is done only once when the task starts, after which resources are increased automatically)
Produce product units	Select the building + mouse left click on building
Construct a building	Select the labor unit + mouse left click on Area iii

Table 2. Operation method.

2. 5 Behavioral data analyses

To compare Expert and Low Skill players in their performance of the Easy Task, we defined the score of behavioral performance as:

(number of constructed buildings + number of produced units),

For the Moderate Task and the Hard Task, the score was defined as:

(number of constructed buildings + number of produced units) ×2+(number of destroyed enemy units)×3

The reason for using different constant is to strongly emphasize the number of destroyed enemy units.

In order to compare the number of clicks between the Expert and Low Skill players, we measured the number of key presses and mouse clicks per minute, and defined it as Actions Per Minute (APM). APM were automatically counted in the StarCraft program.

2. 6 Equipment

The experiment utilized 24 - 34 inch computer monitors. Participants selected the monitor they wanted to use. There was no significant difference in the selected monitor size between Expert players (average of monitor size: 27.00 inch ± SD 3.87) and Low Skill players (average of monitor size : 28.77 inch ± SD 4.35) (Wilcoxon Rank-Sum test, p = .30). Before the task started, we measured the distance (40 inches) between each participant's head and their monitor. After measuring the distance, we instructed participants to keep the position of their head steady. Participants used their own keyboard and mouse.

Gaze movement was measured by the Pupil Labs eye tracker (Pupil Labs UG haftungsbeschränkt, Berlin, Germany). The open source software called Pupil-Capture version 1.15 was used for measurement (https://github.com/pupil-labs/pupil/releases/tag/v1.15). Gaze movement was measured by one field camera (60Hz @ 1910 × 1080 pixels) and two eye cameras (200Hz @ 192 × 192 pixels). The field camera was used to record the locations of the calibration markers. The Screen Marker Calibration method was used to measure gaze movement (see Screen Marker Calibration [32]). In addition, four surface markers (4cm × 4cm, height × width) were attached to each corner of the monitor. These markers were used to assign X and Y coordinates to the horizontal and vertical gaze positions. The coordinates of all gaze movements on the monitor were normalized to the width and height of that particular monitor and expressed with values between 0 and 1.

2. 7 Gaze signal analyses

Measured eye movement data were analyzed using Pupil-Player (Pupils Labs, v 1.15). The Pupil Labs guidelines recommend that detection data be used only when the confidence value of the pupil center location is more than 60% (https://docs.pupil-labs.com/core/software/pupil-player/#raw-data-exporter). In this experiment, all gaze data with confidence value less than 70% were excluded (total ratio of excluded data: 6.92%) to improve analysis reliability. Accuracy was calculated as the average angular offset (distance) (in degrees of visual angle) between fixation location and the corresponding location of the fixation target [32]. All gaze movement data were normalized to a value between 0 and 1 with the Pupil-Player Surface Tracker software using the monitor size (mm) of each participant, because participants used different sized monitors. Standard deviations of gaze distribution in horizontal and vertical directions (SD of gaze distribution) were separately calculated to compare the distributions of gaze position.

2. 8 Classification of gaze movement

The Eye Movement Detector in the Pupil-Player (Pupil-Labs, v 1.15) software was applied to classify the type of gaze movement into two categories (saccade, fixation) based on a linear regression curve obtained by gaze movement segmentation [33]. The word saccade describes fast ballistic eye movements which radically change visual input on the retina [34]. When the eyes remain stable at a point it is called fixation [35]; fixation helps the eyes align with the target and avoid perceptual fading [36]. The classification was based on the Hidden Markov model (I-HMM),which classifies gaze movement using this probabilistic model (I-HMM is not based on velocity threshold and duration time) [33, 37]. In this identification method, two probabilistic models classify gaze movement: observation probabilities and transition probabilities. When the expected velocity of a gaze movement is high, the observation probabilistic model defines the movement as saccade. When the expected velocity is low, the movement is defined as fixation. The transition probabilities model calculates the probability of conversion between saccade and fixation. After classification, the numbers of saccade and fixation events were calculated as percentage of all gaze movements (saccade percentage, fixation percentage). To compare the characteristics of saccade between Expert and Low Skill players, velocity, length, and number of saccadic movements were analyzed.

We investigated the ratio of fixation in each area (Area of Interest; AOI); that is, the areas on the monitor that subjects looked at during task execution. To calculate the ratio, fixations in an area were extracted from the gaze movement, and the ratio was obtained as the summed time of the fixations in the area divided by the total fixation time in all areas in the three minutes of total task execution.

