Effectiveness of Inducing the Sense of Body Ownership over Un-humanoid Avatar for Flying Tele-Existence

(飛行型テレイグジスタンスにおける非ヒト型アバターへの身体所有感生起の有効性に関する研究)

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Abstract

A drone is a useful device for various domains, such as rescue operations and disaster investigation. Users can interact with a distal environment by transmitting sensory information from a drone. However, as manipulating a drone is complicated, extensive time and training are required to master the manner to fly it. Previous research works reported the use of a natural user interface, stereoscopic camera for improving the sense of depth, and sensory feedback system for obstacle avoidance. In contrast, they have not argued about cognitive functions for driving a typical vehicle. Specifically, their system lacks support system for the sense of the size of a vehicle and emotional control, which are cognitive functions in driving a vehicle.

Thus, we aim to develop a support system for these cognitive functions using IVBO over a non-humanoid avatar. In VR psychology, a user can feel an avatar as their own body. It is referred to as Illusion of Virtual Body Ownership (IVBO). Previous works have reported that IVBO can lead to modify spatial awareness and a peripersonal space, in which works as a defensive mechanism. Furthermore, previous works has also reported that an avatar appearance affects user's behavior and attitude. It is referred to as the proteus effect. Impressions and preconceptions to an avatar cause the proteus effect. We propose that inducing IVBO over a non-humanoid avatar that has a flight ability (e.g., a dragon avatar and a bird avatar) simultaneously resolve above issues.

We conducted three experiments. First, we investigate conditions of inducing IVBO over a non-humanoid avatar, because their body construction Cleary differ from a physical body. As results, IVBO can be induced even in a bird avatar by synchronizing a motion. Next, we investigate how an avatar appearance affects task performance for spatial awareness. Participants are instructed to aim for the destination while passing through rings that are located in virtual environments. As results, a dragon avatar significantly improves task performance in comparison to a drone condition. Finally, we investigate how the proteus effect of a dragon avatar affects the fear of heights. In this experiment, participants are instructed to manipulate an avatar, and they are exposed to various altitudes. As results, a dragon avatar can significantly reduce the fear of heights in comparison to a human avatar. Taken together, our results show the effective of IVBO over a non-humanoid avatar. Especially, a dragon avatar is proper for a flight experience.

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Abstract

1. Introduction

A drone is a useful device for various domains, such as rescue operations, disaster investigation, and infrastructure maintenance, transportation and aerial sports. The demand for a drone is increased upon reduction in their prices. The Ministry of Economy, Trade, and Industry referred to drones as the aerial industrial revolution [1]. In addition, it mentioned that it was important to develop a support system beyond the visual line of sight.

In recent years, the emergence of flight tele-existence has enabled drone manipulation beyond the visual line of sight. Using the technology named tele-existence [2], users can interact with a distal environment by transmitting sensory information from a robot while being within the robot. The traditional tele-existence uses a humanoid robot. However, recent studies used a tele-existence robot in the form of a drone [3,13]; this particular technology referred to as flight tele-existence [3]. Using the flight function of drone, this technology can enhance our physical ability to travel into aerial space where we cannot work directly (to perform rescue operations, disaster investigation, and infrastructure maintenance), thereby creating an experience that cannot be realized otherwise.

However, as manipulating a drone is complicated, extensive time and training are required to master the manner to fly it. Further mastery is required when drone operators have to manipulate a drone while performing complex tasks. In recent years, as depicted in Fig.1, many accidents have been a result of human errors [4]. Therefore, we must develop a support system for improving or enhancing the manipulation skills of drone operators.

