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論　　文　　題　　名

Ability to predict collision with moving objects in older adults

高齢者における移動物体との衝突予測能力

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Ability to predict collision with moving objects in older adults

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Abstract

The ability to predict collisions with moving objects deteriorates with aging. Many traffic accidents involving older adult pedestrians are assumed to be caused by the deterioration of the ability to predict collisions with moving objects. To prevent such accidents, it is helpful to understand how aging affects the ability to predict collisions and to develop methods for its improvement.

For this purpose, I designed two experiments (Figure 1): one to identify optical variables (e.g., parameters related to vision such as an object's size, shape, visual angle, and spatial position) that older adults have difficulty using for predicting collisions, and the other to develop a perceptual task to improve the ability to predict collisions by enhancing older adults' sensitivity to the optical variables they had difficulty using for predicting collisions. The aim of Experiment 1 was to identify the effects of aging on sensitivity to three optical variables considered critical to predicting collisions with moving objects based on the affordance-based model (Fajen, 2013): (a) vertical and (b) horizontal expansions of a moving object and (c) the bearing angle produced between participants and a moving object. I reproduced a modified version of the interception task used by Steinmetz et al. (2020) in a virtual reality (VR) environment. In the present study, a perturbation was originally applied for each of the three optical variables. Using the perturbation paradigm, I expected that perturbation would negatively affect the performance only for those who rely on the optical variable to perform the interception task effectively. On the contrary, if aging negatively affected using an optical variable in an effective manner, then

there should be no significant impact of perturbation on that variable in older adults. In other words, it is possible to specify the optical variables that are vulnerable to aging by identifying the optical variables for which no perturbation effects were found in older adults. I tested 18 older and 15 younger adults. The results indicated that older participants were not negatively affected by the perturbation for the vertical and horizontal expansion of a moving object, while they showed decreased performance when the perturbation was introduced with a bearing angle. These findings suggest that the ability to predict collisions with moving objects deteriorates with aging because the perception of object expansion is impaired with aging.

The findings of Experiment 1 indicated that enhancing sensitivity to object expansion would be helpful for improving collision-prediction ability in older adults. In Experiment 2, therefore, I created two perceptual tasks under a virtual environment that could potentially improve the sensitivity to object expansion and, as a result, lead to accuracy in predicting collisions: a distance-estimation task and a time-to-contact (TTC)-estimation task. These two tasks were the same in that older participants observed the expansion of a frontally approaching target for a number of trials, but they were different in what was estimated based on the perceived expansion rate. In the distance-estimation task, older participants estimated the distance to an object on the basis of object expansion, whereas in the TTC-estimation task, they estimated the time to colliding with an approaching target on the basis of object expansion. In the distance-estimation task, participants repeatedly estimated the distance to the target (i.e., focusing on spatial aspects) while approaching that target. In the TTC-estimation task, they repeatedly observed an approaching target while staying in place and estimated the time until collision with the target. Twenty-seven older adults were randomly assigned to one of the three task groups: (a) a group performing a distance-estimation task (DE-task group), (b) a group performing a TTC-estimation task (TE-task group), and (c) a group performing an interception task (IC-task group), the same task as used in Experiment 1. The results showed that, although sensitivity to object expansion was not significantly improved in any of the three groups, participants in the TE-task group showed significant improvement in the false-alarm rate, which indicates accuracy in deciding whether to pursue the target. Furthermore, the false-alarm rate during the post-evaluation session was significantly lower (i.e., more accurate) in the TE-task group than in the IC-task group. These findings suggest that training to improve TTC estimation (i.e., focusing on temporal aspects) could lead to improvement of collision-prediction ability. I attributed the improved ability to predict collisions—in spite of no improvement in sensitivity to the rate of object expansion—to enhanced decision-making processes throughout the training.

Based on the two experiments, I concluded that older adults' ability to predict collisions with moving objects is likely to be decreased, particularly as a result of their reduced sensitivity to the expansion of objects on the retina. Because object expansion information was critical to perceiving the speed, distance, and TTC of an approaching object, impairment in detecting such information may lead older adults to fail to predict collision with moving objects. I found that training in which the estimation of TTC was improved after repeated estimation experiences has improved the ability of older participants to predict collisions. I also found that such improvement was limited to the interception task; improved ability to predict collisions in road-crossing decisions was not observed. Future studies are necessary to further discuss the generalization of the effect of training using a relatively simple, experimental task to collision detection in practical situations.

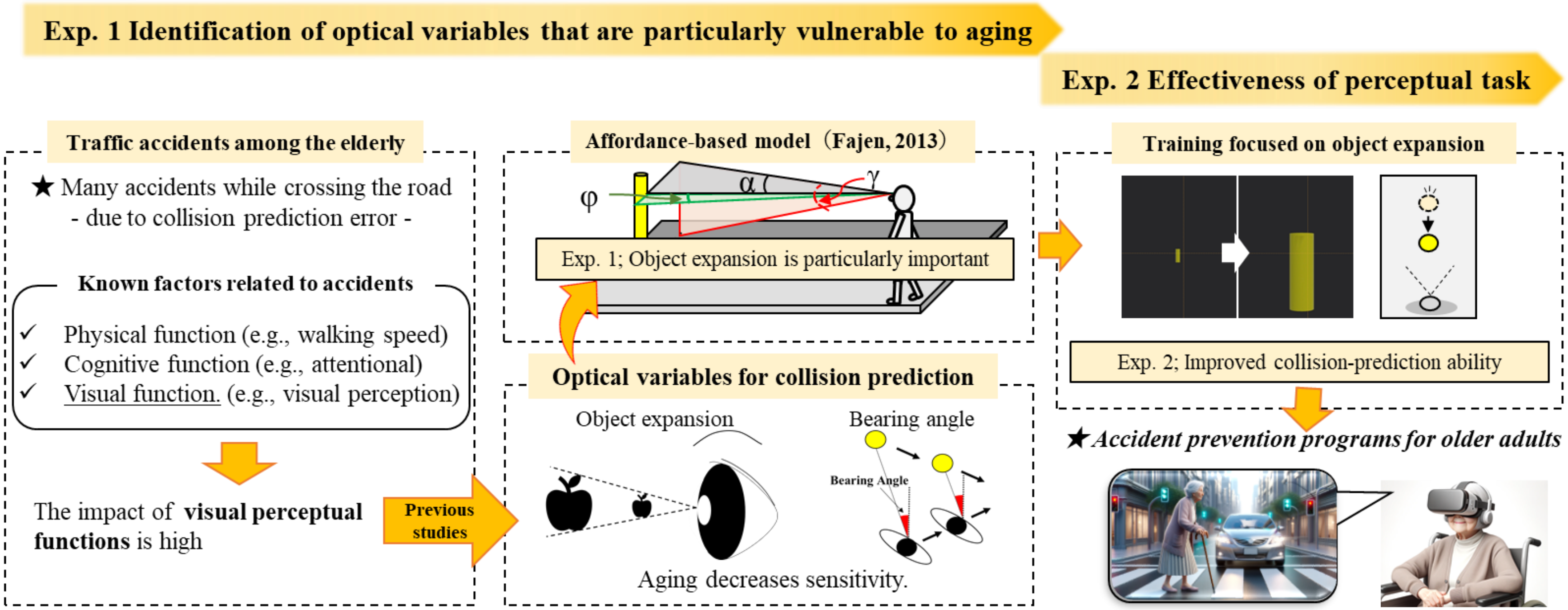

Figure 1. Outline of two experiments in the present study. Experiment 1 was designed to identify optical variables vulnerable to aging. In Experiment 2, three perceptual tasks that involved observing a moving object and that could potentially improve collision prediction were tested. I addressed whether these tasks helped improve the ability to predict collisions with moving targets. I also addressed whether the tasks also helped improve collision detection in road-crossing situations.

Chapter 1. Introduction

Predicting risks for collision with obstacles or pedestrians in daily life is essential for safety. Older adults often face accidents while crossing roads; it is possible that some of these are due to inaccurate collision predictions. Chapter 1.1 presents statistics about traffic accidents involving this age group. Chapter 1.2 explores several key optical variables, such as object expansion and the bearing angle on the retina, that play crucial roles in collision prediction. In Chapter 1.3, I address the effects of aging on sensitivity to such optical variables. In Chapter 1.4, the affordance-based model is described as useful for understanding how several optical variables are used in an integrative manner and for identifying which of these visual cues are likely to be impaired by aging.

1.1. Statistics regarding pedestrian collision accidents

In Japan, the accident fatality rate among older adults over 65 is about twice that of all age groups combined, indicating that older adults are especially at high risk of fatality from accidents (Figure 1-1). Among these accidents, pedestrian accidents are particularly severe. In 2017, about 40% of traffic fatalities were due to pedestrian accidents. This is a significantly higher rate as compared with those of other Western countries (Figure 1-2). Moreover, many traffic accidents involving older adults have been shown to occur while crossing roads (Lassarre et al., 2007). The data obtained in 2020 revealed that this demographic accounted for 76% of all pedestrian fatalities in road-crossing incidents. Efforts to reduce the number of pedestrian fatalities are, therefore, necessary (Cabinet Office, Government of Japan,11th Traffic Safety Basic Plan).

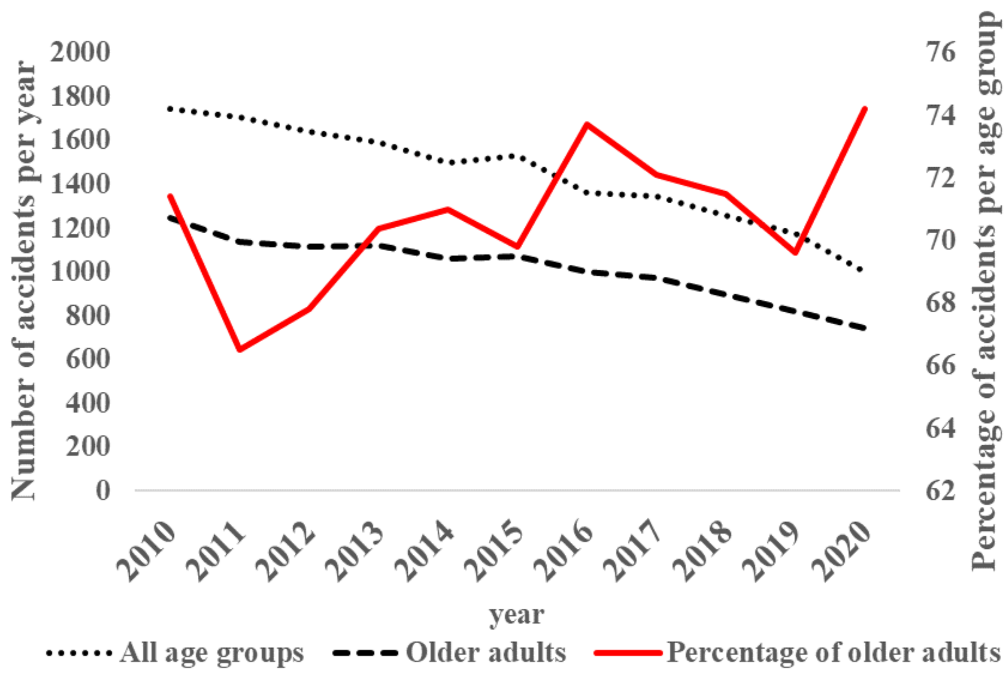

Figure 1-1. The number of pedestrian fatalities categorized by age group (Cabinet Office, White Paper on Traffic Safety, 2021 (https://www8.cao.go.jp/koutu/taisaku/r03kou_haku/zenbun/genkyo/feature/feature_02_3.html).

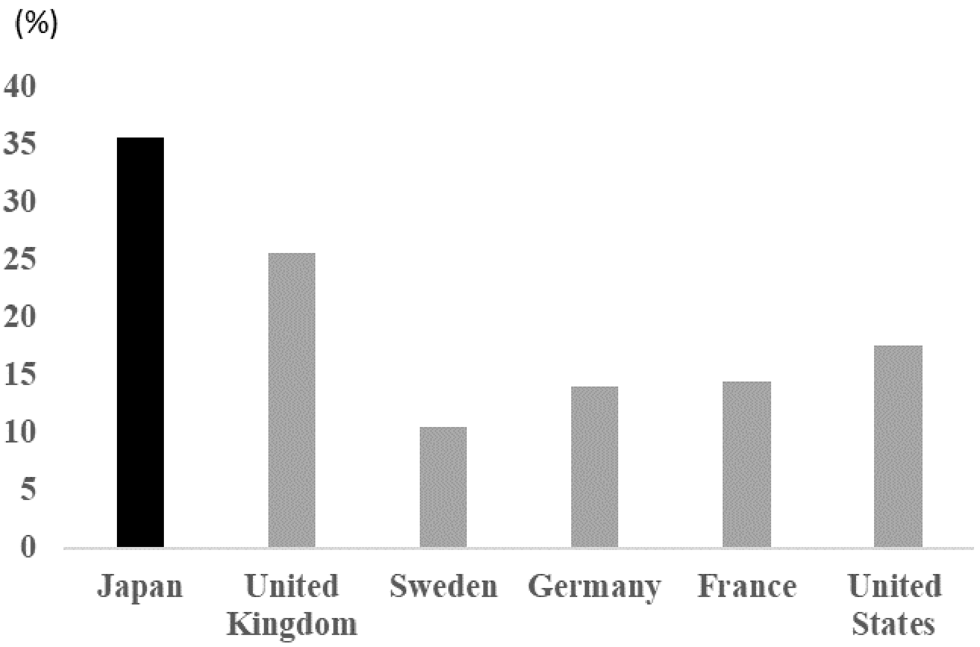

Figure 1-2. The percentage of pedestrians in traffic fatalities in Western countries and Japan. Data is from the Metropolitan Police Department (https://www8.cao.go.jp/koutu/taisaku/r03kou_haku/zenbun/genkyo/feature/feature_02_3.html).

1.2. Visual information used for making road-crossing decisions

Many risky road-crossing decisions are caused by age-related declines in visual functions (Wilmut & Purcell, 2022). Thus, it is crucial to thoroughly understand age-related effects to develop interventions and countermeasures that will prevent traffic accidents. The present study focused on age-related declines in visual functions, particularly on the functions relevant to perceiving the optical variables obtained on the retina. This focus is plausible, as crossing decisions largely rely on visual perceptions of vehicle speed and distance (Soares et al., 2021). Moreover, factors such as visual processing speed and attentional shifts have a greater impact on risky road-crossing decisions than walking speed or attentional inhibition (Dunbar, 2012). In the following section, I review relevant studies that demonstrate how the optical variables on the retina are used to predict collision and how aging would affect the use of these optical variables.

1.2.1. Visual information used to estimate time to contact

When walking and crossing a road, visual information such as vehicle speed, distance to vehicles, and distance between vehicles plays an important role in ensuring safety. In particular, it is important to accurately estimate the time to contact (TTC) based on the relationship between the distance to the approaching vehicle and the approaching speed (Butler et al., 2016; Choi et al., 2019; Dommes et al., 2013). TTC represents not only the time a vehicle takes to reach a specific point but also the time remaining for pedestrians to cross safely. Thus, inaccuracies in estimating TTC can result in collision with a vehicle (Zhuang et al., 2020).

Previous studies have shown impaired estimation of TTC in older adults (Butler et al., 2016; Dommes et al., 2013; Petzoldt, 2014; Schleinitz et al., 2016). Specifically, older adults have made incorrect estimates of TTC by ignoring speed information and relying on distance information (Dommes & Cavallo, 2011; Zito et al., 2015). If the pedestrian's decision is based solely on distance information, even though the approaching vehicle speed is high, they are more likely to decide to cross. Therefore, incorrect estimates of TTC, particularly as the results of ignoring speed information and relying solely on distance information, could lead to collisions in older adults.

1.2.2. Expansion rate

Previous studies have shown that the optical variable obtained based on the optical flow, that is, the expansion rate of objects on the retina, is available for predicting collisions (Andersen et al., 2000; Andersen & Kim, 2001; DeLucia et al., 2021; Markkula et al., 2021; Rio et al., 2014; Yan et al., 2011). The expansion rate of objects serves as the primary visual cue for determining both distances to the object (Rio et al., 2014) and the time to collision, expressed as the inverse rate of expansion (the instantaneous change in the visual angle) of an approaching object (Andersen & Enriquez, 2006; Yan et al., 2011). For example, Rio et al. (2014) showed that the target expansion rate is used to pursue the moving target while maintaining a specific distance from the target. Similarly, other studies showed that, in driving situations, changes in the optical expansion of the lead vehicle can serve as a cue to modulate braking movement (Liebermann et al., 1995; Yilmaz & Warren, 1995). It is assumed that humans can detect the threat of a collision when the optical expansion of the obstacle's projection onto the observer's retina exceeds a looming detection threshold (Markkula et al., 2021). This concept of threshold is supported by basic perceptual psychology research on collision avoidance and target interception (Gómez & López-Moliner, 2013; Regan & Gray, 2000), time-to-contact estimation studies (Hosking & Crassini, 2011), sports science (Gray, 2002), and applied research in the road traffic safety domain (Morando et al., 2016; Wann et al., 2011). Hence, object expansion is an important optical variable for predicting the timing of collisions.