2. 9 Statistical analyses

All statistical analyses were conducted using RStudio version 1.3 (RStudio, Boston, MA). Homogeneity of variance was tested with Levene's test and normality of variance was tested with Shapior-Wilk's test. As a result, SD of gaze distribution (vertical gaze), ratio of fixation in each area (AOI), and saccade velocity did not follow a normal distribution of variance and show homoscedasticity. For this reason, these data were calculated by a non-parametric method. When the Kruskal-Wallis test detected significance, the Wilcoxon Rank-Sum test was performed to find the difference between each group of task difficulties (Bonferroni's correction ($p < .05$ divided by 3 tests: significance threshold at .017)).

Comparison in behavioral data and APM between Expert and Low Skill players was conducted by an unpaired t-test at each level of difficulty (Easy, Moderate, and Hard). SD of horizontal gaze distribution, type of gaze movement (saccade or fixation) as classified by the Hidden Markov model, and two saccade characteristics (saccade number, saccade length) were analyzed by 2 (skill level: Expert, Low Skill) × 3 (task difficulty: Easy Task, Moderate Task, Hard Task) two-way repeated measures ANOVA. When a significant main effect of task difficulty was found, simple main effect analyses were used to check difference in task difficulty. When significant interaction was found, Tukey's Honestly Significant Difference (HSD) post-hoc analysis was performed. Partial η^2 indicated effect size for the ANOVA. Correlation between gaze movement and performance level (performance level versus horizontal gaze movement, saccade percentage, saccade velocity and saccade number) was analyzed by Pearson correlation coefficient (r^2). All statistical significance was set at $p < .05$.

3. Results

3. 1 Behavioral data

APM index			
	Easy Task	**Moderate Task**	**Hard Task**
Expert	232.42 ± SD 42.42	257.28 ± SD 69.16	260.42 ± SD 54.70
Low skill	212.77 ± SD 61.85	267.00 ± SD 42.01	256.33 ± SD 52.24

Performance level			
	Easy Task	**Moderate Task**	**Hard Task**
Expert	15.00 ± SD 2.64	170.28 ± SD 19.20	208.14 ± SD 26.01
Low skill	10.11 ± SD 3.72	137.22 ± SD 25.97	155.55 ± SD 37.26

Table 3. APM index and Performance level.

There was no significant difference in Easy Task performance score between Expert (mean 15.00 ± SD 2.64) and Low Skill (mean 10.11 ± SD 3.72) players. For the Moderate Task and the Hard Task, an unpaired t-test revealed that the performance level of Expert was significantly higher than that of Low Skill players (Moderate Task: mean 170.28 ± SD 19.20 vs. mean 137.22 ± SD 25.97, t = 3.31, df = 15.89, p = .004, and Hard Task: mean 208.14 ± SD 26.01 vs. mean 155.55 ± SD 37.26, t = 3.75, df = 15.71, p = .001). For APM, there was no significant difference between Expert and Low Skill players in all tasks (Easy Task: mean 232.42 ± SD 42.42 vs. mean 212.77 ± SD 61.85, t = 1.06, df = 13, p = .30 , Moderate Task: mean 257.28 ± SD 69.16 vs. mean 267.00 ± SD 42.01, t = -0.03, df = 7.55, p = .97, and Hard Task: mean 260.42 ± SD 54.70 vs. mean 256.33 ± SD 52.24, t = 0.29, df = 9.99, p = .77).