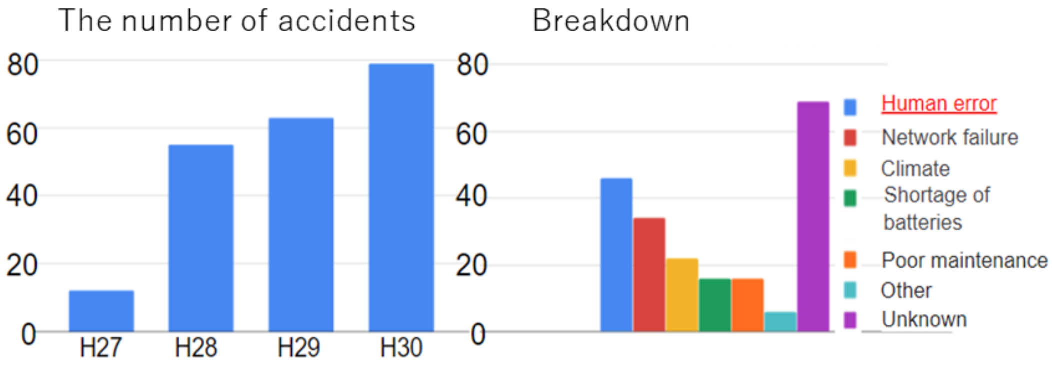


Fig.1 The number of accidents and the breakdown of a cause of accidents

Particularly, previous works have developed support systems for improving both operability and obstacle avoidance. Previous research works reported the use of a natural user interface (NUI) [5-12], stereoscopic camera for improving the sense of depth [13], and sensory feedback system [14-16] for obstacle avoidance. NUI uses anthropomorphic features such as gestures, gaze, and brain-like machine interface [6,7,8], to build an intuitive manipulation method. A previously conducted study obtained the sense of depth by using a stereoscopic camera [13], while another one reported the use of a sensory feedback system that provided operators with sensory information via devices when approaching obstacles [14]. Using this alerting system, drone operators could decide the extent up to which they should approach obstacles.

Although some differences exist between manipulating a drone and driving a typical vehicle, to the best of our knowledge, previous studies have not discussed cognitive functions for driving a typical vehicle. Michon et al. proposed a hierarchical structure that comprised three cognitive processes for driving a vehicle (see Fig. 2) [17]. First, the strategical level represented a cognitive level for a driving plan, e.g., where, what, when should we depart to arrive the destination while considering the effects of weather and congestion. Second, the tactical level represented a cognitive process to consider safety while coping with situations that changed every moment, e.g., adjustments of speed and distance between other vehicles and obstacles. Third, the operational

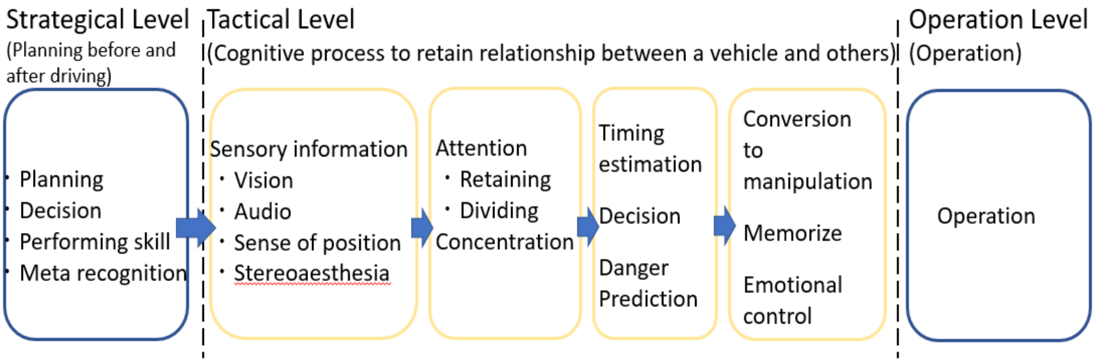


Fig.2 Cognitive processes for driving vehicles [17, 18]

level represented a cognitive process to convert the required motor command to manipulation, e.g., manipulation skills such as brake, and accelerator handling). We show specific cognitive functions that correspond to the aforementioned three cognitive processes in Table 1. Accordingly, both a haptic feedback system and stereoscopic camera correspond to the sensory information, such as visual, audio, sense of a position, and stereoaesthesia, at the tactical level because these systems explicitly provide information. NUI systems correspond to the operational level because they aim to develop an intuitive controller.

However, to control the relationship between a vehicle that users drive and environments, no systems exist to support some cognitive processes, such as attentional functions (retaining and dividing attention), concentration, decision-making, danger prediction, estimation of timing and positional relationship, conversion to manipulation, and emotional control, at the tactical level, except for the sensory information depicted in Fig. 2. Therefore, we aim to develop a manipulation system to support these cognitive functions. In addition, based on previous support systems, we expect that a support system for drone manipulation will cover all the cognitive functions required for driving a typical vehicle.