1.2.3. Bearing angle

The bearing angle is the angle produced between the observer and a moving object. The bearing angle is also an important optical variable for making collision predictions accurately (Andersen & Kim, 2001; Fajen & Warren, 2004; Hardiess et al., 2013; Ni & Andersen, 2008; Ni et al., 2012; Zhao & Warren, 2017). Individuals rely on bearing angles to make collision predictions, known as the constant bearing angle strategy; CBA strategy (Lenoir et al., 1999). A description of the CBA strategy is shown in Figure 1-3. For example, if individuals perceive that they are approaching each other with a constant bearing angle, they can judge that they are on a collision course. Conversely, if the bearing angle is changing, they can judge that they are not on a collision course. Ni et al. (2012) compared collision detection performance when the use of bearing angle information was limited by moving the objects in a curvilinear trajectory. The results showed that the ability to detect collisions was lower on curved trajectories than on straight trajectories, suggesting the important role of bearing angle information.

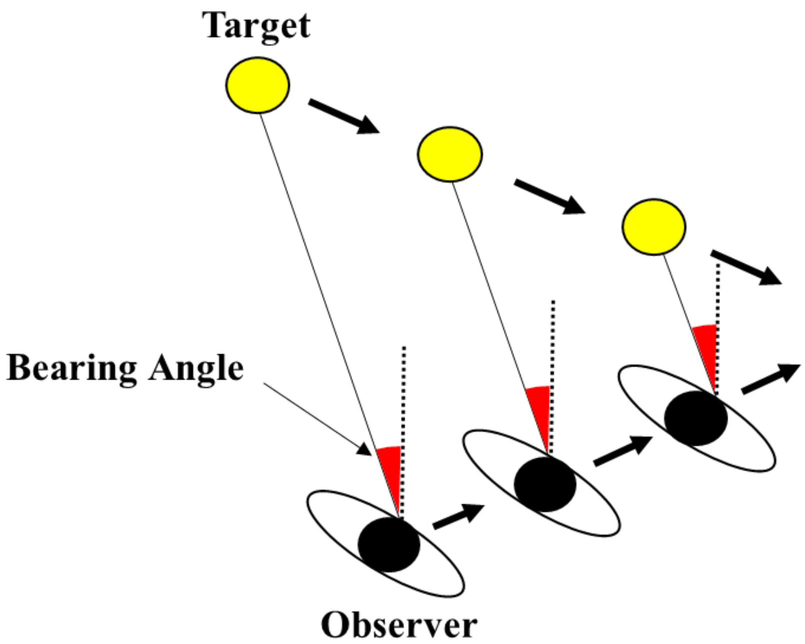

Figure 1-3. The CBA strategy of interception. The bearing angle (red wedge) is the optical angle between the target and a fixed reference direction. In this case, they are on a collision course as they are approaching each other with a constant bearing angle.

1.3. Sensitivity to visual cues susceptible to aging

A number of studies have shown that sensitivity to optical variables, such as the expansion rate of objects on the retina and bearing angle, declines with aging. Andersen et al. (2006) demonstrated that older adults have difficulty using the information obtained as the expansion of a moving object on the retina to predict whether a collision will occur. In their study, participants were presented with a moving object that was approaching them. By manipulating the speed of the approaching object or the time the object is displayed, they evaluated the ability to detect collisions based on the perception of expansion information. The expansion information was manipulated by a combination of speed and time. The results showed that the aging-related decline in detecting collisions with moving objects is the result of reduced sensitivity to recovering expansion information.

The negative effect of aging was also reported in using bearing angles to detect collision (Francois et al., 2011). François et al. (2011) tested middle-aged individuals (57.85 ± 1.95 years old) and analyzed the velocity profiles of participants' movements while they were performing an interception task in a virtual reality (VR) environment. Whereas younger participants showed smooth velocity profiles to maintain consistent bearing angles, middle-aged adults exhibited jerky velocity profiles, leading to a failure to maintain consistent bearing angles. This suggests that aging leads to decreased sensitivity to the bearing angle, making it more challenging to use the CBA strategy.

1.4. Affordance-based model

The affordance-based model (Figure 1-4) proposed by Fajen et al. (2013) describes how these two important optical variables—the rate of expansion and the bearing angle—are used for predicting collisions in a single framework. According to this model, moving objects are detected, avoided, and intercepted by perceiving not only the bearing angles (α) but also the vertical (γ) and horizontal (φ) expansion rates of a moving object. Optical angle γ represents the optical angle between the target–ground contact and the point on the target at the observer's eye height, while optical angle φ represents the angle of the target's edges. When the observer and target are moving, the expansion or contraction of the optical angle α (i.e., not constant) provides the observer with a position that is not on a collision path. Optical angles γ and φ increase as the object approaches. In other words, the expansion of γ and φ provides the observer with information about the object's approach. Thus, the affordance-based model considers distinct properties of each of the three optical variables. In particular, the perception of the vertical expansion of a moving object (γ angle) is critical (Wraga, 1999) because the γ angle includes the eye-height information that works as an intrinsic metric for affordance perceptions, such as perceiving the minimum passable width without collision (Warren & Whang, 1987) or the minimum climbable height (Mark, 1987). If I use a task based on the concept of the model and experimentally manipulate the availability of each optical variable (e.g., introducing perturbation for the variable), I could investigate the impact of aging on each variable for collision prediction with a single experiment.

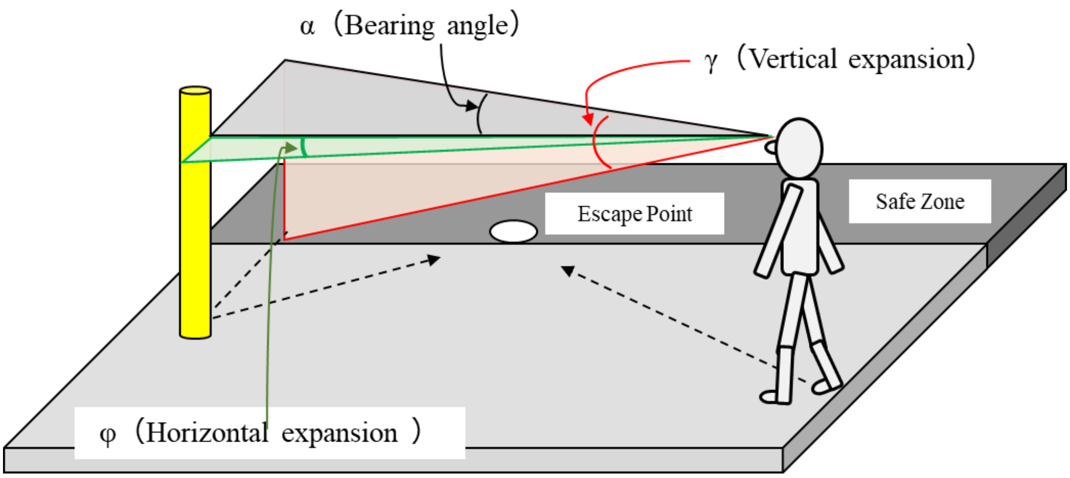

Figure 1-4. Top-down view of a scenario in which an actor is attempting to catch a moving target (yellow circle) before it escapes into a “safe zone” (dark gray region). The optical angle (γ) between the target–ground contact and the point on the target at the actor’s eye height (i.e., angular declination), the lateral optical angle formed by the leading edge of the target and the locomotor axis (α), and the optical angle of the edges of the target (φ). This figure from Fajen (2013) has been partially modified.

Chapter 2. Experiment1

2.1. Experiment 1 Overview

Experiment 1 aimed to identify visual cues that tend to become less sensitive with aging and to examine the age-related decline of the ability to perceive optical variables to predict collision, based on the affordance-based model (Fajen, 2013). To investigate the effect of aging on the use of three optical variables proposed by the affordance-based model, I reproduced the interception task used in Steinmetz et al. (2020), which was developed to investigate the validity of the model, with a minor modification in VR (Steinmetz et al., 2020). The task involves pursuing and intercepting an escaping target within a time limit. The task demands the accurate perception of visual information within the field of view and the prediction of the target's future position. The results of Steinmetz et al. (2020) showed that the absence of γ impaired the accuracy of collision prediction. The results also showed that the accuracy of collision prediction was not impaired even when the observer was stationary so that participants were unable to use the information about the bearing angle. This suggests that individuals do not depend solely on bearing angle information to predict collisions.

A unique method employed in the Experiment 1 was to introduce perturbation to each optical variable at a level that participants were unaware of. For the perturbation to the expansion rate, I reduced the size of the moving target. As the observer becomes closer to the target, the image of the target on the retina expands. However, due to the perturbation, the expansion rate was reduced. As a result, the moving target appeared farther away than it actually was. For the perturbation to the bearing angle, I shifted a portion of the bearing angle component horizontally. This induced errors in determining whether the target was located on a collision trajectory based on the bearing angle. I expected that perturbation of an optical variable should negatively affect the performance of the interception task only when participants were able to use it effectively for collision prediction. Conversely, if aging negatively affected using an optical variable in an effective manner, then there should be no significant impact of perturbation on that variable in older adults. In other words, I can specify the optical variables that are vulnerable to aging by identifying the optical variables for which no perturbation effects were found in older adults. To quantify the performance, I not only used the performance scoring used in Steinmetz et al. but we also calculated the signal detection power based on the signal detection theory (Green & Swets, 1966), with which I could assess the accuracy of visual perception without the influence of behavioral adjustments.

2.2. Material and Methods

2.2.1. Participants

Eighteen older adults (73.00 ± 5.4 years, female: 12) and 15 younger adults (23.5 ± 4.0 years, female: 6) participated. The older participants were recruited from community-dwelling adults aged 60 years or older who are registered to participate in experiments for understanding human motor control conducted in our laboratory. The younger participants were recruited from university students at Tokyo Metropolitan University. All participants had normal or corrected-to-normal vision. For older adults, cognitive function was assessed using the Mini-

Mental State Examination (MMSE). The MMSE is an 11-question measure that tests five areas of cognitive function, with the maximum score being 30 (Folstein et al., 1975). A score of 23 or lower is indicative of cognitive impairment. I ensured that all older participants had MMSE scores of 24 or higher, indicating less risk of cognitive impairment. All participants provided written informed consent and received a bookstore gift card for their participation. The procedures for the Experiment 1 were approved by the Ethics Committee of Tokyo Metropolitan University (Approval No. H3-63).

2.2.2. Apparatus and Task

The virtual environment of Experiment 1 was generated using UNITY (Unity Technologies, San Francisco, US) on an HP Omen X 2S 15 Laptop (HP Inc., Palo Alto, CA, USA) equipped with two NVIDIA® GeForce RTX™ 2080 with Max-Q Design graphics cards (NVIDIA, Santa Clara, CA, USA), a 5.0-GHz Core i9 processor (Intel, Santa Clara, CA, USA), and 8 GB of RAM running Windows 10 (Microsoft, Redmond, WA, USA). Participants wore a head-mounted display (HMD; Vive Pro Eye, HTC Corporation, Xindian, New Taipei, Taiwan) with a resolution of 2880 × 1600, a 90 Hz refresh rate, and a 110-degree viewing angle (Figure 2-1-A). Participants sat in chairs and controlled their movement in the virtual environment using a hand-held Vive Pro Eye controller (Figure 2-1-A). The direction of movement was adjusted in response to the direction of the HMD. The setup of the experimenter and the participant is shown in Figure 2-1-B.

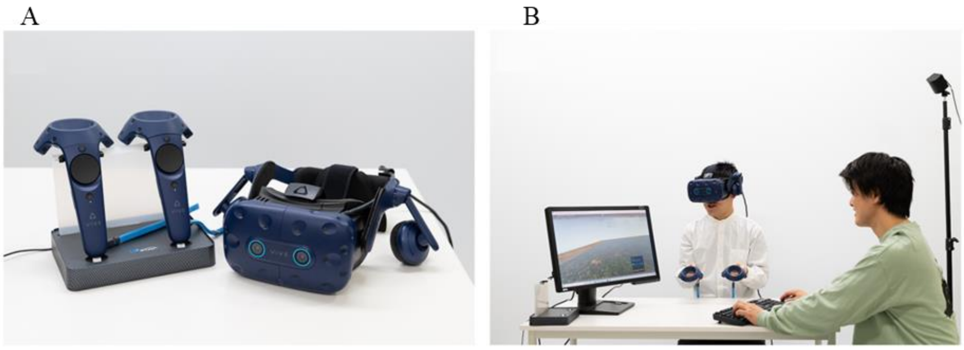

Figure 2-1. Experimental setup. Panel A shows the HTC Vive Pro Eye used to display the virtual reality environment to participants. Panel B shows the seated posture of a participant, who uses a handheld controller in each hand to stop and move their actions in a VR environment.

The virtual reality (VR) environment was designed to replicate real-world distances, ensuring that the egocentric distance in the VR scene corresponded to that in the real world. The VR scene consisted of brown textured ground on the left side, which served as the escape zone, and green textured ground on the right side (Figure 2-2-A).

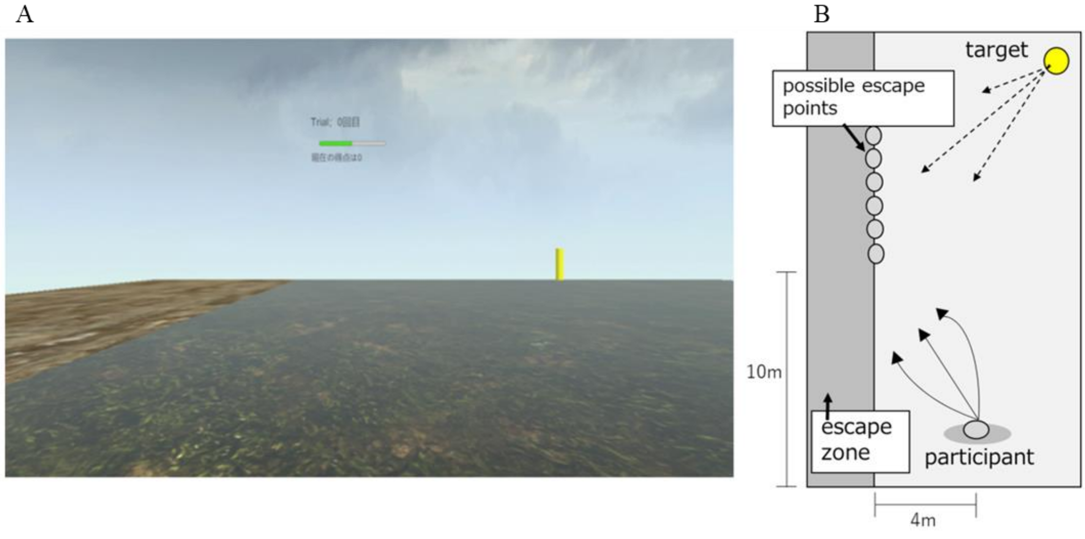

Figure 2-2. Virtual reality environment used in an interception task. Panel A shows an original image projected onto the head-mounted display worn by the participant. Panel B shows the scene from a bird's-eye view.

The target was represented by a yellow cylindrical object with a height of 1.4 meters and a radius of 0.4 meters, which was placed in contact with the ground. The initial position of the target was randomized. After the experimenter announced, "Here we go," the target moved toward one of six escape points, which were spaced 1.2 meters apart. The participant's starting point was fixed at 10 meters away from the nearest escape point (Figure 2-2-B), with the participant's eye height set at 1.2 meters. The time it took the target to reach the escape zone (referred to as "target escape times" in Steinmetz et al., 2020) was one of five predetermined times (2.3, 2.8, 3.3, 3.8, and 4.3 seconds). The target's angle of approach to the escape point ranged from 50 to 75 degrees, and the movement distance ranged from 10 to 25 meters. As a result of combining different movement distances and target movement times, the movement speed of the target for each trial ranged from 2.3 meters per second to 10.9 meters per second. Although I mostly reproduced the interception task used in Steinmetz et al. (2020), there were several differences, as summarized in Table 2-1.

Table 2-1. Differences in task properties between Steinmetz et al. (2020) and the Experiment 1

		Steinmetz et al. (2020)	The Experiment 1
Display	Display	27 in. monitor	Vive Pro Eye
	Resolution (pixels)	1920 × 1080	2880 × 1600
	Refresh rate	60 Hz	90 Hz
Locomotor properties	Tool for controlling locomotion	Foot pedal	Controller button
	Tool for controlling the direction of locomotion	Steering wheel(6.36 degrees/s)	Head mount display direction
Target	Move velocity	0-450 cm/s (variable)	450 cm/s (constant)
	Size (radius × height)	0.05 × 2.0 m	0.4 ×1.4 m

Participants were asked to pursue catchable targets and refrain from pursuing uncatchable targets, as the scoring system deducts points based on the distance moved by the participant. Participants moved their location in the virtual environment while pressing a button on a controller held in their right hand. They could give up pursuing an uncatchable target by pressing a button on a controller held in their left hand. The controller only defined whether the participant moved, and the direction of movement was adjusted according to the direction of the HMD. At the outset of each trial, participants viewed the target movement for 1 sec during an observation period in which participants could not move through the virtual environment. At the end of the observation period, a beep sounded and the participant decided whether to start pursuing or give up. The participant's movement speed was set at 4.5 m/s. Of the 30 trials per block, 17 targets were catchable and 13 were uncatchable. Notably, I aimed to replicate the task setting in Steinmetz et al. (2020) as closely as possible, so that the same dependent variables and definitions of performance success were available in The Experiment 1. For example, the length of the observation period (1s) was identical to that in Steinmetz et al. Unfortunately, there was no clear explanation as to why these values were determined. However, I speculate that, as the observation time extends, which leads to a longer stationary state, judgments tend to rely more on visual expansion information than on CBA strategies. Thus, it was necessary to set observation times to avoid bias raised by overreliance on the visual expansion information.