3. 2 Gaze Signal Analysis

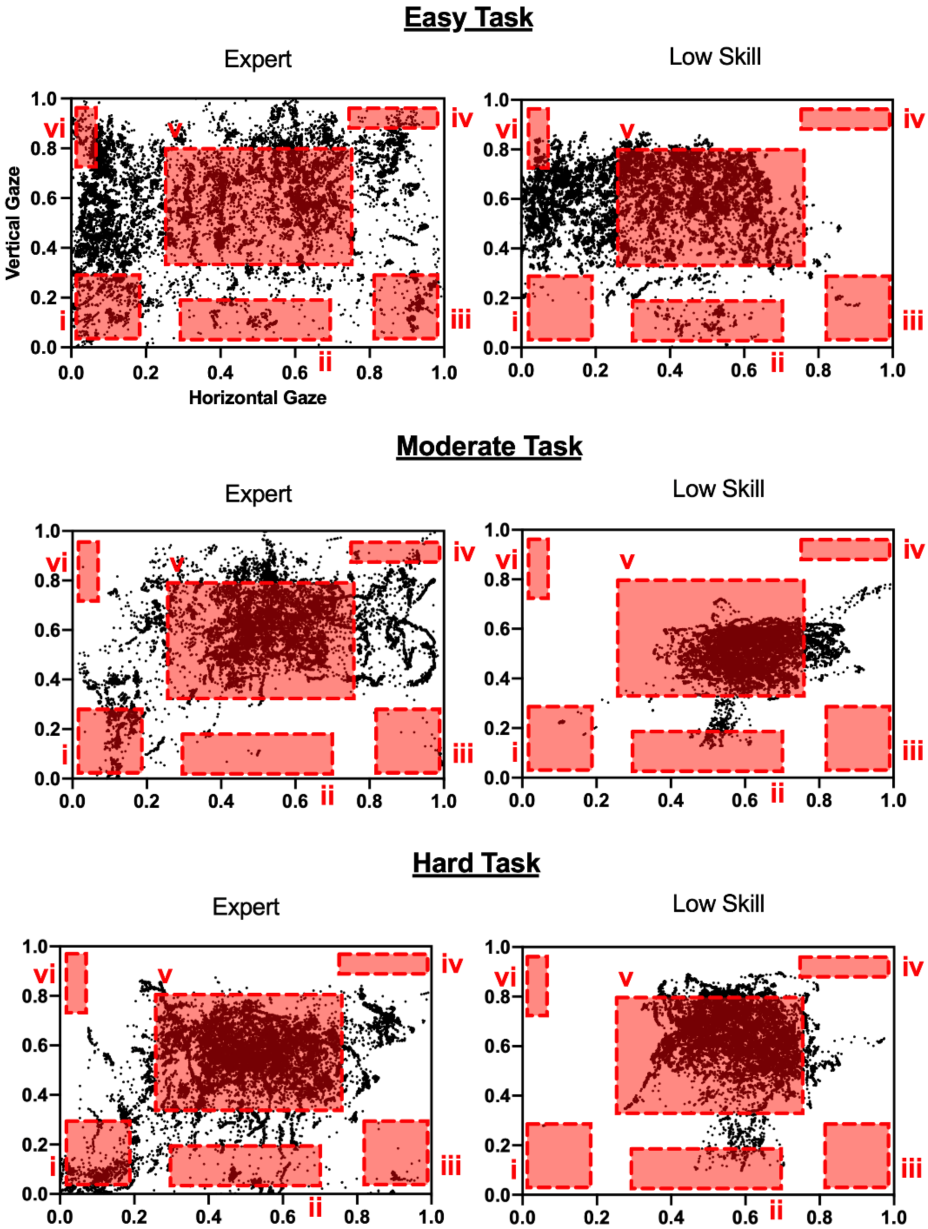

Figure 7. Examples of gaze distribution. Figure 7 shows the representative gaze distribution on the monitor in one trial. Each black dot indicates one sample of measured gaze location.

The darker areas represent denser gaze location concentrations, meaning that gaze movement was concentrated on that area. Each red square represents the AOI (See Figure 2). Areas which are not included in an AOI have relatively low importance. Vertical axis and horizontal axis are the numerical values obtained by normalizing the monitor size.

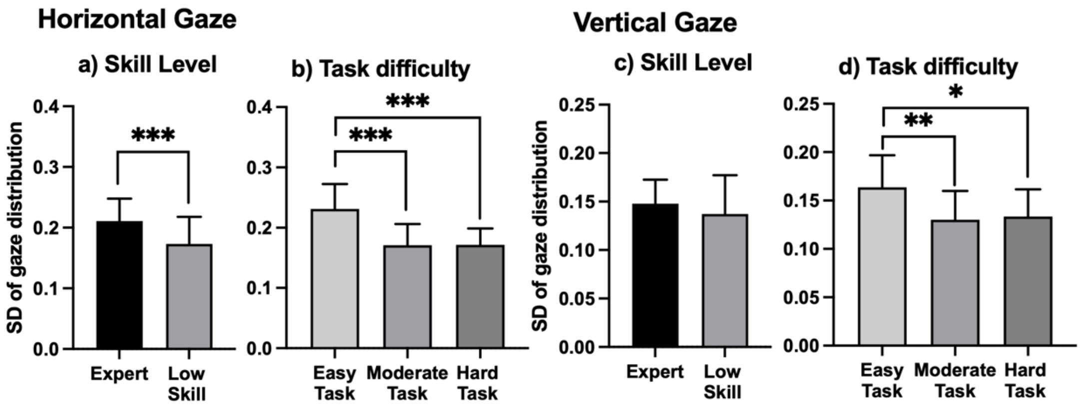

Figure 8. Gaze distributions. The gaze of the Expert was distributed over wider areas than the gaze of the Low Skill player. Figure 8 shows the difference in SD of gaze distribution (Significance level was set at *** $p < .001$).