Table.1 Conceptual model of driver behavior and the corresponding cognitive abilities [17,18]

The strategical level	The cognitive process of driving planning and changing planning before and while driving	Selection of the optimal destination, path and time, and danger avoidance and prediction	Execution functions (planning and execution), and recognition of self-abilities
The tactical level	The cognitive process of controlling the relationship between a vehicle and the surrounding while driving	Maintaining a distance between a vehicle and obstacles, thereby requiring speed control and obstacle avoidance	Attention function, execution function, visual-search ability, visuospatial cognition function, visual motor conversion ability, information-processing speed, emotion control
The operational level	The cognitive process of manipulating a vehicle while driving	Manipulating a vehicle while maintaining a certain speed and controlling an acceleration and brake.	Attention function, kinesthetic function, operation knowledge, visual - motor conversion ability

Subsequently, we defined a system to support these cognitive functions. As shown in Table 1, timing estimation, visuospatial cognition, visual-scanning ability, working memory, attention functions (retaining and dividing attention), danger prediction, performing skill, conversion from the required motor command to manipulation and emotional control corresponded to this process as definite cognitive functions. First, we divided the required cognitive functions into the sense of the size of a vehicle and emotional control.

A driver can adaptively interact with environments while driving by implicitly and introspectively understanding the size of a vehicle and the positional relationship between the vehicle and other vehicles, i.e., understanding the positional relationship between the vehicle, other vehicles, and obstacles, and moving the vehicle to another side or parking while avoiding obstacles. Therefore, we can exert some cognitive functions, such as danger prediction, attention functions, visuospatial ability, and timing estimation, using this innate ability. However, in the case of previous works, one involving a haptic feedback system and another a stereoscopic camera system, user feed-back actions were based on the information provided, as these systems explicitly provide sensory information [13,14]. In contrast, the sense of the size of a vehicle is a body scheme to interact with environments. Therefore, we must develop a support system to exert this innate ability. For convenience, in this study, we refer to these comprehensive innate abilities, which include the required cognitive functions (i.e., timing estimation, visuo-spatial cognition, visual-scanning ability, working memory, attention functions (retaining and dividing attention), danger prediction, and performing skill) as the sense of the size of a vehicle. Particularly, we define the sense of the size of a vehicle as an innate ability to implicitly and introspectively interact with the environment. The aforementioned innate ability can be explained on the basis of peripersonal space (PPS). Notably, the human body region includes not only the body part but also the space extended by specific body parts, trunk, hands, and head. In cognitive neuroscience, this space is regarded as a body region and is referred to as PPS [45]. In this space, our brain specifically processes sensory information to interact with environments (see Fig. 3). Therefore, it is argued that PPS supports defensive mechanisms such as danger prediction.

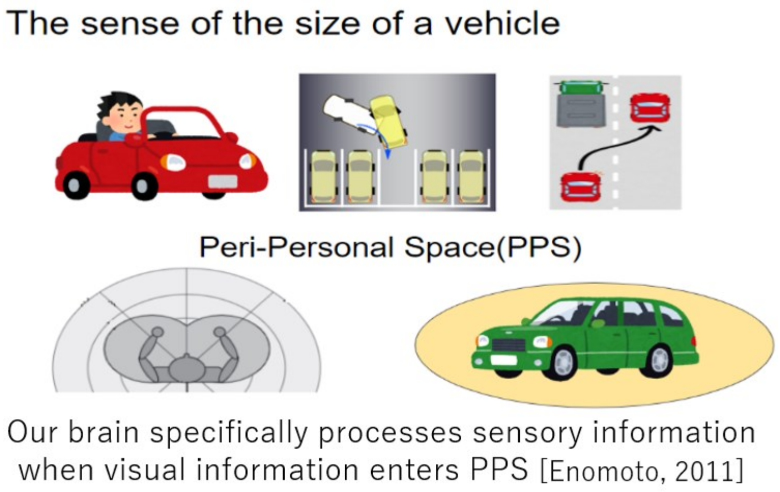


Fig.3 Sense of size of a vehicle explainable via PPS

It is assumed that the sense of the size of a vehicle extends PPS toward the vehicle. Therefore, it is closely related to some required cognitive functions such as timing estimation, visuospatial recognition, visual-scanning ability, working memory, attention functions (retaining and dividing attention), danger prediction, performing skill, and conversion required manipulation into motor command. Specifically, we use the evaluation method defined by Bowman et al. as a design guideline for sensing the size of a vehicle [19]. They defined quality factors of locomotion in virtual environments as given in the following. As shown by these factors, these items are similar with the required cognitive functions.