I followed the example of Steinmetz et al. (2020) regarding how to score the performance of the interception task. Scores were determined on the basis of (a) the trial outcome (Catch, Miss, Give up, No-go) and (b) the distance moved by the participant (movement points). When participants successfully intercepted a target (defined as “Catch”), they received +10 points. In our system, the trial was regarded as “Catch” when participants were able to reach the target at 1.05 m or closer. This criterion about the “Catch” was determined in consideration of a relatively low sampling frequency in the VR environment. The judgment of whether participants caught the target was made in every sampling frame. Because the sampling rate was relatively low, the judgment of a “Catch” could be incorrect without setting a time span (i.e., judgment was not necessarily made at the moment the distance between the target and participants was zero).

When the target reached the escape zone before they intercepted the target (defined as “Miss”), they lost 2 points. When they gave up pursuing the target (defined as “Give up”) or gave up without pursuing (defined as “No-go”), they received 0 points. The score was reduced by 0.5 points for every meter traversed through the virtual environment. As a result, depending on the distance participants moved, the gain obtained with a “Catch” trial ranged from +2 to +5 points, the loss obtained with a “Miss” trial ranged from -5 to -10 points, and the loss obtained with a “Give up” trial ranged from -1 to -5 points. No points were given for “No-go” for all trials because participants remained stationary for the trial. Participants were informed of this scoring system before performing the task and were instructed to try to achieve the highest score possible.

2.2.3. Procedure

Prior to performing the main task, three types of practice tasks were conducted to ensure that participants fully understood the interception task. The first practice task was designed to give participants experience in catching the target. To make it easy for participants to catch the target, the time the target took to reach the escape zone was set at 5.75–6.75 seconds, which was slower than the main trial. This allowed participants to make multiple catches and understand how close they needed to be to the target and their own movement speed. The practice block ended after 10 successful catches.

The second practice task aimed to familiarize participants with the concept of "No-go" and to give them experience with it. Two ranges of target escape time were set; either 1–2 seconds, where they felt they could not catch the target, or 5–6.2 seconds, where they felt they had sufficient time to catch it. To help participants understand the appropriate behavior for uncatchable targets, they were instructed to press the stop button without moving for trials with extremely short movement times. The number of trials for the second practice task was 20, regardless of the success of the catch. Escape points were fixed at two locations, 10 m and 13 m away from the participant. To confirm that the understanding of the "No-go" concept was sufficient, I checked that there were not repeated "Go" decisions when the target was clearly uncatchable.

The third practice task was meant to familiarize participants with the scoring system. The score bar and numerical value of the score were displayed during the task, allowing participants to understand the results of the trial and how their score changed according to the distance moved. The level of difficulty was slightly lower than that of the main trial, with the target movement time set to either 1.65–1.95 seconds, which is clearly uncatchable, or 3.6–5.2 seconds. Thirty trials were performed, the same number as in the main trial. To confirm that the participants fully understood the scoring system, I checked whether the participant repeatedly resulted in “Miss” for trials in which they should have opted to “No-go” or “Give up” to obtain better scores.

The total time from the practice block to the main trial block was approximately 1 hour and 30 minutes to 2 hours. To sufficiently consider the fatigue of the participants, I checked each participant's fatigue level for each block in the main task and set rest times appropriate to each participant. The total time for the practice block and the main task was generally consistent across participants. Therefore, the variation in the experiment time (90 to 120 minutes) among participants indicated that the participants were sufficiently rested based on their level of fatigue. Since participants could conduct the experiment seated, like playing a game, physical demand for performing the task was minimal and they remained engaged without showing signs of boredom.

The main task was conducted under four distinct conditions in terms of perturbations of the optical variables: (i) the α-perturbation condition, (ii) the γ-perturbation condition, (iii) the φ-perturbation condition, and (iv) the control condition, where no perturbation was applied. In the α-perturbation condition, I perturbed the bearing angle by horizontally moving the escape line (30.9 cm maximum) with the intention of making the bearing angle unreliable for judging. Immediately after a target began to move, the escape line moved to the left side from the participant’s viewpoint; this increased the bearing angle and led participants to judge that they would be able to intercept the target. As soon as the target reached the midpoint of the path to the escape point, the escape line moved in the opposite direction, which reduced the bearing angle and led participants to judge that they would not be able to intercept the target. It should be noted that the amount of the target's movement was virtually random; as a result, the initial position of the target and the target's movement speed were changed for every trial. This could prevent learning to anticipate a constant shift when the target reaches the midway point and still use the bearing angle strategy. In the γ-perturbation condition, I artificially shrank the vertical size of the object (in the y-axis direction), whereas in the φ-perturbation condition, I artificially shrank the horizontal size of the object (in the x- and z-axis directions). These perturbations began immediately after the target started moving and were stopped when the target was reduced by an amount equal to 1/3 of its original size. The main task was comprised of 90 trials per condition (30 trials per block x 3 blocks).

To set the magnitude of perturbation at a level at which participants were unaware of the perturbation, a preliminary experiment was conducted with six younger participants. To ensure the validity of the results, it was crucial that participants did not notice the perturbation. Recognizing it could have altered their behavioral strategy and introduced bias. In the preliminary experiment, the magnitude of perturbation to each optical variable was gradually increased. The threshold at which all participants noticed the perturbation or felt uncomfortable was verified. The magnitude of the perturbation used in the main experiment was set just below the largest threshold observed among all participants.

Participants completed the experiment on two separate days. On one day, participants performed the main task under two conditions: control and α-perturbation. On the other day, they performed the task under three conditions: control, γ-perturbation, and φ-perturbation. For several reasons, there was a 90- to 120-day interval between the two experimental days. Considering the concern caused by comparing two experimental conditions conducted a few months apart (e.g., a different aging effect), I decided to ask participants to perform the task under the control condition on both days and statistically compared the conditions that were performed on the same day. For that day, the order of the two experimental conditions to be performed was counterbalanced. Participants performed the task under the following experimental conditions in one of three predetermined orders: (a) control, γ-perturbation, and φ-perturbation, (b) φ-perturbation, control, and γ-perturbation, or (c) γ-perturbation, φ-perturbation, and control.

2.2.4. Data analyses

Participants' performances were evaluated using two metrics: the performance score as in Steinmetz et al. (2020; see the apparatus and task section for details regarding scoring) and the discriminability index (d' score) based on the signal detection power theory (Green and Swets, 1966). The d' score is a measure of the ability to distinguish between signal and noise. For instance, if the "Go" judgments for uncatchable targets or "No-go" judgments for catchable targets are more frequent, the value of d' will decrease. The higher the d' score was, the more accurate the judgment was. The d' score was calculated using the following equation (Randerath & Frey, 2015):

$$d' = Z\,(Hit\ rate) - Z\,(False\text{-}alarm\ rate)$$

In this equation, “Hit rate” was the ratio of "Go" judgments made for catchable targets, and “False-alarm rate” was the ratio of "Go" judgments made for uncatchable targets. Performance scores and d' scores were calculated for each block to examine the improvement through task experience.

To better understand how aging would affect pursuing the target, I quantified the curvilinearity of the movement trajectory in the x direction. Figure 2-8 showed the trajectories under the control condition performed on the day on which participants performed the task under the α-perturbation condition. The trajectory became curvilinear when participants started their movement toward the current target location. In contrast, the trajectory became straight when they started their movement toward the future path accurately. Therefore, I considered that the more curvilinear the trajectory was, the less accurate was subjects’ ability to predict the target’s movement. To quantify the magnitude of curvature, I extracted the x-axis coordinates showing the maximum displacement in the direction opposite to the escape zone (i.e., the direction of the target’s initial position) and calculated the lateral distance. A t-test was conducted to assess the differences in lateral distance between younger and older adults.

As mentioned previously, I decided to statistically compare (a) the control and α-perturbation conditions and (b) control, γ-perturbation, and φ-perturbation as separate analyses, based on concerns about comparing two experimental conditions a few months apart. For each comparison, a three-way (age, perturbation, and block) analysis of variance (ANOVA) with repeated measures of perturbation and block was performed for the performance score and d' score. The effect size was calculated as a partial η^2 for each of the main and interaction effects. Mauchly's sphericity test was used to test for sphericity. When sphericity was not confirmed, the degrees of freedom and F values were adjusted using the Greenhouse-Geisser estimate. ANOVAs and unpaired t-tests were conducted using SPSS software, with a significance level set at $p \leq .05$.

2.3. Results

2.3.1. Performance score

Mean performance scores under each experimental condition are shown in Figure 2-3 and 2-4. An ANOVA examining the effect of α-perturbation showed a main effect of age ($F(1, 31) = 48.56$, partial $\eta^2 = 0.61$, $p = .000$). The performance scores of younger participants were higher than those of older participants. The main effect of perturbation was also significant ($F(1, 31) = 4.80$, partial $\eta^2 = 0.13$, $p = .036$). Scores under the control condition were significantly higher than those under the α-perturbation condition. The main effect of the block was not significant ($F(2, 62) = 0.10$, partial $\eta^2 = 0.00$, ns). No interactions were significant.

An ANOVA examining the effects of the γ- and φ-perturbations showed a main effect of age ($F(1, 31) = 41.61$, partial $\eta^2 = 0.57$, $p < .001$). The performance scores of younger participants were higher than those of older participants. The main effect of perturbation was also significant ($F(2, 62) = 3.33$, partial $\eta^2 = 0.10$, $p = .042$). Scores under the control condition were significantly higher than those under the γ-perturbation condition. There was no significant difference between the φ-perturbation and the control condition. With regard to the effect of the block, Mauchly's test indicated that the assumption of sphericity had been violated ($W = .806$, χ^2 (2) = 6.454, $p = .040$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = .838$). The main effect of the block was significant (F (1.676, 52.06) = 22.03, $p < .001$, partial $\eta^2 = .415$), indicating significantly higher scores in blocks 2 and 3 than in block 1.

The interaction between age and perturbation was significant (F (2, 62) = 4.13, partial $\eta^2 = 0.12$, $p = .021$). Post hoc comparisons of the interactions showed that the simple main effect of perturbation was significant only for younger participants (F (2, 30) = 6.75, partial $\eta^2 = 0.310$, $p = .004$). Their performance scores were higher under the control condition than under the γ-perturbation condition. A simple main effect of perturbation was not significant for older participants (F (2, 30) = 0.25, ns). A Greenhouse–Geisser correction was applied, considering the results of the test of sphericity in block ($W = .619$, χ^2 (9) = 14.089, $p = .120$). In contrast, the interaction of age, perturbation condition, and block was not significant (F (3.352, 103.925) = 1.657, partial $\eta^2 = 0.051$, $p = .175$).

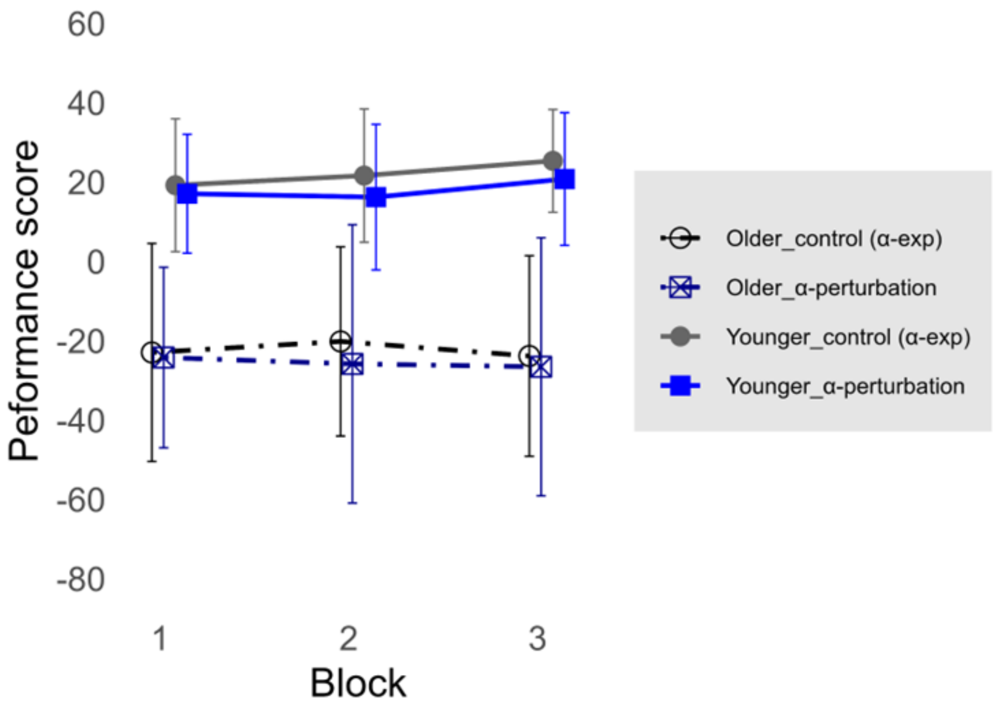

Figure 2-3. Mean performance scores under the α-perturbation condition. Error bars represent standard deviation.

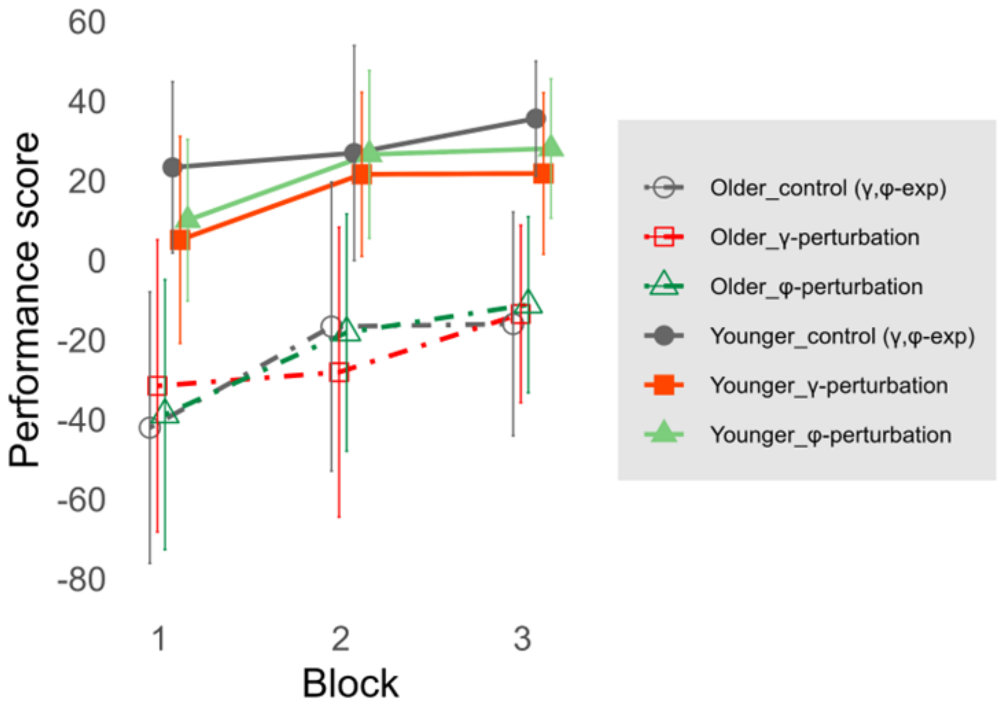

Figure 2-4. Mean performance scores under the γ- and φ-perturbation conditions. Error bars represent standard deviation.

2.3.2. Discriminability index (d' score)

Mean d' score results under each experimental condition are shown in Figure 2-5 and 2-6. An ANOVA examining the effect of the α-perturbation showed a main effect of age ($F\ (1, 31) = 34.35$, partial $\eta^2 = 0.53$, $p = .000$). Younger participants showed d' scores higher than those of older participants. The main effect of perturbation was not significant ($F\ (1, 31) = 0.81$, partial $\eta^2 = 0.03$, ns). Neither was the main effect of the block significant ($F\ (2, 62) = 1.08$, partial $\eta^2 = 0.03$, ns). None of the interactions was significant.