Two-way ANOVA revealed a significant main effect of skill level (F = 30.99, $p < .001$, partial $\eta^2 = .42$) and task difficulty (F = 29.23, $p < .001$, partial $\eta^2 = .58$). However, there was no interaction effect between skill level and task difficulty. Simple main effect analysis found that SD of horizontal gaze distribution during the Easy Task was higher than that during the Moderate Task and Hard Task ($p < .001$ for both). Kruskal-Wallis test detected significance in task difficulty of SD of vertical gaze distribution ($p = .002$). Vertical gaze distribution of Easy Task was significantly higher than Moderate Task and Hard Task, irrespective of skill level ($p = .004$ and $p = .011$).

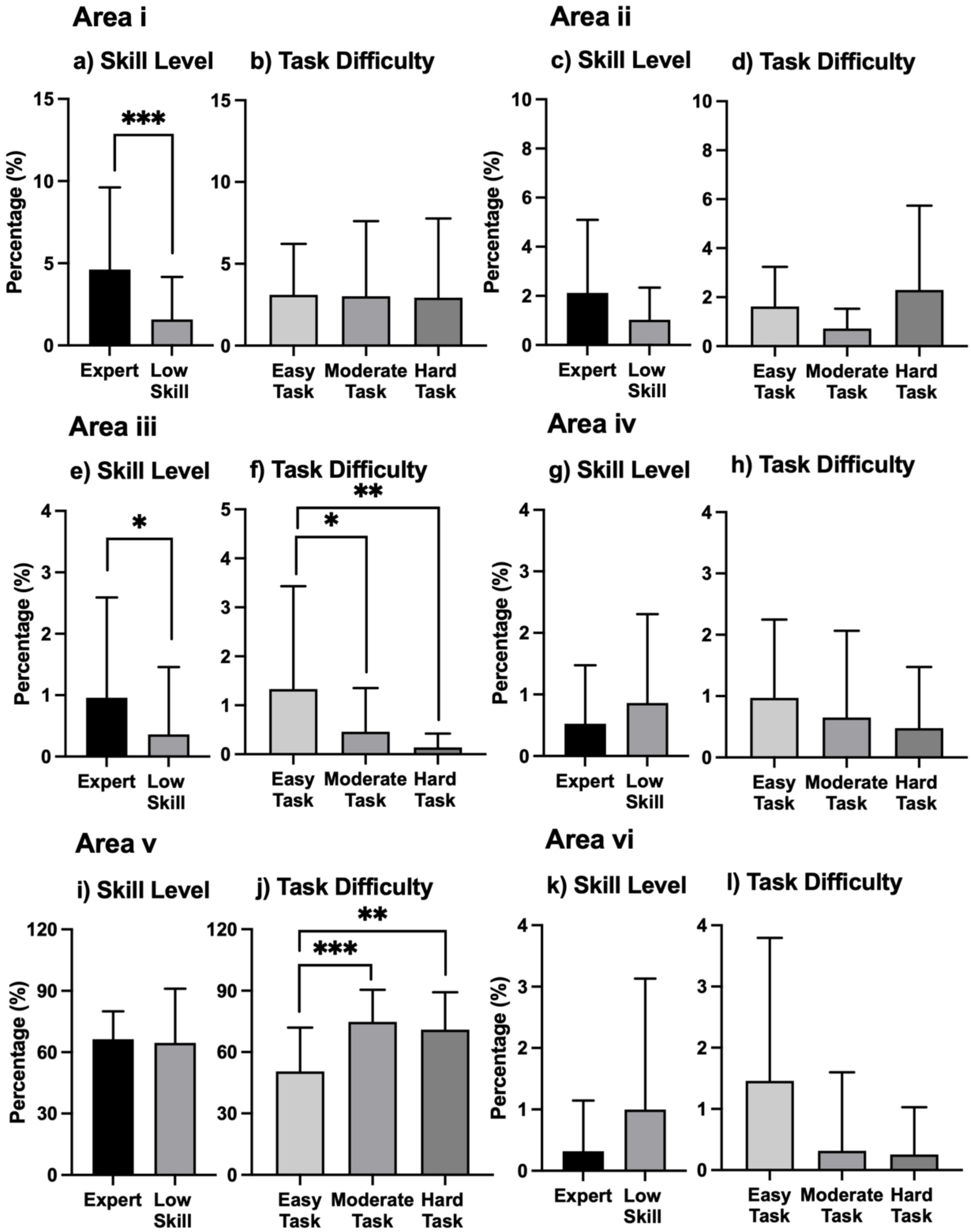

Figure 9. Ratio of gaze distribution in six Areas. The proportion of time that the gaze stayed on each AOI (ratio of gaze distribution) is shown in Figure 9 (Significance level was set at * $p < .05$, ** $p < .01$ and *** $p < .001$).