1. Speed (appropriate velocity)

2. Accuracy (proximity to the desired target)

3. Spatial Awareness (the knowledge of a user regarding his/her position and orientation within the environments, both during and after travel)

4. Ease of Learning (the ability of a novice user to use a technique)

5. Information Gathering (the user ability to actively obtain information from the environment while traveling)

7. Presence (the "sense of immersion" of the user or his/her feeling of "being within" the environment while traveling)

8. User comfort (lack of simulator sickness, dizziness, or nausea)

Emotional control is a cognitive function that controls the emotion while driving, to ensure safe driving. A flight tele-existence operator must travel heights that pose risks even in a virtual environment. However, the operator might suffer from the fear of heights. A previously conducted work reported that the fear of heights distorted the sense of distance [62]. Therefore, we must prevent accidents due to distorted cognition and perform sober judgment. Accordingly, a support system for enabling emotional control is to reduce the fear of heights. We consider emotional control as a required factor that is different from the sense of the size of a vehicle, as it is a cognitive function that controls the emotion while driving a vehicle.

We summarize these factors as the required components for our support system, as depicted in Fig. 4. Upon achieving both the above-mentioned factors, it can be expected that a support system that considers cognitive functions on the hierarchical structure is completed. Based on the above-mentioned research work, we propose a research map that considers cognitive processes (see Fig.5).

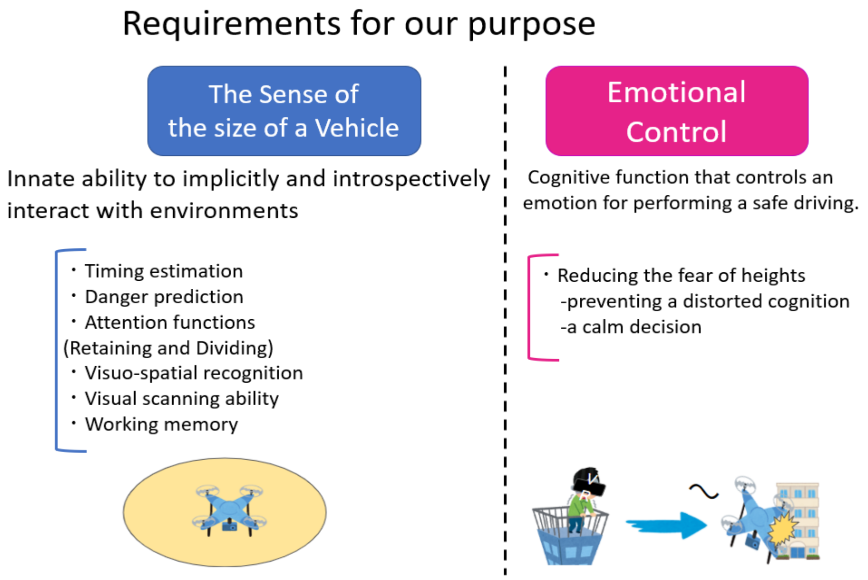


Fig. 4. Required components for our proposal system

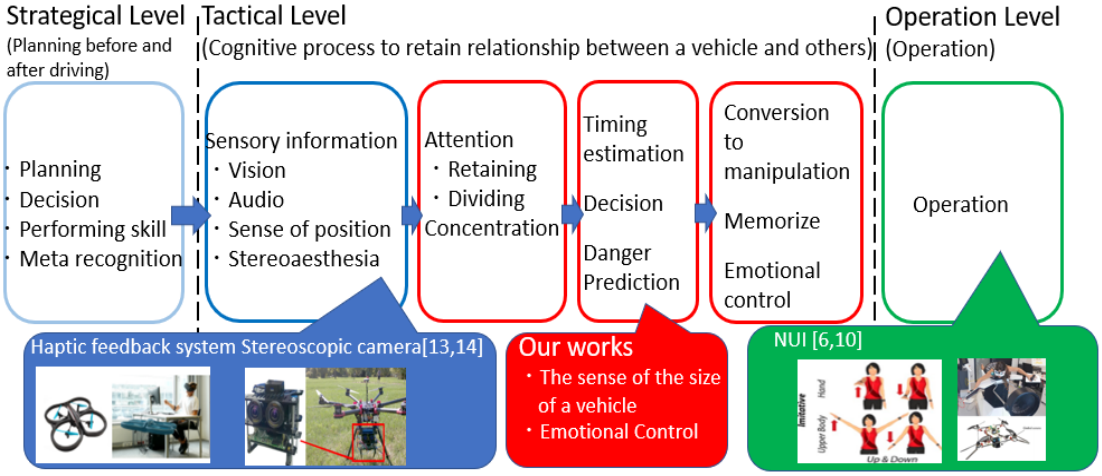
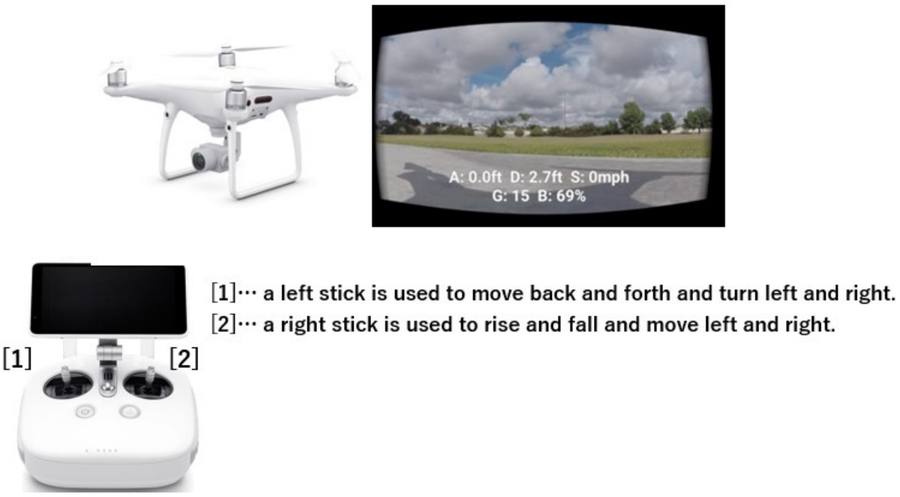