An ANOVA examining the effects of γ- and φ-perturbations showed a main effect of age ($F\ (1, 31) = 29.86$, partial $\eta^2 = 0.49$, $p = .000$). Younger participants had d' scores higher than those of older participants. The main effect of perturbation was not significant ($F(2, 62) = 2.05$, partial $\eta^2 = 0.06$, ns). Neither was the main effect of the block significant ($F(2, 62) = 0.99$, partial $\eta^2 = 0.03$, ns).

The interaction between age and perturbation was significant ($F(2, 30) = 4.23$, partial $\eta^2 = 0.12$, $p < .019$). Post hoc comparisons of the interactions showed that the simple main effect of perturbation was significant only for younger participants ($F(2, 30) = 4.04$, partial $\eta^2 = 0.21$, $p = .028$). Their d' scores were higher under the control condition than under the γ-perturbation condition and the φ-perturbation condition. A simple main effect of perturbation was not significant for older participants ($F(2, 30) = 0.22$, ns). The three-way interaction between age, type of perturbation, and block was not significant ($F(4, 124) = 1.326$, partial $\eta^2 = 0.041$, $p = .264$).

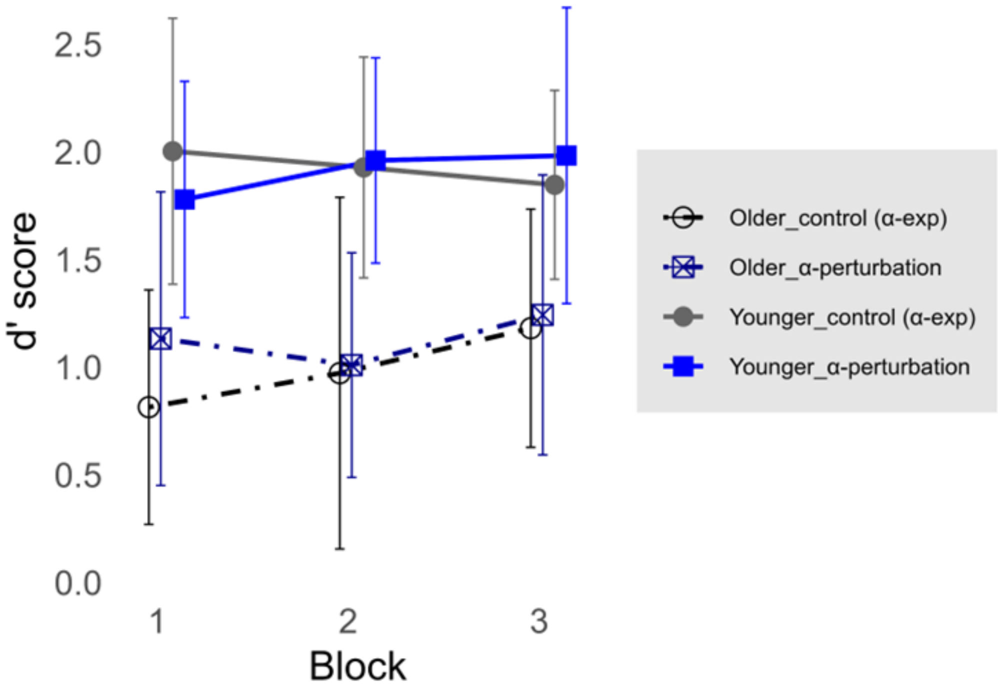

Figure 2-5. Mean d’ scores under the α-perturbation condition. Error bars represent standard deviation.

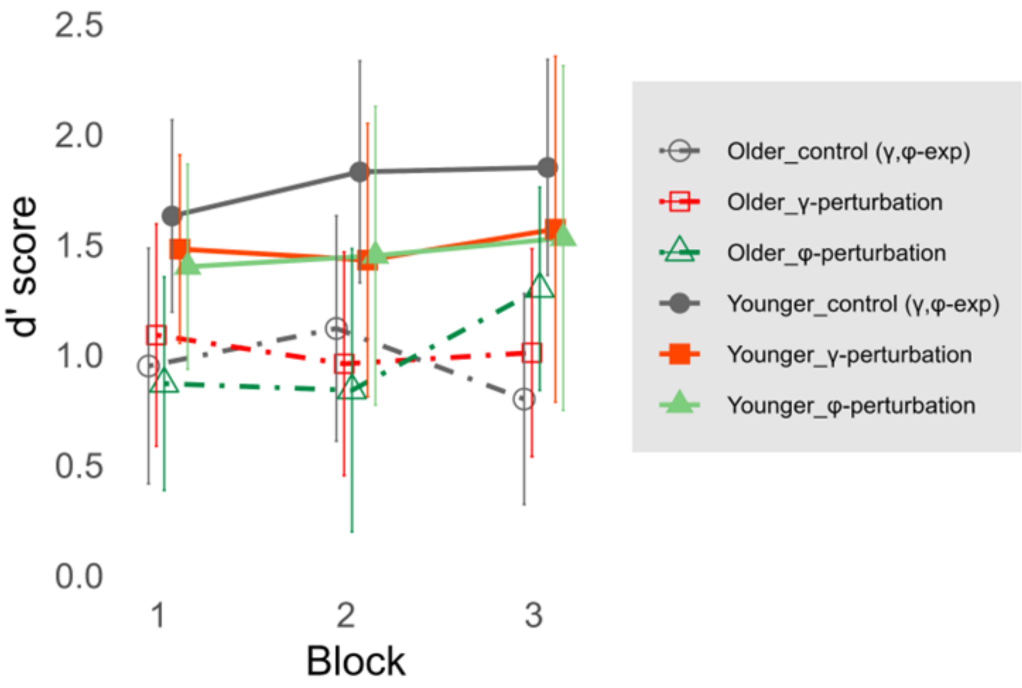

Figure 2-6. Mean d' scores under the γ- and φ-perturbation conditions. Error bars represent standard deviation.

2.3.3. Trajectories of participants' movements

The mean positive deviations on the x-axis for the two groups are shown in Figure 2-7 and the representative trajectories of the participants' movements are shown in Figure 2-8. A t-test showed that the deviation was significantly greater for the older participants than for the younger participants ($t\ (50.16) = 4.68$, $p = .000$).

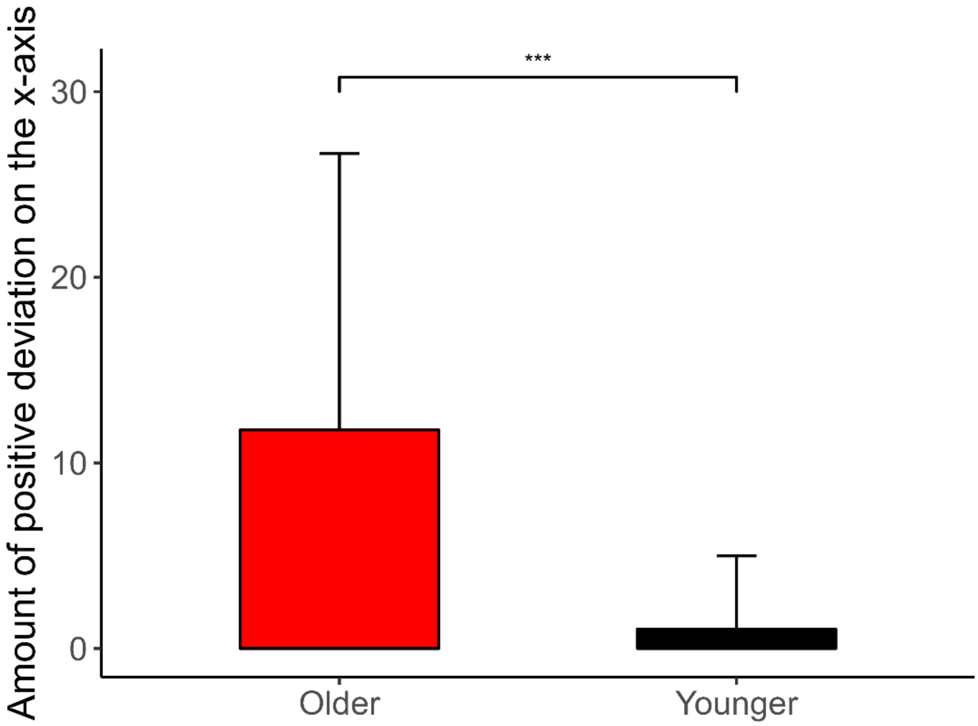

Figure 2-7. Comparison of mean positive deviations on the x-axis between older and younger participants. Error bars represent standard deviation.

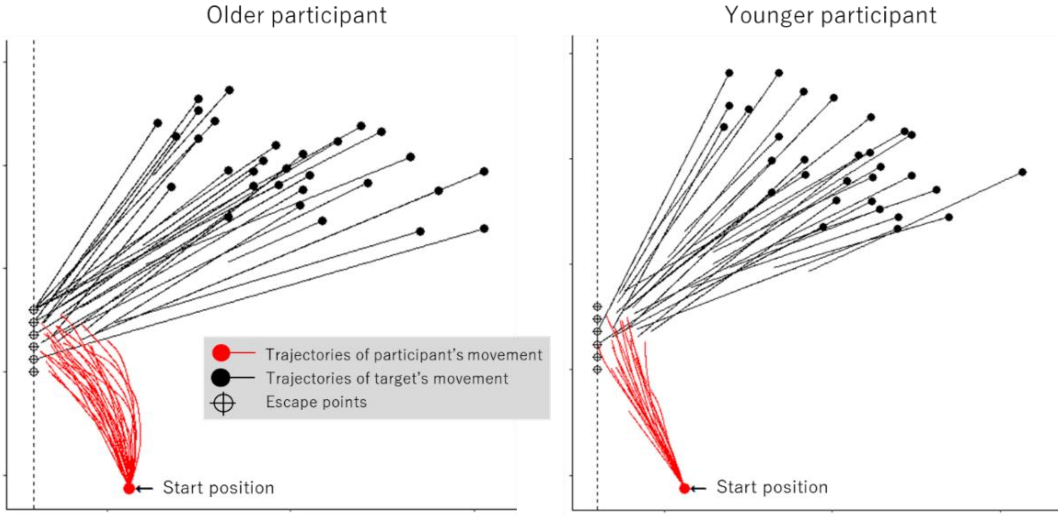

Figure 2-8. Representative target trajectories of participants' movements under the control condition are shown in a younger participant and an older participant. White circles show the initial locations of the target, determined randomly. The figures show that the older participant moved curvilinearly to catch the target.

2.4. Discussion

Int the Experiment 1, I aimed to identify optical variables vulnerable to aging by reproducing the interception task in Steinmetz et al. (2020). I expected that perturbation would negatively affect performance on the interception task only for those who are able to use optical variables in an effective manner, while those with declined sensitivity would not be affected by the perturbation. The results showed that perception of the bearing angles was negatively affected by perturbation in both age groups, suggesting that older adults also maintained sensitivity to the bearing angle. In contrast, older adults' perceptions of both vertical and horizontal expansion rates of moving objects were not affected by the perturbation. These findings suggest that sensitivity to the expansion rate of a moving object on the retina is likely to be vulnerable to aging, and likely depends on the bearing angle.

Before discussing the main findings about the effect of perturbation, I would like to note that for most dependent variables, performance was worse for older adults than for younger adults. Consistent with a previous study (de Dieuleveult et al., 2019), this suggests difficulty in collision prediction in older adults. A critical difference in the two age groups is clearly shown in the curvilinearity for the trajectories of movement toward the target (Figure 2-8). The movement trajectories were relatively curvilinear for older adults, whereas they were linear for younger adults. Generally, in an interception task, the target's motion information should be extrapolated over time, and the future object position should be predicted, resulting in a linear trajectory toward the future interception point (Brenner & Smeets, 2018). The curvilinear trajectories that deviated in the direction opposite from the escape zone suggest that older participants have difficulty predicting the future interception point. It has been reported that aging affects object-motion perception, visual processing speed, speed discrimination, estimation of direction of heading, and ability to estimate collision time (Andersen, 2012; Owsley, 2011). The decline in these visual perceptual abilities with aging may underlie the difficulty in estimating the interception point. Previous studies examining brain activities showed that the frontal lobe, parietal lobe, insular cortex, thalamus, and visual cortex are involved in perceiving and predicting the trajectories of moving objects and that these brain areas are affected by aging (Cheong et al., 2012). Age-related changes in these brain functions may reduce the ability to predict object-motion information for moving objects, resulting in poorer performance of the interception task.

The results of reduced sensitivity to the expansion rate of a moving object are consistent with the findings of Andersen & Enriquez (2006), which show that older adults have difficulty using the information obtained as the expansion of a moving object on the retina to predict whether a collision will occur. Generally, the expansion of an approaching object serves as the primary visual cue for determining both the distance to the object and TTC perception. Given that the γ angle includes the eye-height information that works as an intrinsic metric for affordance perceptions (Wraga, 1999), sensitivity to the vertical expansion of an approaching object, including eye-height information, is particularly important in the perception of TTC. Brain regions involved in responding to object approach and estimating TTC include the superior colliculus and the pulvinar nucleus of the thalamus (Billington et al., 2011). Studies have shown that these brain regions function less effectively in older adults, both in terms of anatomical differences and information processing (de Dieuleveult et al., 2017). These age-related changes in brain regions involved in the perception of approaching objects and estimate collision prediction may explain the results of the Experiment 1, which found that older adults are less sensitive to the expansion rate of a moving object.

The Experiment 1 showed that sensitivity to bearing angles is preserved with aging, which contradicts the findings of a previous study (Ni et al., 2012). However, our results are consistent with the findings of a previous study (Bian et al., 2013) that showed that older adults' ability to accurately detect collision events depends on the trajectory of the moving object. Bian et al. (2013) found that detection accuracy decreased when the moving object had a linear trajectory but not when it had a curvilinear trajectory. If the moving object has a linear trajectory, its position is stationary at a constant location in the flow field (i.e., a constant bearing angle). In contrast, if the trajectory of the moving object is curved, its position is dynamically changing in the flow field (i.e., a constant bearing angle change). Therefore, they noted that the ability to perceive a constant bearing angle decreases with aging, but the ability to perceive a constant bearing angle change may be maintained. The target trajectories used by Ni et al. (2012) were linear trajectories, which differed from the trajectories used in the previous study conducted by Bian et al. (2013). Although the target of the Experiment 1 was a linear trajectory, the older adults moved in a curvilinear trajectory, so it was assumed that the bearing angles in the field of view were dynamic, in relative terms. Therefore, as mentioned by Bian et al. (2013), it is possible that older adults could have used the bearing angles for collision prediction. This difference in experimental design may have contributed to the discrepancy between the findings of the previous study conducted by Ni et al. (2012) and the Experiment 1.

The results of Experiment 1 indicated that sensitivity to object expansion is susceptible to the effects of aging, while sensitivity to the bearing angle is maintained even in older adults. While I cannot provide a definitive explanation for these contrasting results, it is possible that visual perceptual functions are selectively, rather than universally, affected by aging. The influence of aging on sensitivity to the expansion rate of moving object could be attributed to age-related changes in the associated brain regions, as mentioned earlier. On the other hand, there are no previous studies that support the idea that sensitivity to the bearing angle is preserved at the brain function level. Given that the ability to detect the direction of object movement is maintained even with aging {Evans, 2020 #335} and that the effects of perceptual learning training on the ability to discriminate the direction of object movement are greater in older adults (Bower et al., 2013), it is plausible that aging primarily affects sensitivity to object expansion. Furthermore, the results of Experiment 1, which demonstrate a decline in sensitivity to object expansion due to aging, suggest that older adults may be more vulnerable to collision with moving objects approaching from the front rather than a lateral direction, such as approaching pedestrians or vehicles. Therefore, it would be desirable to devise intervention tasks aimed at enabling accurate judgment of collision risks with objects approaching from the front.

2.5. Limitation

The Experiment 1 has several limitations. First, experiments that provided α-perturbation and those that provided γ- and φ-perturbations were conducted on separate days, which could have resulted in a bias. A limitation related to the procedure was that I needed to separately perform statistical comparisons on sensitivity to bearing angles and sensitivity to object expansion. To determine whether conducting the Experiment 1 on two separate days biased the results, I additionally conducted t-test analyses to compare the performance scores (and d' scores) between the control conditions corrected in the two days and found no significant differences (performance scores: $t\ (32) = 0.48$, $p = 0.634$, 95%CI [-5.199,8.412], d' score: $t\ (32) = -1.234$, $p = 0.226$, 95%CI [-0.224,0.055]). This suggests that the possible biases would be minimal, if any.

Another limitation was related to the amount of perturbation. The amount of perturbation to each visual cue was set at a level at which the participant was not aware of the perturbation (i.e., an unconscious level). However, due to the different characteristics of the perturbation given to each optical variable (the perturbation to the object expansion directly manipulated the size of the target, while the perturbation to the bearing angle manipulated the escape line), achieving a uniform perturbation effect across variables was challenging. Consequently, it is possible that the perturbation to the object expansion had a stronger effect than the perturbation to the bearing angle.