In Area i, there was a significant difference of skill level (Wilcoxon Rank-Sum test, $p < .001$) while there was no significant difference between task difficulty. In Area ii, there was no significant difference in skill level or task difficulty. In Area iii, a significant difference of skill level and task difficulty was found (Wilcoxon Rank-Sum test, p = .02 and Kruskal-Wallis test, p = .01). In Area iii, AOI of Easy Task was significantly higher than Moderate Task and Hard Task (Wilcoxon Rank-Sum test, p = .01 and p = .001). In Area iv, there was no significant difference in skill level or task difficulty. In Area v, there was no significant difference in skill level. However, a Kruskal-Wallis test detected significance in task difficulty (p < .001). The time proportion of the Easy Task was significantly shorter than the time spent on the Moderate Task or the Hard Task (Wilcoxon Rank-Sum test, p < .001 and p = .014, respectively). In Area vi, there was no significant difference in skill level or task difficulty.

3. 3 Classification of type of gaze movement

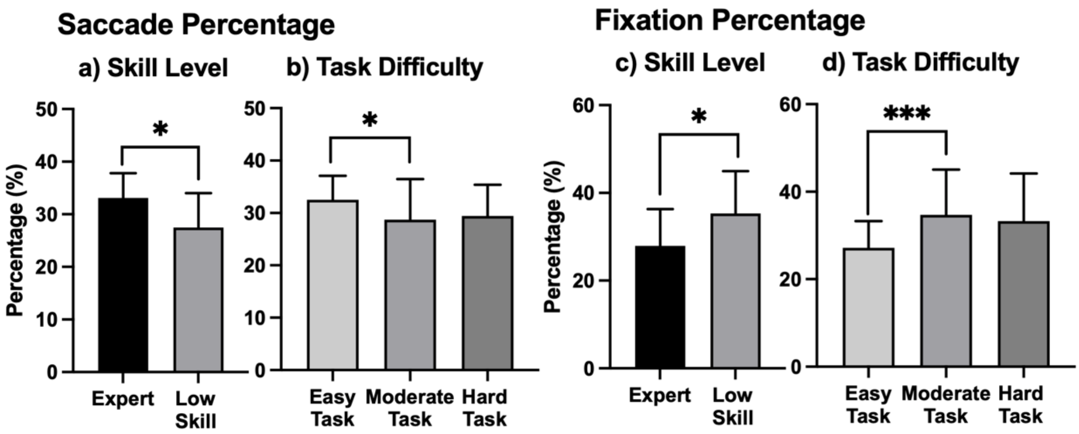

Figure 10. Classification of gaze movement. Figure 10 shows the average percentage of gaze movements (saccade and fixation; The significance level was set at ***p < .01 and *p < .05).

For saccade percentage, a significant main effect of skill level and task difficulty was found (F = 4.20, p = .02, partial η^2 = .12 and F = 4.99, p = .01, partial η^2 = .15). There was no interaction between skill level and task difficulty. Simple main effect analysis indicated that saccade percentage in the Easy

Task was significantly higher than in the Moderate Task (p = .01). These results indicate that the saccade percentage of Expert players was significantly higher than that of Low Skill players, irrespective of task difficulty.

For fixation percentage, a significant main effect of skill level and task difficulty was observed (F = 3.89, p = .02, partial η^2 = .10 and F = 8.23, p < .001, partial η^2 = .22, respectively). However, there was no interaction. Simple main effect analysis indicated that fixation percentage in the Moderate Task was significantly higher than in the Easy Task, irrespective of skill level (p < .001).