Fig.5 Overview of the research map for improving manipulation skills

Drone manipulation requires three-dimensional manipulation, and it does not have sufficient sensory fidelity because of visual latency and narrow field of view (see Fig.6). In addition, operators cannot see the entire body of the drone while they manipulate it. Furthermore, operator's physical body are diminished when they put on a head mounted display. Therefore, compared with typical-vehicle drivers, drone operators might rely on visual feedback instead of the sense of the size of a vehicle. It is assumed that it is difficult to construct the sense of the size of a vehicle in the case of a typical drone system.



[1]··· a left stick is used to move back and forth and turn left and right.
[2]··· a right stick is used to rise and fall and move left and right.

Fig 6. Perspective from a drone and drone manipulation method

Our ultimate goal is to obtain the sense of the size of a vehicle on a drone to interact with environments (e.g., entering to a narrow space, danger prediction, and obstacle avoidance) autonomically and unconsciously. In this study, we point out the importance of the sense of body ownership to obtain this sensation in the case of drone manipulation. The process of building the physicality such as the sense of the size of a vehicle is similar to the sense of body ownership. Body ownership refers to a feeling of perceiving an object as our own body [20]. Typically, we cannot recognize another physical body as our own body. However, previous studies in VR psychology and neuro-cognitive psychology reported that the sense of body ownership could be transferred to another body by simultaneously presenting multisensory information, e.g., visuo-tactile stimulation and visuo-motor information [21]. For example, a user can feel the sense of body ownership with a virtual body when his/her movements are synchronized with those of the virtual body (an avatar). This phenomenon is referred to as the illusion of virtual body ownership (IVBO) [24]. Upon interacting with VR devices, our physical bodies are diminished. However, previous works reported that the presence of an avatar influenced the sense of both distance and size around us [37, 51]. It has been reported that the sense of distance depends on the presence or absence of body ownership [44, 45]. Furthermore, previous works reported that PPS, which supports defensive mechanisms, can be modified depending on avatar properties such as size, shape, and position [25, 49]. Therefore, IVBO might be effective for obtaining the sense of the size of a vehicle.

A disadvantage of the sense of body ownership is fear of heights caused by enhancing the sense of presence over the flight experience. In contrast, IVBO can also resolve the fear of heights. IVBO can even be induced for avatars that are clearly different from our own physical bodies. Therefore, other previous IVBO-based studies also reported the manner in which IVBO affected our attitude and behavior. For example, IVBO on a robot avatar can improve acrophobia [56]. The psychological phenomenon caused by the visual and behavioral characteristics of an avatar is referred to as the Proteus-Effect [52], which might improve emotional control while maintaining the sense of body ownership. Preconceptions and impressions of avatars influence human attitudes. We have a preconceived notion or impression that dragons have strong bodies and the ability to fly. The sense of fear arises from the anxiety of falling, and we aim to remove it using a dragon avatar. Therefore, IVBO might simultaneously resolve both the sense of the size of a vehicle and the fear of heights. Therefore, we aim to develop an IVBO- based support system to obtain the sense of the size of a vehicle and improve emotional control. In addition, we aim to investigate the effectiveness of inducing IVBO for flight tele-existence.