Finally, the Experiment 1 employed a task using a protocol of Steinmetz et al. (2020) in which participants navigated a VR environment using a controller while seated, with no vestibular feedback from walking. I believe that this was still reasonable, given that I asked each individual maximum of 270 trials to test our hypotheses. However, given that older adults tend to exhibit a downward gaze, walking in scenarios where they need to observe a moving object could lead to unique responses and alterations in performance. It is essential to fully understand these differences between seated position and walking when generalizing the results of Experiment 1.

2.6. Conclusion

In Experiment 1, I examined performance changes for each of three optical variables included in the affordance-based model when perturbations were applied. The findings of this study suggest that aging has a particularly negative effect on sensitivity to the vertical and horizontal expansion of an object, while sensitivity to bearing angle is maintained. These results imply that enhancing sensitivity to the expansion rate of a moving object may be essential for improving older adults' ability to predict collisions.

Chapter 3. Experiment 2

3.1. Introduction

The results of Experiment 1 suggest that enhancing sensitivity to the expansion rate of a moving object may help improve older adults' ability to predict collisions. Therefore, I developed two perceptual tasks which could potentially improve sensitivity to object expansion and, as a result, lead to accuracy in predicting collisions: a distance-estimation task and a time-to-contact (TTC)-estimation task. These two tasks were the same, in that older participants observed the expansion of a frontally approaching target for a number of trials, but they were different in what was estimated based on the perceived expansion rate. In the distance-estimation task, older participants estimated the distance to an object based on object expansion, whereas in the TTC-estimation task they estimated the time to collision with an approaching target based on object expansion. In other words, performing the distance-estimation task involves spatial aspects, whereas performing the TTC-estimation task involves temporal aspects.

The background information that led to the idea of developing these two tasks is summarized as follows. In the theory of visual perceptual learning, intensive and repetitive exposure to visual stimuli is considered to be important for improving the sensitivity of those stimuli (Carmel & Carrasco, 2008; Dosher & Lu, 2017; Sagi, 2011). It might be natural to consider that the repetitive experience of performing the interception task used in Experiment 1 is a more straightforward method of improving accuracy in predicting collisions assessed on the basis of the performance of that task. However, because the interception task requires participants to perceive not only the object expansion but also the bearing angle produced between the observer and a moving object, repeated experience in performing the task might not efficiently enhance sensitivity to the expansion rate of a moving object. In fact, in Experiment 1, there was no significant improvement in the d' score, which represents sensitivity to object expansion, as the participants performed the task (i.e., from first to third trial blocks). Therefore, I concluded that developing a perceptual task in which participants could exclusively focus on object expansion would be suitable.

The visual stimuli presented in the two tasks tested in Experiment 2 (i.e., a distance-estimation task and a TTC-estimation task) were determined based on Yan et al. (2011). Yan et al. manipulated the visual environment to investigate the contribution of object expansion to collision detection abilities (Figure 3-1). Elimination of ground information means the removal of the optical flow obtained from the ground (i.e., the expansion rate of the ground on the retina, as discussed in Chapter 1.2.2.). In Experiment 2, the visual cues used by participants were controlled by manipulating the visual environment in accordance with the method of Yan et al. A critical point of this manipulation was the restriction of ground information. To create a situation in which participants could focus only on object expansion, no ground information was provided during training (i.e., optical flow from the ground was unavailable). Because the perception of object expansion was very difficult without the ground, participants initially took part in an adaptation task session in which a moving target was observed with ground information. This was followed by the main task session.

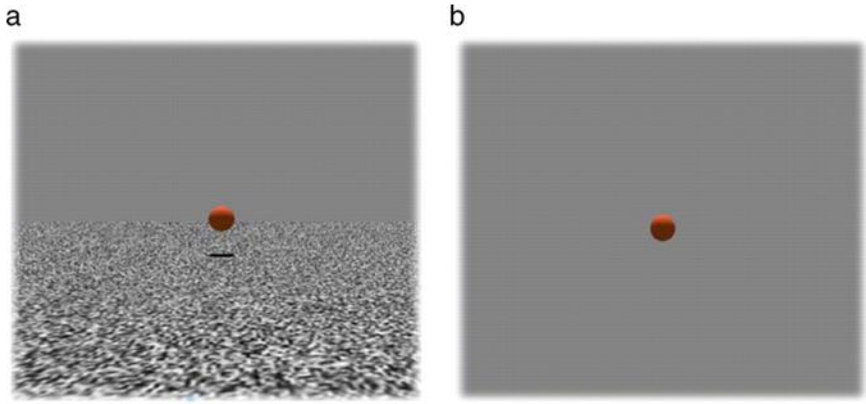

Figure 3-1. The visual environment used in the study by Yan et al. (2011). “(a) With-ground condition. (b) Without-ground condition. The ground and shadow shown in the with-ground condition provided observers with additional distance and speed information (Adapted from Yan et al., 2011, p.5).

As explained, the two perceptual tasks tested in Experiment 2 were different in that performing the distance-estimation task involved the spatial aspects, whereas performing the TTC-estimation task involved the temporal aspects. Previous studies showed contradictory findings about which aspects would be more worth focusing on to improve collision prediction. A study testing young adults showed that training to estimate the temporal aspect of object expansion (i.e., the TTC of an approaching object) improved the ability to predict collisions (Braly & DeLucia, 2020; Das et al., 2023). In contrast, another study showed that older adults have reduced sensitivity to the velocity of moving objects and rely on distance to predict collisions (Zito et al., 2015). Because these studies used only a single task involving either a spatial or temporal aspect, I tested two perceptual tasks, each of which involves either a spatial or temporal aspect and addressed which of the tasks would be more effective.

In Experiment 2, the effectiveness of these two tasks as training to improve sensitivity to the expansion rate of a moving object and accuracy in predicting collisions were compared with the interception task used in Experiment 1. As a result, there are three experimental groups: (a) a group performing a distance-estimation task (DE-task group), (b) a group performing a TTC-estimation task (TE-task group), and (c) a group performing an interception task (IC-task group). In the distance-estimation task, participants controlled their own movements toward the target and actively adjusted and estimated the distance to the target in order to make decisions based on spatial aspects. In the TTC-estimation task, on the other hand, participants remained stationary and estimated the time to collision (TTC) with the approaching target.

To evaluate the effectiveness of performing these tasks, participants were also asked to perform three types of evaluation tasks: (a) a target approach detection task, designed to assess the sensitivity to object expansion, (b) an interception task, the same as the main task in Experiment 1, to evaluate the ability to predict collisions; and (c) a road-crossing task, based on Stafford et al. (2021), to evaluate the transfer of learning to real-world scenarios by evaluating the accuracy of crossing decisions. Using these evaluation tasks, I tested the hypothesis that enhancement in sensitivity to object expansion contributes to improved collision-prediction ability.

3.2. Materials and Methods

3.2.1. Participants

Twenty-eight older adults (71.32 ± 5.9 years, 16 females) were recruited similarly to Experiment 1. All participants provided written informed consent and received a bookstore gift card for their participation. The procedures for Experiment 2 were approved by the Ethics Committee of Tokyo Metropolitan University (Approval No. H5-13).

3.2.2. Apparatus and task

Apparatus

I changed an HMD from Experiment 1 and newly used Oculus Quest 2 (Meta Platforms, Inc., Menlo Park, CA, USA) at LCD 1832 × 1920 resolution with a 72 to 120 Hz refresh rate with a 110-degree viewing angle and controllers (Figure 3-2). Changes were made because it was necessary to use hand-held controllers equipped with a joystick. For the system development, I also used a G-Tune E5 laptop computer (Mouse Computer Co., Ltd., Chuo-ku, Tokyo, Japan) with two NVIDIA® GeForce RTX™ 3060 with Max-Q design graphics cards (NVIDIA, Santa Clara, CA, USA), a 2.3 GHz Core i7-12700H processor (Intel, Santa Clara, CA, USA), and 32 GB of RAM running Windows 11 (Microsoft, Redmond, WA, USA). The virtual environment was generated in UNITY (Unity Technologies, San Francisco, CA, USA) as in Experiment 1.

Figure 3-2. Oculus Quest 2 and equipped hand-held controllers

Perceptual tasks

Distance-estimation task (DE-task group)

For participants in the distance-estimation task, the purpose was to move forward to the target (height 1.6 m, radius 40 cm) and stop at one of the predetermined distances (1 m, 3 m, or 5 m). To focus on the perception of object expansion, a VR environment was constructed where only the target was projected onto a black background (the scene of the main task session is shown in Figure 3-3). The initial distance between the participant and the target was consistently set at 30 meters per trial. Participants approached the target by operating a joystick on the controller; their movement speed ranged from 0-450 cm/s, depending on the joystick's degree of inclination. Immediately after participants stopped by pressing the button, estimation error feedback was displayed on the screen. Participants were allowed time to review the feedback but were instructed to minimize the time between trials. The feedback display disappeared when the next trial began. The experimenter-indicated pre-determined distance was altered randomly every 10 trials, and participants were verbally informed of the changes. The predetermined distances were displayed in Japanese at the center top of the screen, allowing participants to constantly check. For instance, if the pre-determined distance was 3 meters, it was displayed as "Please stop at a location 3 meters away."

There was concern that detecting object expansion without background information would be too difficult for older adults to work as training. For the purpose of eliminating this concern, an adaptation task session using two different scenes with ground information was performed prior to the main task session (the scene of the adaptation task session is shown in Figure 3-3). I expected that initiating the DE-task with background information would help participants adapt to performing the task. The two scenes differed in the amount of visual information provided on the ground. In the first scene, the target was presented against a black background on a green surface with the ground in front of them. Additionally, red cones were placed every 5 meters. In the second scene, the target was presented against a black background and positioned on a green ground surface. The absence of the red cones in the second scene emphasized the contribution of object expansion to performing this task. Participants performed 30 trials for each scene, with the predetermined distance (1 m, 3 m, or 5 m) of 10 trials each.

While the duration of the adaptation task session varied slightly among participants, it took about 7-10 minutes. The total time allotted for the main task session was the time remaining within a 60-minute period, after excluding the adaptation task session. Therefore, the main task session typically lasted for more than 50 minutes. Rest times during the task were generally set after every 60 trials. I checked each participant's fatigue level after 30 trials and set rest times appropriate to each participant. As the experiment could be conducted while seated, the physical demands of performing the task were minimal. The perceptual task concluded once a total of 60 minutes had passed, including the adaptation task session, the main task session, and rest times.

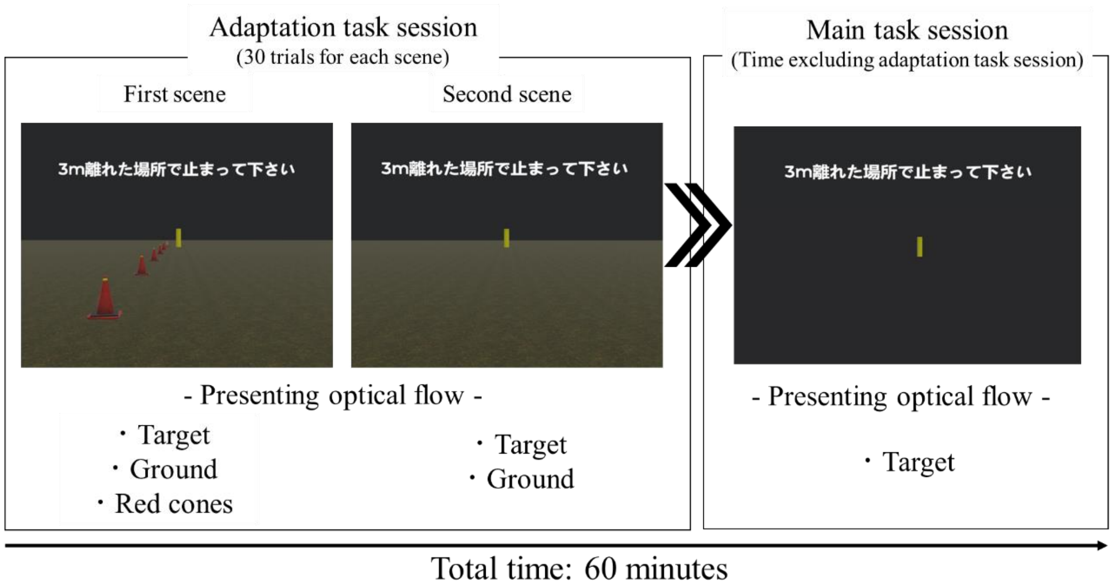

Figure 3-3. The VR scene used in the distance-estimation task for the DE-task group. This image shows the scene where the visual information (optical flow) presented from the adaptation task session to the main task session was gradually reduced. The adaptation task session and the main task session combined lasted for 60 minutes.

TTC-estimation task (TE-task group)

The purpose of the TTC-estimation task was for participants to estimate the TTC of an approaching target and to press the button on the controller at the moment that the TTC of the approaching target reached a predetermined time (1, 3, or 5 seconds). The visual environment used for this task was the same as the DE-task except for the instruction text displayed on the screen (i.e., the instruction is changed to a predetermined time instead of a predetermined distance). The initial distance between the participant and the target was set within a range of 40 to 80 meters. The target's approach speed varied from 6.8 to 16.2 m/s (24.48 km/h to 58.32 km/h), corresponding to each TTC condition. Target speed and distance were randomly set within these parameters. For example, if the predetermined time was 3 seconds, the target's speed and distance from the participant were adjusted to ensure that the actual TTC was not less than the pre-determined time.

Immediately after participants pressed the button, the feedback on their estimation error was displayed on the screen. Participants were provided time to review the feedback, after which, participants waited for the experimenter to announce "Here we go" before proceeding to the next trial. The predetermined time was changed randomly every 10 trials, and participants were verbally informed of each change. The predetermined times were displayed in Japanese at the center top of the screen, allowing participants to constantly check. For instance, if the predetermined time was 3 seconds, it was displayed as "Press the button 3 seconds before the collision."

As in the distance-estimation task, participants in this group were initially involved in an adaptation task session using two different scenes with ground information prior to the main task session. The purpose of introducing the adaptation task session was to address the concern that detecting object expansion without background information would be too difficult. This concern was addressed by practicing from an environment rich in visual information and becoming adept within the environment. The visual contents of the two scenes and the number of trials to be performed using each scene were identical to those of the distance-estimation task (see Figure 3-3). The only exception was the instruction shown in the scene on predetermined time. The general procedure of performing the task was the same as in the distance-estimation task.

Interception task (IC-task group)

As in Experiment 1, participants were instructed to aim for the highest score by pursuing only catchable targets to minimize point deductions from unnecessary movement. Several modifications were made from Experiment 1, particularly regarding the protocol of task familiarization. In Experiment 1, some older participants needed more time than expected to become accustomed to operating two controllers. It was difficult for them to move and stop using different control systems (i.e., head movement to control the direction and manipulating button on a controller to stop). To solve this problem, I modified the system so that both were controlled by a single controller. Participants held the controller in their left hand. The thumb operated the joystick, and the index finger operated the stop button. The direction of movement was determined by the direction of the joystick. The participant's movement speed was not fixed at 450 cm/sec but could be adjusted within a range of 0-450 cm/sec depending on the joystick's degree of inclination.

The virtual environment was also modified (Figure 3-4). The background was changed to black for consistent contrast with the other tasks in Experiment 2. The addition of multiple trees in the escape zone increased the optical flow, enhancing participants' sense of forward movement and allowing them to perceive the escape zone more three-dimensionally. The scoring system, target movement speed and direction, as well as other task system contents remained the same as in Experiment 1.

The total task time was set at 60 minutes. Rest times during the task were generally given after every 60 trials. To sufficiently consider the fatigue of participants, I checked each participant's fatigue level every 30 trials and set rest times appropriate to each participant.

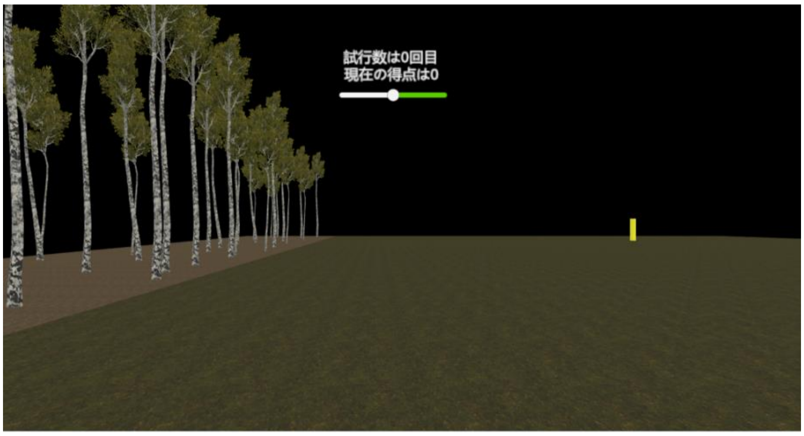

Figure 3-4. Virtual reality environment used in the interception task for Experiment 2, showing an original image projected onto the head-mounted display worn by the participants

Evaluation tasks

Target approach detection task

This task was used to evaluate sensitivity to the expansion of an approaching object and measured the reaction time to perceive the approach of the target. The participant sat on the chair while wearing the HMD and observed the VR scene in which only the target (height 1.6 m; radius 40 cm) was projected onto a black background (Figure 3-5). The distance between the target and the participant was set at two levels: a far distance of 40 meters and a close distance of 20 meters. There were two target speed conditions: fast at 100 cm/sec and slow at 50 cm/sec. Participants were instructed to press a button as soon as they detected the target's approach. If the button was pressed during the target's stationary time, a beep sounded to indicate that the trial was invalid. The faster this reaction time, the higher the sensitivity to the expansion rate of the approaching object. The evaluation was conducted for distance (two levels: near, far) x velocity (two levels: slow, fast) x three trials for a total of 12 trials. The order of distance and velocity (i.e., 2 x 2 = 4 conditions) being presented was counterbalanced.