3. 4 Characteristics of saccade

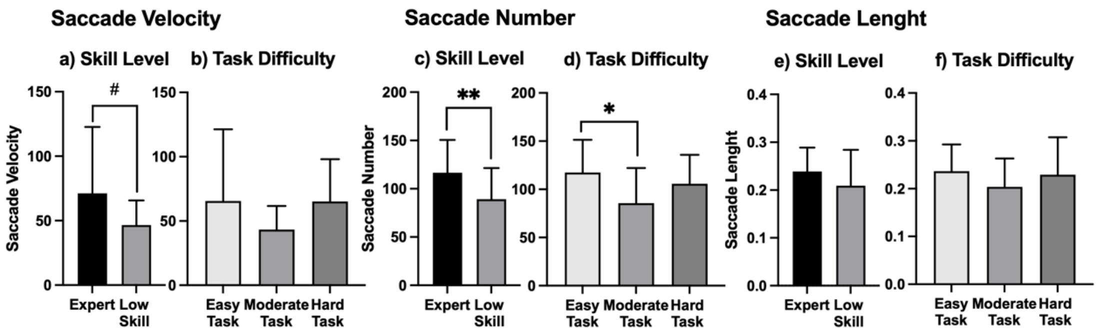

Figure 11. Saccade characteristics. Figure 11 shows the average of the saccade velocity (a, b), saccade number (c, d), and saccade length (e, f). The significance level was set at #p = .08, *p < .05 and **p < .01.

The Skill Level of saccade velocity was marginally significant (Wilcoxon Rank-Sum test, p = .08). However, there was no significant difference in task difficulty. For saccade number, a main effect of skill level and task difficulty was found (F = 8.60, p = .005, partial η^2 = .16 and F = 4.52, p = . 01, partial η^2 = .13). However, there was no interaction. Simple main effect analysis found that saccade number in the Easy Task was significantly higher than in the Moderate Task (p = .02). For saccade average length, there was no significant main effect or interaction effect.