In Chapter 2, we summarize the contributions of this study by describing research related to support systems. In addition, we also describe IVBO to utilize this for the sense of the size of a vehicle and emotional control. In Chapter 3, we summarize the points that this study reveals by considering the related studies in Chapter 2, and we also summarize the experiments that should be performed for this purpose. In Chapters 4–6, we conduct the experiment described in Chapter 3. In Chapter 7, we discuss the results from Chapters 4–6. In Chapters 8–10, we conclude the findings of this study.

In recent years, artificial intelligence has been utilized to automate many functions that are manually performed by operators. However, a human operator is required to collect data sets for AI or perform complex manipulation. Additionally, as previously mentioned, it is considered that it can be used to augment the human ability.

In this study, we did not discuss the sense of agency that is considered in the domain of an avatar. The sense of agency refers to a feeling of an action being triggered by self. Typically, both the sense of agency and sense of body ownership can be simultaneously induced via visuo-motor synchronization. We applied motion synchronization in all the conditions. Namely, it was assumed that the sense of agency was induced in all the conditions. Therefore, only the sense of body ownership and avatar appearance affected the experimental results.

2. Related works

2.1. Support systems for manipulating a drone

In this chapter, we explain previous studies in terms of a support system for manipulating a drone. In previous studies, a general drone manipulation system has used proportional control with a radio controller. However, it is difficult to manipulate a drone immediately because it requires practice on how to fly. Meanwhile, previous studies have developed NUI systems using anthropomorphic features such as gesture, gaze direction, and brain-machine interface to build an intuitive manipulation system. NUI does not require extensive practice because of the intuitive manipulation method. Sanna et al. developed a manipulation system that users can manipulate by using specific gestures with Microsoft Kinect, which uses a depth sensor camera [5]. Furthermore, Peshkova et al. have proposed proper flying gestures based on a mental model to manipulate a drone (See Fig. 7) [6]. Other studies have developed a gaze direction system and a brain-machine

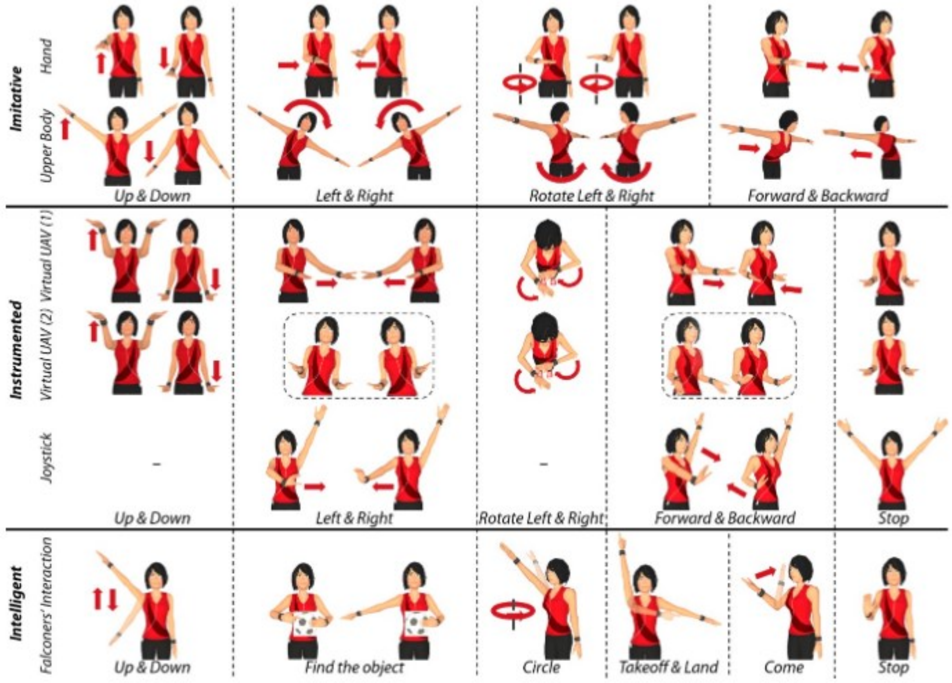


Fig.7 Natural User Interface using gestures [6]

interface to move directly into a place where users want to go. Yu et al. have developed the manipulation system using gaze direction for a drone [7]. Akce et al. developed a controller based on electroencephalographic (EEG) signals [8], in which the user has to think left or right to turn the plane into the simulation. Furthermore, gaze gesture, in combination with EEG signals, has also been used in drones [9].