Two types of practice sessions were conducted. First, to familiarize participants with operating the button, they observed a fast-moving target (300 cm/s) approaching at a speed that was easy to detect, and they performed three trials. Second, to discourage premature button pressing, participants practiced refraining from pressing the button until the target's approach was detected. Participants observed the target to remain stationary for 20 seconds. If a participant pressed the button while the target was stationary, a beep sounded to indicate an error. This practice was repeated until the participant no longer pressed the button prematurely, even with a 20-second hold time.

Figure 3-5. Panel A shows the VR environment where only the target was projected against a black background. Participants were required to detect the approach of the target solely based on object expansion. Panel B shows the scene from a bird's-eye view.

Interception task

The task was the same as the task used in Experiment 1 and in the IC-task group in Experiment 2. The performance score for one block (30 trials) and the accuracy of judgments were calculated using the same procedure as in Experiment 1.

VR Road-crossing task

This task was constructed based on the experimental protocol of Stafford et al. (2021). To assess the accuracy of participants' crossing decisions, participants were asked to decide whether a gap within the flow of traffic would allow them enough time to safely cross the virtual road and to cross the virtual road when they perceived it was safe to do so. Participants were further told that if they could not cross at any timing, they should cross only after the last vehicle had passed by. Participants were allowed to adjust their walking speed only if they were about to collide with a vehicle. Participants were allowed to freely turn their head and gaze while crossing the street.

In the study, the VR scene simulated a crosswalk in a Japanese cityscape, including five vehicles approaching from the participant's right side and four gaps formed by these vehicles (Figure 3-6-A). To enhance the immersive experience, the surrounding objects were made as close to a real environment as possible. The road was designed to be 4.3 meters wide, with each lane—identified as a potential collision zone with vehicles—set to a width of 2.15 meters. The width of each gap—either crossable or uncrossable—between the 5 vehicles was determined based on each participant's premeasured normal walking speed. A crossable gap was set to allow a participant to cross at their normal walking speed, whereas an uncrossable gap was set at widths participants could not theoretically cross at their normal walking speed. In trials where a crossable gap was included (crossable condition), only one of the four gaps was designated as crossable. Conversely, in trials without a crossable gap (uncrossable condition), all four gaps were set as uncrossable at the normal walking speed. A total of 15 trials were conducted: 8 for the crossable condition and 7 for the uncrossable condition.

To familiarize participants with the VR setup, they first practiced walking without vehicles in the VR environment while wearing the HMD. Once they felt they were familiarized with walking in the VR environment, their normal walking speed was measured three times in the VR environment. Participants were instructed to walk a 4.5 m path in the virtual crosswalk setting at their usual pace. The fastest walking speed out of the three measurements was chosen as the representative value and reflected in the settings for the main trial. The walking speed was calculated using the 6DoF (six degrees of freedom) tracking system of the HMD, which captures participants' movements in three-dimensional space, including forward / backward, up / down, left / right, as well as rotations around three perpendicular axes, allowing for a comprehensive measurement of their walking speed. To prevent accidents involving falls and colliding with obstacles during actual walking, an experimenter accompanied each participant directly beside them during the crossing (Figure 3-6-B).

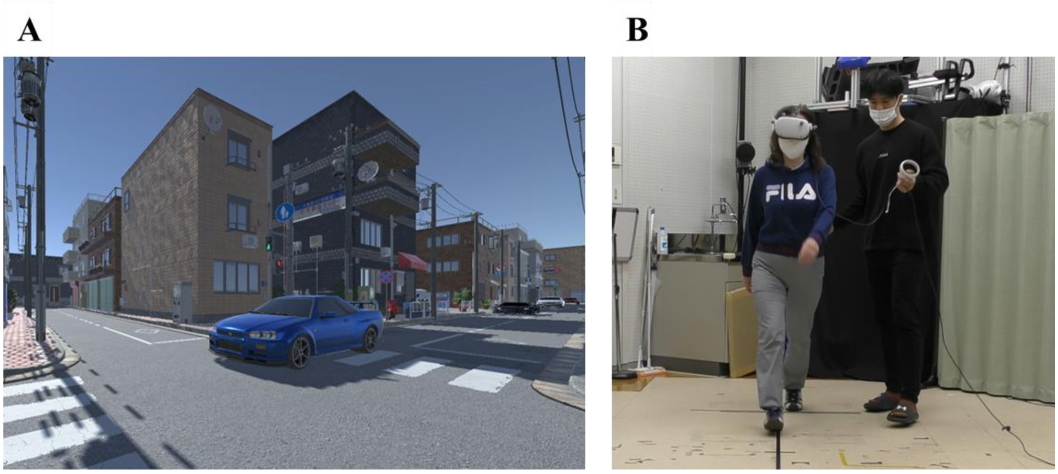

Figure 3-6. Panel A shows the VR scene of a pedestrian crosswalk in a Japanese cityscape including the vehicles. Panel B shows a participant engaged in the task, wearing a head-mounted display and accompanied by an experimenter to ensure safety during the actual walking.

3.2.3. Procedure

Participants were randomly assigned to one of three groups: DE-task (n=8), TE-task (n=10), and IC-task (n=10). The experimental protocol is shown in Figure 3-7. It consisted of a pre-evaluation session composed of three evaluation tasks, 60 minutes of a perceptual task, and a post-evaluation session that was identical to the pre-evaluation. The protocol was approximately 2 hours and 30 minutes in total. The order of tasks in the pre- and post-evaluation sessions was counterbalanced.

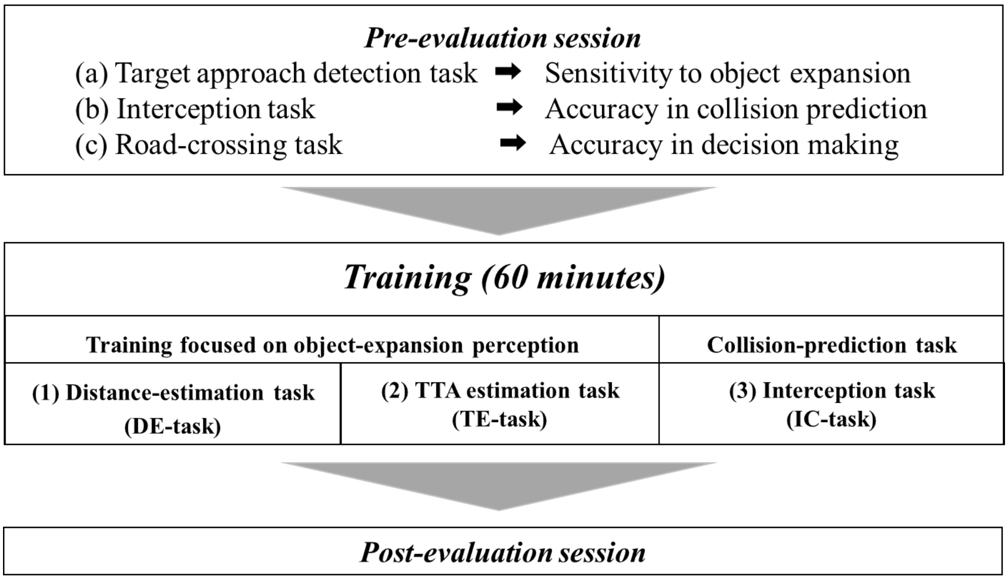

Figure 3-7. Experiment 2 Protocol: Comprising three phases - pre-evaluation session, 60-minute task, and post-evaluation session. Both pre- and post-evaluation sessions had the same content.

3.2.4. Data analyses

Participants' performances were evaluated using nine measures: the detection time in the target approach detection task, and the performance score, d' score, hit rate, false-alarm rate, criterion (c) and bias (β) in the interception task, and the correct-rate and miss-rate in the road-crossing task.

For the target approach detection task, the time between when the target started moving and when the participant pressed the button (i.e., detection time) was used as the dependent variable. The mean detection time was calculated over 12 trials.

For the interception task, the performance score and d' were calculated using the same method as in Experiment 1. To analyze the accuracy of participants' decisions in more detail, hit rate, false-alarm rate, criterion (c) and bias (β) were calculated based on signal-detection theory (Green and Swets, 1966). The hit rate is the proportion of trials where the signal was correctly identified as present (number of hits / number of signal-present trials), and the false-alarm rate is the proportion of trials where the signal was incorrectly identified as present when it was not (number of false alarms / number of signal-absent trials). The criterion quantifies the threshold for a participant to decide signal present, essentially a numerical representation of their subjective decision criterion. A lower value of criterion indicates a tendency to decide signal present on less evidence (i.e., prone to false alarms), whereas a higher value of criterion requires more evidence, making signal-present decisions less frequent (i.e., prone to misses). Bias indicates participant bias towards the signal. Specifically, it is the ratio of the hit rate to the false-alarm rate. If the bias is greater than 1, it suggests a tendency to avoid false-alarms and increase misses (conservative criterion), whereas a bias of less than 1 indicates a tendency to avoid misses and accept the risk of false alarms (liberal criterion). To adjust for extreme values, if the hit rate and false alarm rate were 0, they were set to 1/(2N), and rates of 1 were adjusted to 1 - 1/(2N), with N representing the number of signal or noise trials, respectively (Stanislaw & Todorov, 1999). The formulas for criterion (c) and bias (β) are as follows:

$$c = -1/2[Z(Hit\ \ rate) + Z(False - Alarm\ \ rate)]$$

$$\beta = \frac{\mathrm{Z(False - Alarm\ \ rate)}}{\mathrm{Z(Hit\ \ rate)}}$$

For the road-crossing task, the percentage of choosing a crossable gap (correct rate) and the percentage of crossable gaps missed (miss rate) were measured as dependent variables. The mean for each variable was calculated over 15 trials. For each dependent variable, a two-way (Session and Group) analysis of variance (ANOVA) with repeated measures on Session was performed. The effect size was calculated as a partial η^2 for each of the main and interaction effects. ANOVAs were conducted using SPSS software, with the significance level set at $p \leq .05$.

3.3. Results

Ten participants (72.8 ± 5.78 years, 5 females) were assigned to the IC-task group, 8 participants (73.3 ± 5.69 years, 4 females) to the DE-task group, and 10 participants (69.3 ± 3.91 years, 6 females) to the TE-task group. Although it appeared that the participants were younger in the TE-task group than in the other groups, the difference did not reach significance (F (2, 25) = 2.159, partial η^2 = .147, p = .136).

3.3.1. Detection time

Figure 3-8 shows the mean detection time in the target approach detection task in the pre- and post-evaluation sessions. Neither a main effect of Session (F (2,25) = 0.313, partial η^2 = .012, p = .058), Group (F (2, 25) = 0.512, partial η^2 = .791, p = .605), nor interaction was significant (F (2, 50) = 0.213, partial η^2 = .017, p = .810).

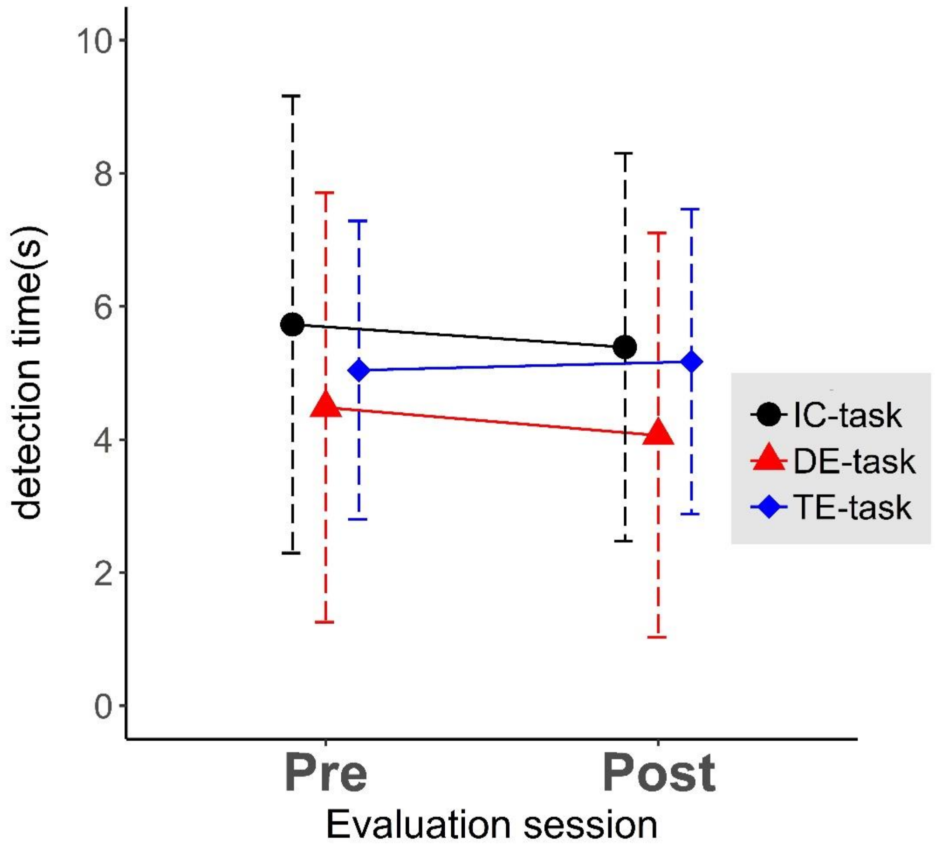

Figure 3-8. Mean detection time under each experimental condition, with the IC-task group represented by the black line, the DE-task group shown by the red line, and the TE-task group indicated by the blue line. Error bars indicate the standard deviation (SD).

3.3.2. Interception task

Performance score

Figure 3-9 shows the mean performance score in the interception task in the pre- and post-evaluation sessions. An ANOVA examining the effect of Session showed a main effect ($F\ (1, 25) = 12.527$, partial $\eta^2 = .334$, $p = .002$). Scores during the post-evaluation session were significantly higher than scores in the pre-evaluation session. The main effect of Group was not significant ($F(2, 25) = 0.149$, partial $\eta^2 = .012$, $p = .862$). No interactions were significant ($F(2, 50) = 1.312$, partial $\eta^2 = .095$, $p = .287$).

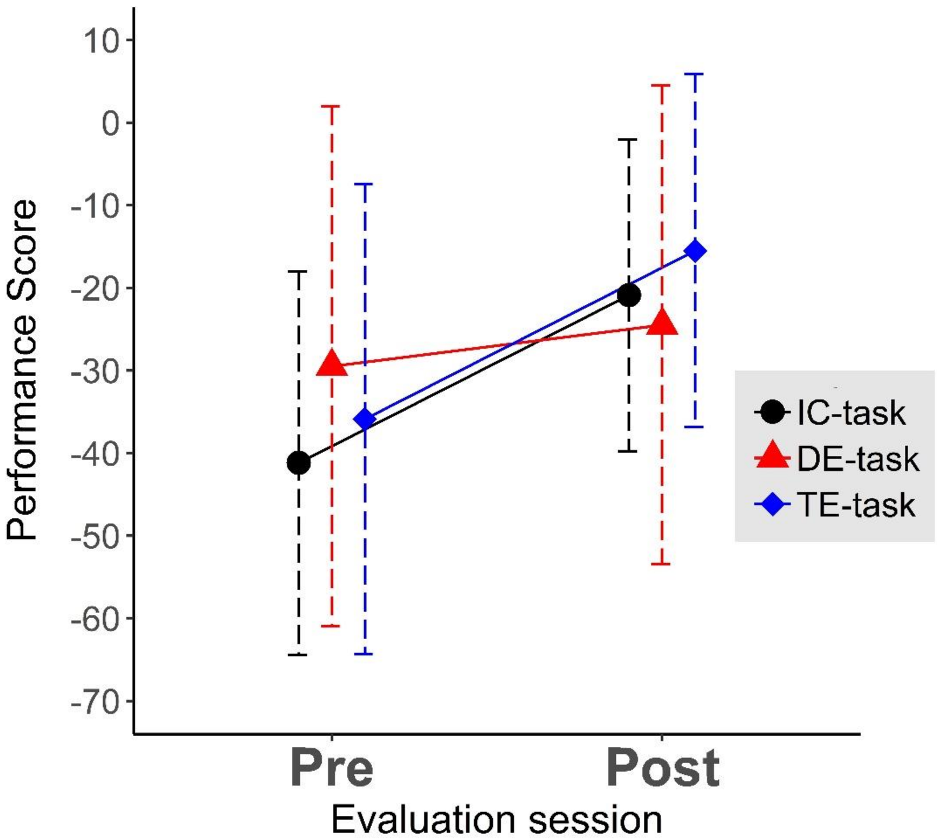

Figure 3-9. Mean performance score in each experimental condition

d' score

Figure 3-10 shows the mean d' score in the interception task during pre- and post-evaluation sessions. Neither a main effect of Session ($F(1, 25) = 3.692$, partial $\eta^2 = .129$, $p = .066$), Group ($F(2, 25) = 1.603$, partial $\eta^2 = .114$, $p = .221$), nor interaction was significant ($F(2, 50) = 2.053$, partial $\eta^2 = .014$, $p = .149$).