3. 5 Correlation between performance level and gaze control

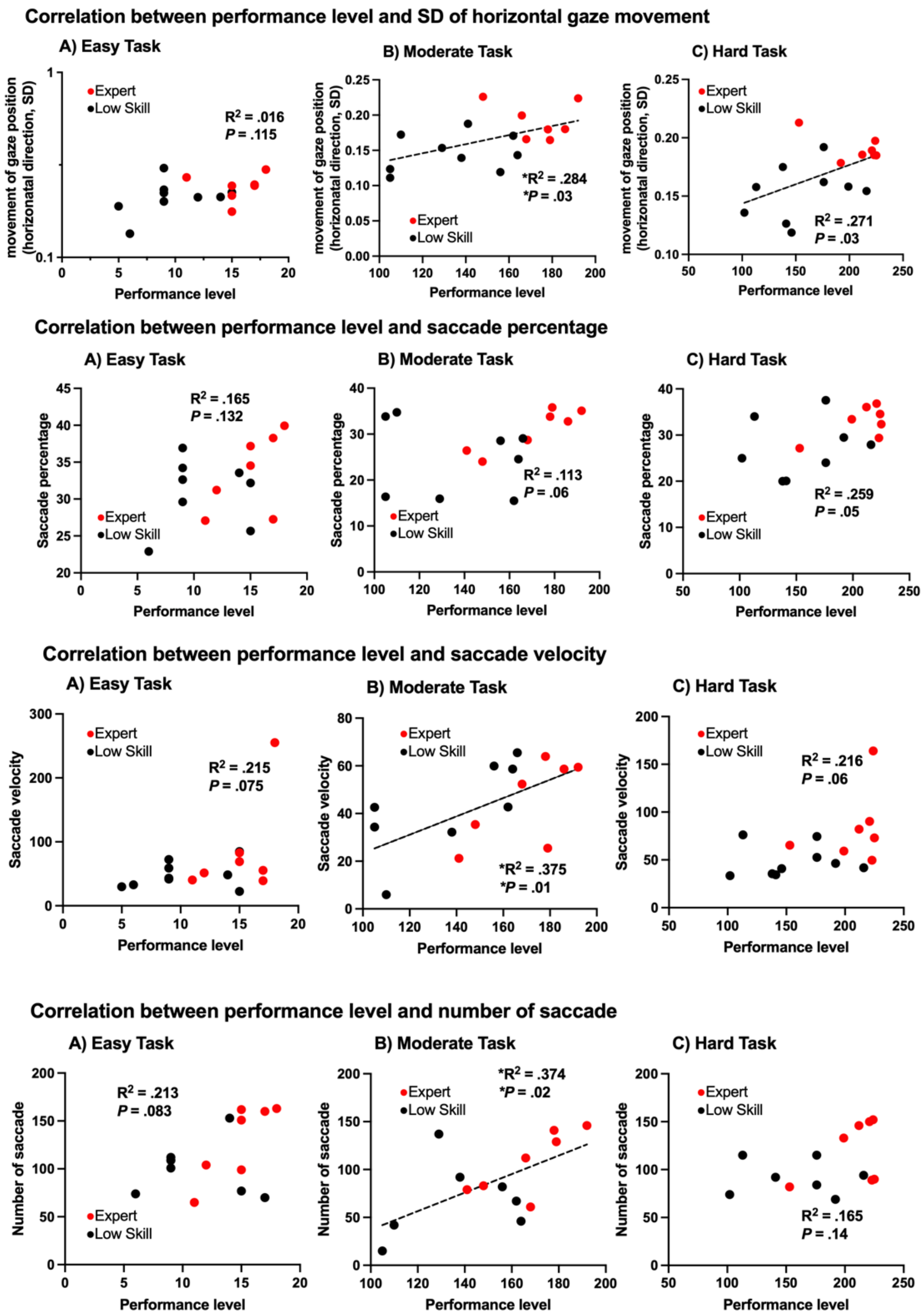

Figure 12. Correlation between performance level and gaze movement. Figure 12 shows the correlation between performance level and each gaze movement.

In performance level versus horizontal gaze of Moderate Task and Hard Task, the positive correlation between performance level and horizontal gaze movement was revealed (p = .03, R^2 = .284 and p = .03, R^2 = .271). However, there was no significant relationship in Easy Task. For performance level versus saccade percentage, there was no significan relationship in all three tasks. For performance level versus saccade velocity, positive correlation was found in Moderate Task (p = .01, R^2 = .375). There was no significant correlation between performance level versus saccace velocity in Easy Task and Hard Task. For performance level versus number of saccade, positive correlation was revealed in Moderate Task (p = .02, R^2 = .374). Otherwise, there was no significant correlation in Easy Task and Hard Task.

4. Discussion

The purpose of this study was to examine the gaze control strategy of the esports experts (Expert) during a game which requires multitasking abilities, by comparing Expert with lower skilled players (Low Skill). The Expert players showed significantly higher performance scores than the Low Skill players in the Moderate Task and the Hard Task. Since the number of jobs that participants had to perform simultaneously in the Easy Task was small, the Easy Task was likely so easy that it was unable to reveal group differences, probably due to a ceiling effect. However, it seems that two of the tasks modeled (Moderate Task and Hard Task) successfully discriminated between the abilities of the two subject groups. There was no significant difference in APM score between Expert and Low Skill players. This result indicates that the better performance of the Expert players did not depend upon the number of keys pressed on the keyboard or moves and clicks of the mouse. The superior performance in this kind of multitasking in accomplished esports players could be due to their specific gaze movement. Indeed, some differences were observed between Expert and Low Skill players in gaze control. First, Expert players showed a wider gaze distribution than did the Low Skill players (Figure

8a). This could mean that Expert players scanned a wider area of the screen, which likely helped them to obtain more information. In RTS esports such as StarCraft, different pieces of important information are distributed all over the screen. Thus, when playing such games, it is necessary to simultaneously pay attention to multiple points and areas on the screen. The games utilized in the present study provided many situations in which different procedures had to be carried out in different places in parallel. In such situations, it is important to obtain as much information as possible and respond accurately and quickly in order to win the game. Second, the ratio of saccade was larger in the Expert than in the Low Skill players, suggesting that esports experts frequently use saccade to quickly process multiple stimuli. Third, the results of AOI analysis suggest that Expert players directed a higher proportion of their gaze into Area i and Area iii than the Low Skill players did. Area i contains important information concerning the overall flow of the task; e.g., the information in Area i indicates which Zone should be checked first. This result indicates that the Expert players placed more importance on the overall flow than the Low Skill players did. In order to achieve a high performance level, players must produce normal units; in order to produce normal units, participants must check Area iii. Thus, in order to achieve a high performance level, players have to check Area iii periodically and this could be why Expert players concentrated a higher proportion of their gaze in Area iii. Finally, the higher percentage of fixation in the Low Skill than in the Expert players (Figure 10c and 10d) indicates that the Low Skill players needed more time to absorb information and therefore needed to keep their gaze on one location longer.

The saccade velocity of Expert was significantly faster than that of Low Skill players, and the number of saccade movements in the Expert players was significantly greater than in the Low Skill players. Thus, the Expert players shifted their gaze more frequently and more quickly from area to area than the Low Skill players did (for example, from Area i to Area v). These eye movements are advantageous to processing multiple stimuli and successfully playing games when multitasking ability is required.