Additionally, recent studies have developed individual devices based on a flight experience. Un-humanoid robots (i.e., a robot that does not have human-like body construction, such as a drone) manipulation cannot apply human body movement. Therefore, previous studies have been aiming to develop a natural and intuitive system for humans using those devices. Cherpillod et al. have used the flight simulation device "birdly" in which users take prone postures like a bird and control a drone using paddles (See Fig. 8) [10]. It is possible to adapt user body construction to a drone construction. They referred to this as "embodied interaction" that allows users to obtain physical transformation of a human into a sensory-motor system (robot) with different morphology and behavior. Rognon et al. have developed a "fly jacket" that allows users to move in the direction in which they lean with an exoskeleton device [11]. Furthermore, another study has reported "the embodied interaction" based system with parts of the body, and not only using the entire body. Suárez et al. have developed a manipulation system that applies the user's hand to three-dimensional drone movements [12].

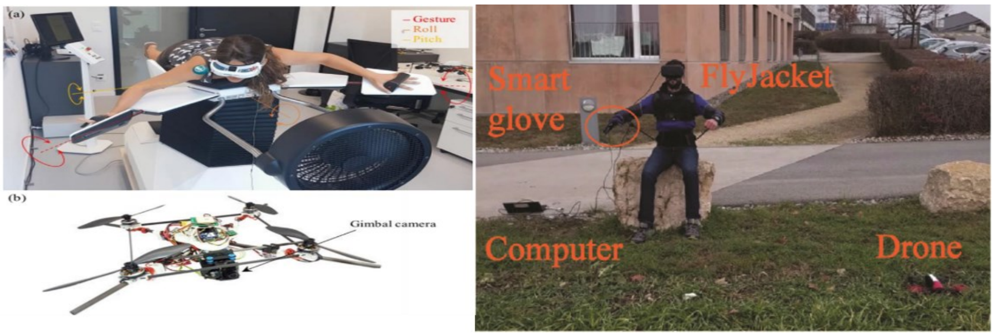


Fig.8 Embodied interaction (left) and Fly jacket (right) [10-11]

Another issue for drone manipulation is obstacle avoidance. Generally, it is difficult to understand how environments are located with a typical drone manipulation due to limited visual function (e.g., latency, and field of view). Et al. have aimed to resolve these issues with a special camera (e.g., stereoscopic camera and 360). Smolyanskiy et al. have developed a visual system using a stereoscopic camera to obtain a sense of depth [13]. Hayakawa et al. resolved time-delay issues that occurred by a delay of the actuator when users looked around the environment using 360-degree camera Ricoh theta [3]. Other studies have proposed sensory-feedback systems to avoid obstacles (i.e., alert function). Spiss et al. have developed a tactile feedback system that gives tactile stimulation when users are close to obstacles [14] (See Fig.9). Marco et al. have developed a force feedback system [15] that uses a combination of a proportional controller and a sensory feedback system. In contrast, a previous study has also developed a combination of NUI and sensory feedback system. Rognon et al. have developed a manipulation system that gives haptic feedback when users deviate from right trajectories and return to them [16].

Fig.9 Haptic feedback system [14]

However, these studies have not indicated cognitive functions for manipulating a vehicle. Michon et al. proposed a hierarchical structure that consists of three levels in terms of cognitive processes for driving vehicles (See Fig. 2 and Table 1) [17,18]. First, the strategic level represents the cognitive process to comprehensively integrate driving planning (e.g., determine where, what route and when to depart and arrive at destination while considering the effects of weather and congestion). Second, tactical level represents the cognitive process to consider safety while driving (e.g., adjustment of speed and distance between vehicles depending on obstacles and location). Finally, operational level represents the cognitive level in terms of basic driving skills (e.g., brake, accelerator, and handling). Considering the cognitive process for driving vehicles, NUI systems have focused on the operational level. The stereoscopic camera system and the haptic feedback system directly provide sensory information. In contrast, we can recognize the size of a vehicle when we drive a car unconsciously for interacting with environments. However, it is assumed that it is difficult to construct the sense of the size of a vehicle. Thus, it is important to incorporate the physicality into the manipulation system to satisfy a required component following sensory information in tactical level.

The strategic level means fundamental cognitive functions that a healthy person already has regardless of a support system. The operational level is related to cognitive functions to manipulate a vehicle based on a full understanding of the operation method (e.g., Kinesthetic functions, operation knowledge, and visual-motor conversion skills). NUI corresponds to this cognitive process for obtaining knowledge of manipulation and visuomotor conversion skills because it aims to create an intuitive controller. The tactical level corresponds to cognitive functions for understanding positional relationships and sustaining speed and distance (e.g., attention function, visual search ability, visual-spatial cognition, visuomotor conversion ability, information processing speed, and emotional control). 360-degree camera, a stereoscopic camera, and a haptic feedback system correspond to this cognitive process as those systems enhance sensory information at the tactical level because these systems explicitly provide information.