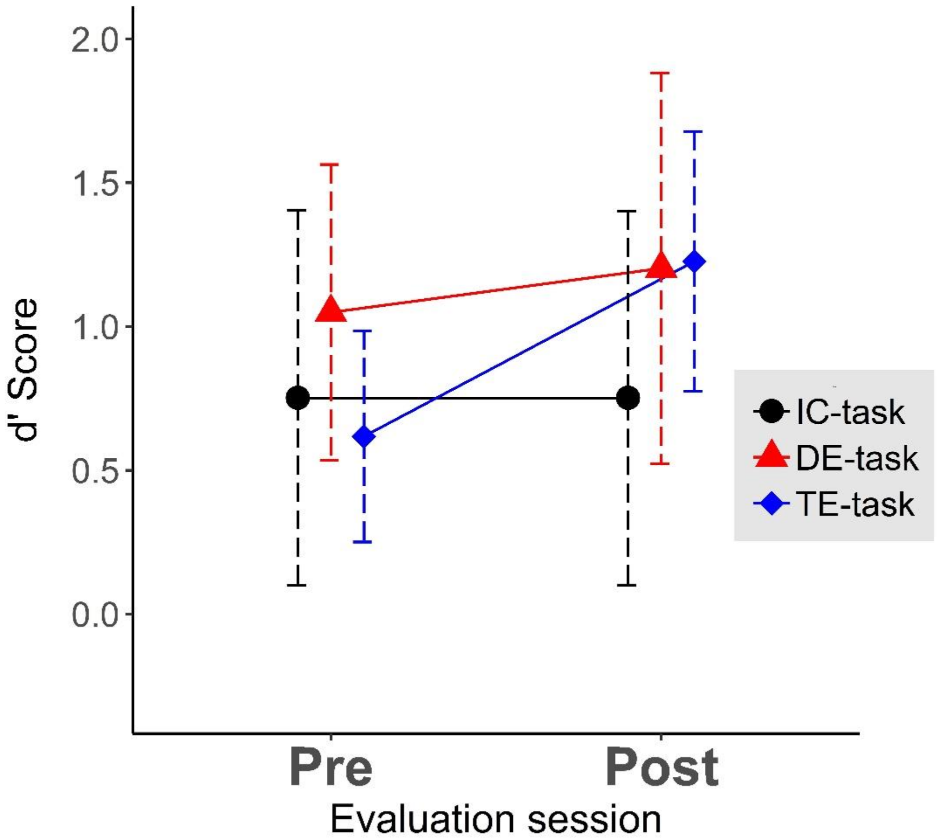

Figure 3-10. Mean d’ score in each experimental condition

Hit rate

Figure 3-11 shows the mean hit rate in the interception task during the pre- and post-evaluation sessions. Neither a main effect of Session ($F\ (1, 25) = 1.512$, partial $\eta^2 = .006$, $p = .230$), Group ($F\ (2, 25) = 0.887$, partial $\eta^2 = .009$, $p = .424$), nor interaction was significant ($F\ (2, 25) = 0.026$, partial $\eta^2 = .002$, $p = .974$).

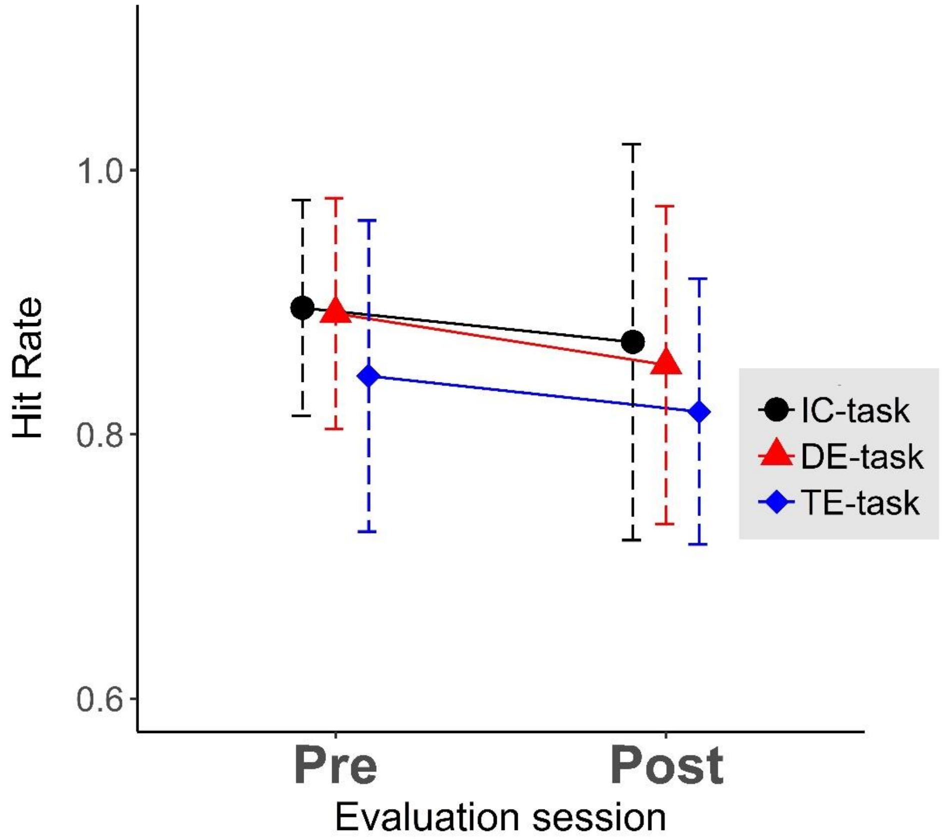

Figure 3-11. Mean hit rate in each experimental condition

False-alarm rate

Figure 3-12 shows the mean false-alarm rate in the interception task during the pre- and post-evaluation sessions. An ANOVA examining the effect of Session showed a main effect (F (1, 25) = 10.788, partial η^2 = .301, p = .003). The false-alarm rate in the post-evaluation session was significantly lower than the false-alarm rate in the pre-evaluation session. The main effect of Group was not significant (F (2, 25) = 2.913, partial η^2 = .189, p = .073).

The interaction between Session and Group was significant (F (2, 50) = 5.022, partial η^2 = .287, p = .015). Post hoc comparisons of the interactions showed that the simple main effect of Group was significant only in the post-evaluation session ($F(2, 25) = 6.390$, partial $\eta^2 = .338$, $p = .006$), where the false-alarm rate was significantly lower in the TE-task group than in the IC-task group.

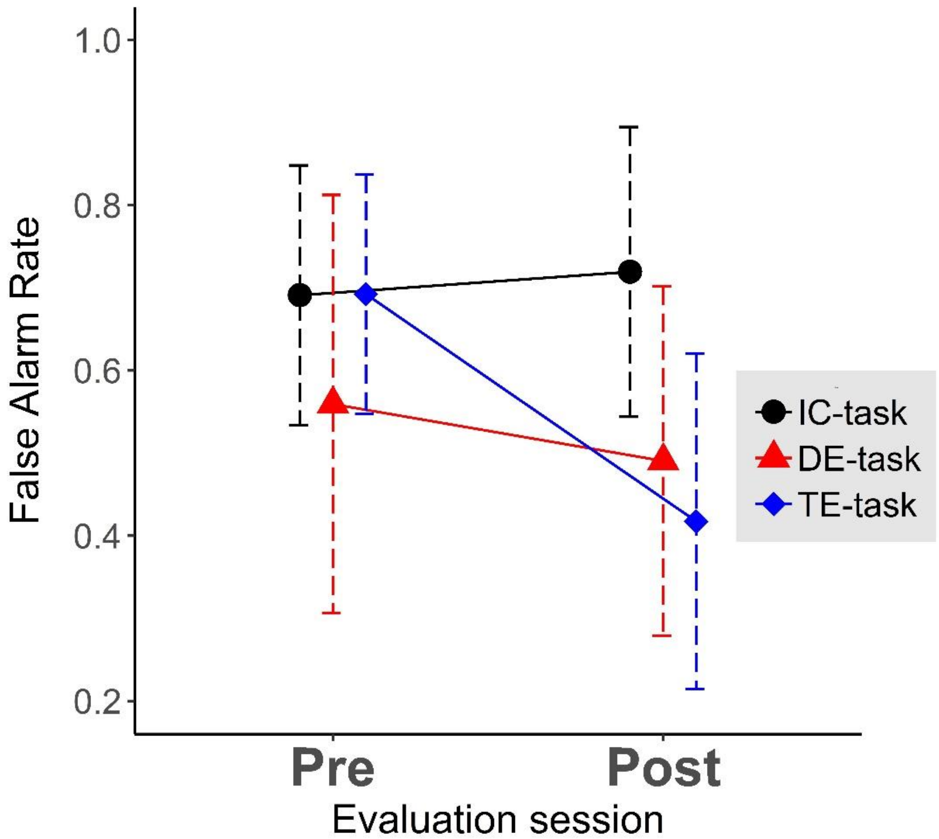

Figure. 3-12. Mean false-alarm rate in each experimental condition

Criterion (*c*)

Figure 3-13 shows the mean criterion in the interception task during the pre- and post-evaluation sessions. An ANOVA examining the effect of Session showed a main effect ($F(1, 25) = 7.112$, partial $\eta^2 = .221$, $p = .013$). The criterion during the post-evaluation session was significantly higher than the criterion during the pre-evaluation session. The main effect of Group was not significant ($F (2, 25) = 3.248$, partial $\eta^2 = .206$, $p = .056$). No interaction was significant ($F (2, 25) = 2.178$, partial $\eta^2 = .148$, $p = .134$).

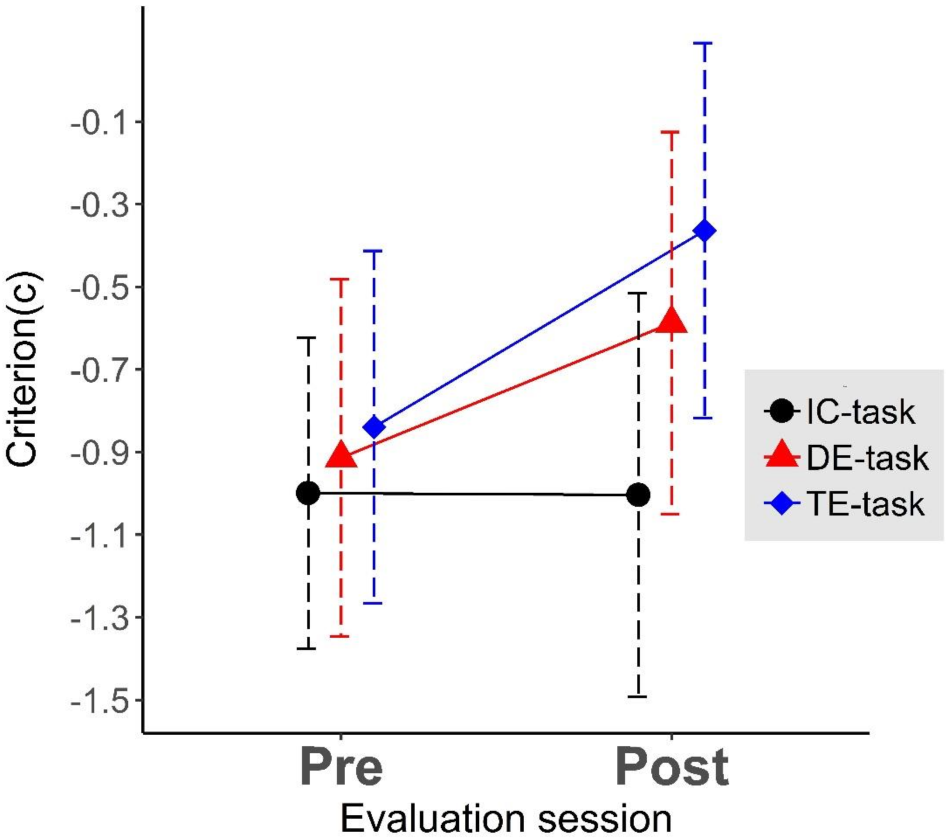

Figure 3-13. Mean criterion (c) in each experimental condition

Bias (*β*)

Figure 3-14 shows the mean bias in the interception task during the pre- and post-evaluation sessions. Neither a main effect of Session ($F (1, 25) = 0.060$, partial η^2 = .002, p = .808), Group (F (2, 25) = 1.006, partial η^2 = .075, p = .380), nor interaction was significant (F (2, 25) = 0.223, partial η^2 = .018, p = .801).

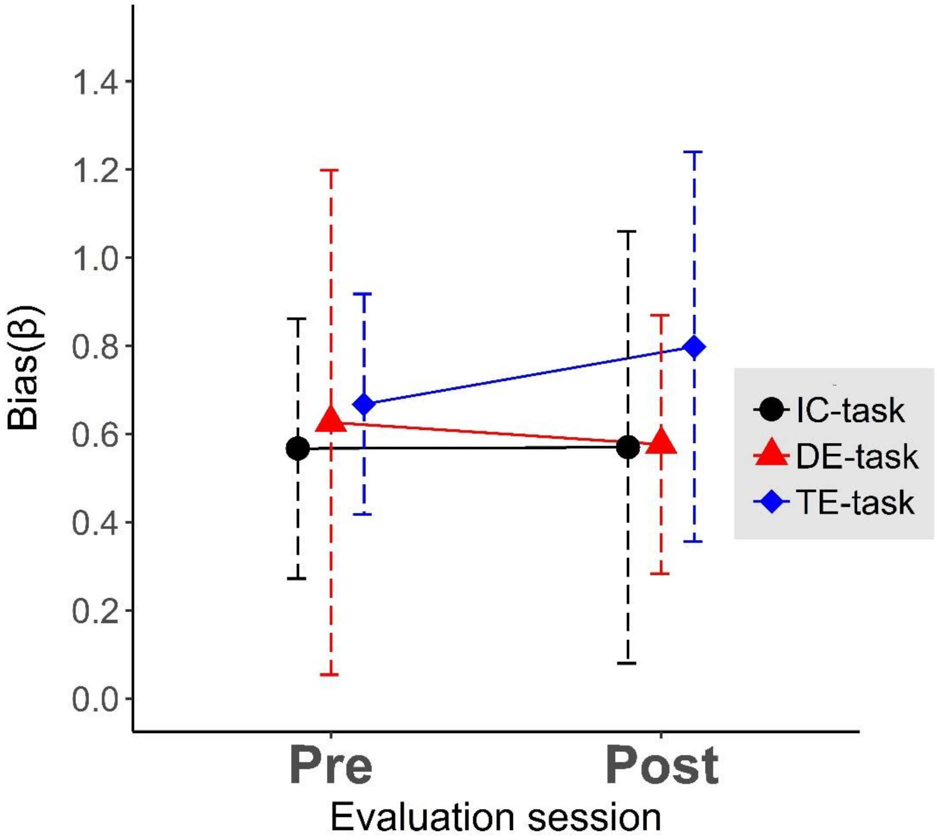

Figure 3-14. Mean bias (β) in each experimental condition

3.3.3. Road crossing task

Correct rate

Figure 3-15 shows the mean correct rate in the road-crossing task during pre- and post-evaluation sessions. Neither a main effect of Session (F (1, 25) = 0.427, partial η^2 = .017, p = .520), Group (F (2, 25) = 0.447, partial η^2 = .034, p

= .645), nor interaction was significant ($F_{(2, 25)}$ = 0.851, partial η^2 = .064, p = .439).