A previous study failed to detect a significant difference between esports players and non-esports players in a visual attention skill, probably because of the low difficulty of the task utilized for the test [38]. However, the present study showed significant differences in game performance and gaze control strategy between Expert and Low Skill players in tasks which required higher multitasking ability. That is, experts in RTS StarCraft could perform saccadic eye movement at higher velocity while playing the actual game. Faster saccade makes it possible to quickly change the gaze point, enabling players to process multiple stimuli on the screen more quickly. The present study suggests that esports experts utilized this superior visual ability when playing three actual games.

It is well known that skilled athletes in general sports also show different gaze behavior from novice or low skill players. For example, in one-on-one defensive situations in soccer, novice players mostly watch the ball, while experienced players watch not only the ball but also the knee and hip of the opponent player [39], probably because experienced players pay attention more broadly to the overall movement of their opponent. Similarly, in RTS players must pay attention to multiple stimuli. The current study may expand the knowledge of gaze control strategy during sports, i.e., the strategy of distributing the gaze to wide areas in the visual field might be common when players in either general sports or esports need to pay attention to multiple information streams simultaneously. Meanwhile, it has been proposed that athletes in general sports use different gaze control strategies depending on the situation [38]. For example, elite basketball players fix their gaze on the hoop significantly longer than novices do in a free throw situation [30]. In this case, throwing the ball into the hoop is the only requirement, so it is advantageous for players to fix their gaze on the hoop. From the above, we can estimate that esports players would probably also utilize different gaze strategies depending on the game genre. However, this remains to be elucidated in future studies.

We conducted correlation analysis to test the hypothesis that participants with higher performance level would have superior gaze control. Positive correlation between performance level and gaze movement was observed (Figure 12). To be specific, correlation between performance level and gaze movement was verified in Moderate Task and Hard Task. The reason why correlation was only verified in Moderate Task and Hard Task would be because of the difficulty of the task. In Easy Task, task difficulty was not enough to induce a correlation between gaze movement and performance level. When performance level was high, both gaze movement was more activated. This fact supports the fact that the more active gaze movement, the better the performance level is.

How are esports experts able to exert gaze control that is superior to the gaze control of players with lower skills? Perhaps esports experts have better functionality in vision-related brain regions thanks to long-term training in esports proficiency, which requires specific visual functions and multitasking ability. Indeed, a previous study revealed an increase in gray matter volume of the frontal eye field (FEF) in adults older than 55 after training of two months in playing AVG, and the subjects obtained precise and delicate gaze control [40]. Since it has been clarified that saccade and the FEF have a close relationship [7], the plastic changes in the FEF likely result in superior saccade control. In addition to the FEF, an increased specific connection between occipital and parietal areas has been confirmed in expert RTS game players compared to non-RTS game players [41]. Therefore, esports experts might also have outstanding function in the FEF and the interhemispheric connections of the visual cortex.

Finally, what kind of training can improve the performance level of lower skill esports players? We recommend gaze movement training which includes longer saccadic gaze movements that cover a wider area of the screen. This training method is likely to improve the gaze control ability of esports players with lower skill or novice players. In physical sports, such as soccer and baseball, training players to follow a moving object with their eyes is known to be effective. Especially, the NeuroTracker system which tracks multiple 3D objects by using gaze direction can improve multitasking ability and the visual attention of athletes [42, 43]. Thus, it is possible that gaze movement training will also contribute to improving the performance level of the esports player with lower skill.

Additionally, knowledge about the gaze control strategy used by successful esports players would be helpful for esports coaching and for devising new training methods.

5. Limitations

In this study, we did not record the participants' experience in playing other esports or their years of esports experience. Therefore, we cannot rule out the possibility that a history of playing other esports affected the difference in gaze movement between the Expert and the Low Skill players. Furthermore, we were not able to strictly control participants' head movements, and the possibility that the difference in gaze movement was caused by head movement cannot be excluded. Additionally, the tasks were performed in the same order, so we cannot completely eliminate the order effect. However, the purpose of the current study was not to ask the level of difficulty of task but to ask whether there is a difference in performance and gaze movements between esports experts and lower skilled players. For this reason, the conclusion of the current study should not be affected by order effect.

6. Conclusion

The present study suggests that esports experts show wider gaze movement, covering all areas of the screen, and especially pay more attention to the overall flow of the game (Area i) compared to the players with lower skills. This wider gaze movement is actualized by their faster and longer saccade than the saccade exhibited by the players with lower skills. These specific gaze control strategies in experts are likely related to the higher performance levels of esports that require multitasking ability.

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