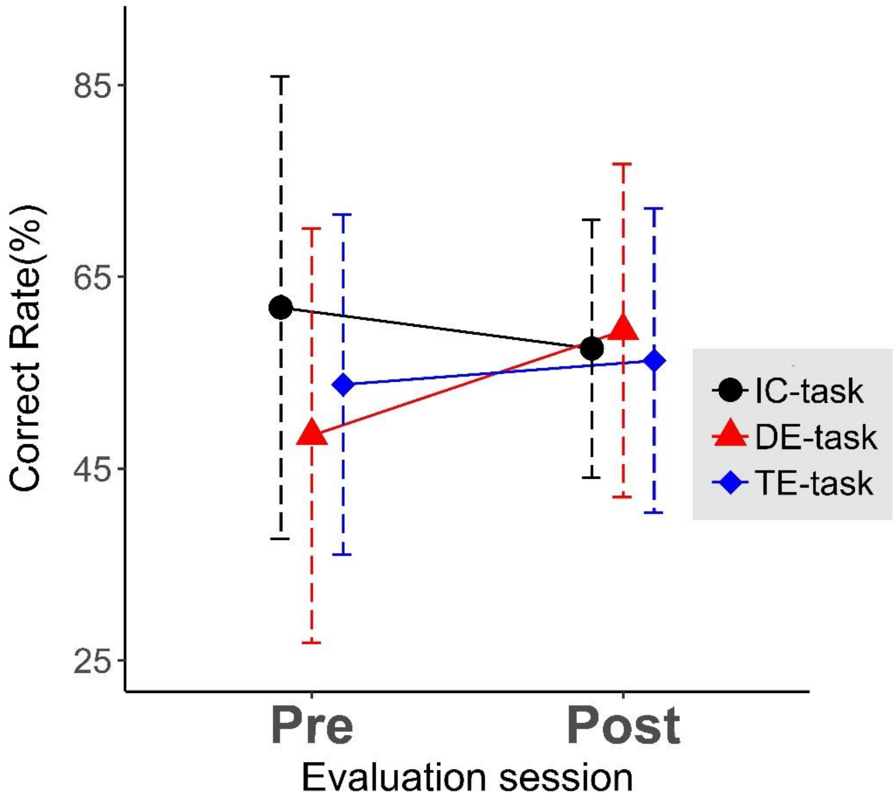

Figure 3-15. Mean correct rate in each experimental condition

Miss Rate

Figure 3-16 shows the mean miss rate in the road-crossing task during pre- and post-evaluation sessions. Neither a main effect of Session ($F_{(1, 25)}$ = 2.314, partial η^2 = .085, p = .141), Group ($F_{(2, 25)}$ = 2.938, partial η^2 = .190, p = .071), nor interaction was significant ($F_{(2, 25)}$ = 3.118, partial η^2 = .200, p = .062).

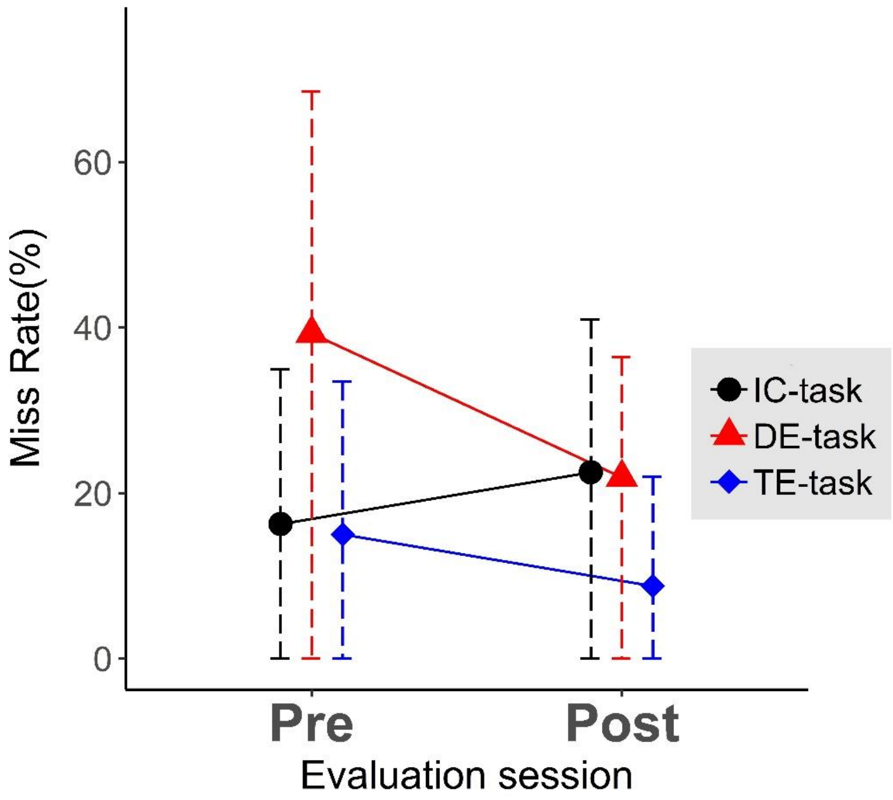

Figure 3-16. Mean miss rate in each experimental condition

3.4. Discussion

The purpose of Experiment 2 was to test the effectiveness of two original perceptual tasks—the distance-estimation task and the TTC-estimation task—to improve sensitivity to object expansion and, as a result, improve accuracy in predicting collisions. Both were designed to focus on the perception of object expansion. I evaluated the effectiveness using three evaluation tasks (see Figure 3-7): a target approach detection task, used for evaluating sensitivity to object expansion; an interception task, used for evaluating accuracy in collision prediction; and a road-crossing task, used for evaluating accuracy in decision making and transfer effect. The results are summarized as follows: No significant improvements in detection time or sensitivity to object expansion were observed in the target approach detection task. However, in the interception task, significant improvements in performance score and criterion were found. In the road-crossing task, neither correct rates nor miss rates showed significant improvements, indicating no perceptual task training effect or transfer of learning. Taken collectively, although the sensitivity to object expansion itself was not significantly improved in any of the three groups, participants in the TE-task group showed a significant improvement in the false-alarm rate, which indicates the accuracy in deciding whether to pursue a target. Furthermore, the false-alarm rate during the post-evaluation session was significantly lower (i.e., more accurate) in the TE-task group than in the IC-task group. These findings suggest that training to improve TTC estimation could lead to improved collision-prediction ability (see Figure 3-17 for the time-series changes in TTC estimation error during the TTC-estimation task).

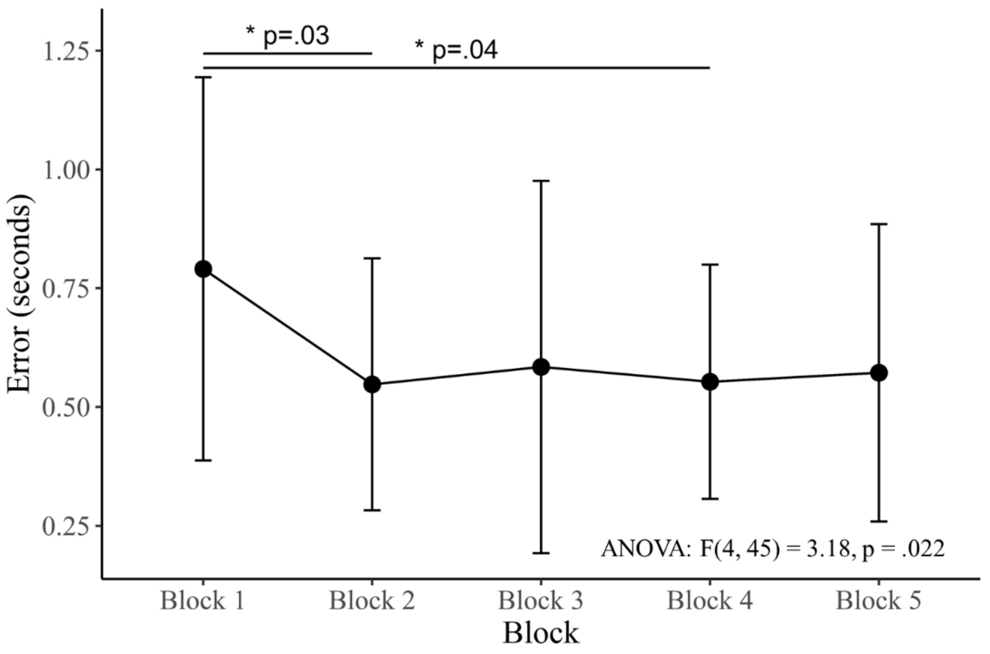

Figure 3-17. Mean TTC estimation errors for blocks 1 through 5. Error bars indicate standard deviations. Estimation errors were converted to absolute values.

Previous studies testing young adults showed that training in estimating the temporal aspect of object expansion (i.e., the TTC of an approaching object) improved the ability to predict collisions (Braly & DeLucia, 2020; Das et al., 2023). Consistently with these studies, the present finding showed that, even for older adults, training to improve TTC estimation could lead to improved collision-prediction ability. Several studies have shown the possibility of improving sensitivity, which declines with age, through perceptual training. DeLoss et al. (2015) showed that one week of perceptual training improved older adults' sensitivity to contrast and visibility at close distances. Furthermore, Andersen et al. (2010) examined the effects of a texture discrimination task in the peripheral visual field and a letter-discrimination task in the central vision on both older and younger adults. They found that visual performance improved after just two days of training. Moreover, the improvement was maintained in both groups for at least three months (Andersen et al., 2010). The findings in Experiment 2 expand these previous findings and show that age-related decline in perceiving visual information necessary for predicting collisions with objects can be improved through repetitive experiences of perceiving relevant visual information.

I hypothesized that enhancing sensitivity to object expansion would help improve collision-prediction ability in older adults. However, for the TE-task group, which showed significant improvement in the false-alarm rate in the interception task (i.e., improved accuracy in deciding whether to pursue a target), no significant improvement in sensitivity to the rate of expansion of moving objects was found in the target approach detection task. Part of the reason for the failure to improve sensitivity to object expansion could be the relatively short period of training. In my study, the length of training period was set at 60 minutes. I had expected that this length could be sufficient for improvement, given that DeLoss et al. (2015), who used a collision-detection task similar to the present study and conducted one week of perceptual training, reported seeing improvement even after a single 60-minute training session. Jeter et al. (2010) also found that perceptual learning progresses rapidly in the initial stages (Jeter et al., 2010), suggesting the possibility of an immediate effect from the 60-minute perceptual task in this study. However, Dosher & Lu (1998) suggested that several days to weeks might be required to achieve learning effects (Dosher & Lu, 1998), and many previous studies demonstrating effectiveness have conducted training over longer durations (Table 3-1). Therefore, it could be considered that the 60-minute perceptual task in this study was not sufficient to improve sensitivity to the object expansion itself.

Table 3-1. Tasks and training frequencies used in previous studies examining the effects of perceptual training

Authors	Subjects	Tasks	Frequency and duration of task
Braly & DeLucia, 2020	YA	Orientation-discrimination task	One session (5 minutes)
Tan et al., 2019	YA	Texture-discrimination task	5 days (40–50 minutes each day)
Yotsumoto et al., 2008	YA	Visual texture-discrimination task	14 days (1520 trials per session)
Pourtois et al., 2008	YA	Multiple object-tracking task	1260 trials (approximately 90 minutes total)
Legault et al., 2013	YA&OA	Orientation-discrimination task	5 days (60 minutes per session)
DeLoss, Watanabe, & Andersen, 2015	YA&OA	Gabor stimulus perception discrimination task	7 days (1.5 hours per day)
Mishra et al., 2015	OA	Motion-discrimination task	10 hours total (over 3–5 weeks, 40 minutes per session)
Bower et al., 2013	YA&OA	Motion-discrimination task	3 days (900 trials per day)
Shibata et al., 2011	YA	Orientation-discrimination task	10 days (1 hour per day)
Jehee et al., 2012	YA	Orientation-discrimination task	20 or more days (1 hour per day)
Li et al., 2017	YA&OA	Texture-discrimination task	3 days
Kang et al., 2018	YA	Motion-discrimination task	14 sessions over 3–4 weeks (840 trials)
Appelbaum et al., 2011	YA	Stroboscopic training	1 and 5 hours
Smith & Mitroff, 2012	YA	Direction discrimination	5–7 minutes (five blocks of 10 training trials)
DeLoss et al., 2014	OA	Collision-detection task	7 sessions (1.5 hours per session)
DeLoss et al., 2015	YA	Motion-discrimination task	7 sessions (1 hour per session)
Zhang & Yang, 2014	YA	Texture-discrimination task and letter-discrimination task	1 session (1.5 hours)
Andersen et al., 2010	OA	Identifying the direction of motion of sine-wave gratings task	2 days

Bower & Andersen, 2012	YA&OA	Texture-discrimination task	6 days (6 blocks per day)
Yotsumoto et al., 2014	YA&OA	Orientation-discrimination, curvature-discrimination, and global-form tasks	3 days (approximately 45 minutes per session)
McGovern et al., 2012	YA	Orientation-discrimination task	10 days

Note: YA—younger adults; OA—older adults

The improved ability to predict collisions (i.e., improved false-alarm rate), in spite of no improvement in sensitivity to the rate of expansion of a moving object, could be attributed to enhanced decision-making processes throughout the training using the TTC-estimation task. Previous studies have shown that perceptual training improves not only perceptual functions but also decision-making processes (Diaz et al., 2017; Sasaki et al., 2010). For instance, visual-categorization task training has been reported to enhance brain activities related to decision making more than those related to perceptual processes. Additionally, perceptual training can lead to a reduction in decision-making biases, such as preconceptions biased toward specific outcomes or tendencies influenced by participants' experiences or prior knowledge. Jones et al. (2015) demonstrated a strong correlation between performance improvement in perceptual tasks and reduction in bias, suggesting that this decrease in bias is a significant component of perceptual learning. Similarly, in this study, a significant main effect was observed in the criterion of the interception task, indicating that participants became more conservative in their decision making, reflecting a decrease in bias toward making a "Go" response in the absence of strong evidence. Considering these findings, the ability to predict collisions might have been improved not due to the improved sensitivity to object expansion but due to improved decision-making processes.

No task groups showed improved performance in the road-crossing task, indicating an absence of transfer of the learning effect to more realistic situations. This seems to be consistent with previous studies showing that learning transfer can be limited when the training context does not closely mirror the target scenario (Barnett & Ceci, 2002). Their study emphasized that task-specific training and context are crucial for skill transfer, indicating that improving a particular cognitive or perceptual skill does not necessarily translate to more complex or different tasks. Future studies need to address whether modifying the perceptual task to match the specific situations aimed to improve, such as making road-crossing decisions and predicting collisions in dynamic environments would be effective for the transfer of the learning effects.

3.5. Limitations

Experiment 2 has several limitations. First, the designs of the DE-task and the TE-task differed based on whether the participant moved (DE-task) or the target approached (TE-task). In the TE-task, the repetitive observation of the target's approach may have improved sensitivity to the target's initial movement. The false-alarm rate evaluated in the interception task serves as an indicator of decision accuracy, especially during the target's initial movement (in the first second of observation time). Therefore, the possibility that design differences between the perceptual tasks may have influenced the results cannot be ruled out.

Another limitation was the difficulty in manipulating the joystick. Although I newly adopted use of the joystick for easier manipulation than in Experiment 1 (see the section 3.2.2. apparatus and task), a few participants still reported difficulty in manipulating the joystick as intended. While there was a significant learning effect on the performance score, participants' manual dexterity could have influenced the results. Implementing measures to reduce the impact of the precision required to operate the controller, such as fixing participants' movement paths, might be an effective solution.

Chapter 4. General Discussion

Through two experiments, I aimed to identify the optical variables used in collision prediction that are particularly vulnerable to aging and to develop an effective perceptual task for older adults. The results showed that impaired collision-prediction ability in older adults was attributed to reduced sensitivity to object expansion (Experiment 1); a newly developed perceptual task, called the TTC-estimation task, in which participants estimated a time to collide with an approaching target on the basis of the object expansion, was shown to improve collision-prediction ability (Experiment 2).

The purpose of Experiment 1 was to examine the effect of aging on sensitivity to three optical variables including an affordance-based model (Fajen, 2013). These optical variables were (a) vertical and (b) horizontal expansions of a moving object, and (c) the bearing angle produced between participants and a moving object. The results revealed that while sensitivity to the bearing angle was maintained in older adults, sensitivity to object expansion tended to decline with age. According to Evans et al. (2020), the ability to detect lateral movement of objects was less affected by aging. Additionally, de Dieuleveult et al. (2017) indicated that brain regions activated during the perception of approaching objects are likely to deteriorate functionally with age. These findings suggest that mitigating the age-related decline in sensitivity to the expansion rate of a moving object is crucial for enhancing the ability to predict collisions in older adults.

Based on the findings of Experiment 1, Experiment 2 aimed to develop a perceptual task designed to improve sensitivity to object expansion and to examine its effectiveness in enhancing collision-prediction ability. The results showed that, although no significant improvement in sensitivity to object expansion itself was found, significant improvement in the ability to predict collisions was found. This indicates that the improved ability to predict collisions may have been due to other factors, such as improved decision-making strategies and/or reduced bias in decision-making processes. Taken collectively, the immediate effect of the TTC-estimation task is likely to be beneficial for older adults.

A potential application of the present findings is to the development of traffic accident prevention for older adults. Experiment 1 revealed the need for older adults to improve their sensitivity to the expansion rate of a moving object, and Experiment 2 led to the development of an effective perceptual task for the ability to predict collisions with moving objects. The interception task used in this study and the newly developed perceptual task may be useful, leading to improved collision-prediction ability while minimizing physical demands. The interception task can serve as an evaluation tool to identify older adults at high risk of collisions. Additionally, the application of the perceptual task developed in this study could potentially reduce their collision risks. This approach could be especially beneficial for older adults apprehensive about moving in areas with high risks of collisions involving pedestrians and vehicles and for hospital patients nearing discharge. The findings of this study can contribute to traffic accident prevention countermeasures in local communities.

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