Considering this, there is no support system for emotional control and the sense of the size of a drone (e.g., timing estimation, visuospatial cognition, visual-scanning ability, working memory, attention functions (retaining and dividing attention), danger prediction) in Fig. 2. We highlight that the sense of the size of a vehicle corresponds to this. Sensory information systems (e.g., 360-degree. camera, a stereoscopic camera, and a haptic feedback system) explicitly provide information. Thus, it is assumed that previous systems affect workload and information processing speed because operators need to feedback with visual information. In contrast, the sense of the size of a vehicle is a body scheme to interact with environments (i.e., it is an innate ability to understand the sense of the size of a vehicle and the sense of distance and execute some actions unconsciously and autonomically). We highlight that this sense relies on a peripersonal space described in chapter 2.2. Our brain processes sensory information implicitly and specifically on the unique bodily area that extends from a human body. Hence, previous works argued that this area works as a defensive mechanism, such as danger prediction [46]. Namely, the sense of the size of a vehicle is a peripersonal space (PPS) that extends toward a vehicle when driving and enables interaction with environments. Thus, it is assumed that the combination of traditional methods and PPS are valid for the sense of the size of a vehicle. Previous works have shown that a PPS is modified by changing in a body representation. For example, in neurocognitive science, Lenggenhager et al. have reported that participants recognize an avatar located in front of a user as their own body by representing synchronous visuo-tactile stimulation [48]. Furthermore, a PPS transfer toward their avatar. Thus, it is assumed that the sense of the size of a vehicle is similar to body recognition that extends toward a vehicle. However, a user's physical body disappears when operators use a head-mounted display. Thus, it is difficult to construct PPS on a drone. It can be expected that a PPS is extended from a drone by inducing the sense of body ownership over a drone. In chapter 2.2, we explain the sense of body ownership and arousal mechanisms in detail to apply its effect over a drone manipulation.

Furthermore, the emotional control corresponds to reducing the fear of height caused when manipulating a drone. Drone operators have to see heights via a head-mounted display for their works. Stefanucci et al. have reported that the fear of height distorts the sense of distance [62]. It is assumed that the fear of height is enhanced when inducing the sense of body ownership at heights.

In contrast, in the virtual reality psychology, previous studies have reported psychological effects (i.e., the proteus effect) depending on the avatar appearance and that can be elicited when inducing the sense of body ownership. Particularly, Lugrin et al. have reported that inducing the sense of body ownership over a robot avatar can reduce fear of heights [56]. It is assumed that it is possible to support emotional control and spatial awareness simultaneously using the proteus effect. In chapter 2.3, we will explain the proteus effect in detail to reduce fear of heights.

2.2. The Illusion of Virtual Body Ownership and the sense of the size of a vehicle

Our sense of self-body size is not consistent with the sense of drone size. This inconsistency can potentially cause a severe accident when interacting with the environment. Thus, it is necessary that we have the sense of drone size. Our ultimate goal is to obtain the sense of the size of a vehicle on a drone. We can interact with environments (e.g., parking in a garage and moving one's car sideways) autonomically and unconsciously when we drive vehicles. However, it is assumed that a typical drone system cannot build the sense of the size of a vehicle because a typical drone manipulation system provides only visual information. The process of building the physicality such as the sense of the size of a vehicle is similar to the sense of body ownership. The sense of body ownership is a feeling in which humans perceive a virtual body as their own body. In neurocognitive research and VR psychology research, previous studies have reported that inducing the sense of body ownership can modify and improve the ability to estimate object sizes and the sense of distance [37, 43, 44]. Thus, we aim to the sense of the size of a vehicle for operability by inducing the sense of body ownership. In this section, we explain the physicality based on the sense of body ownership.

Generally, a human does not recognize other bodies as its own body. However, in neurocognitive psychology, a previous study has reported that we can feel an artificial body as our own body in an experimental manner. This sensation is referred to as the sense of body ownership. The classical method is the "rubber hand illusion (RHI)" to induce the sense of body ownership to an artificial body [20]. In the experiment of RHI, participants see a rubber hand located in front of them, while a real hand is hidden. Most participants experience the rubber hand as if it was their own hand when the experimenter strokes on both hands synchronously and in the corresponding spatial location. Interestingly, the body position perceived shifts to the rubber hand. This sense of body position perceived by oneself is referred to as self-location. The sense of body ownership and self-location are defined as components of the sense of embodiment, which is an index of a sense of presence in a VR space or an avatar [21]. Case studies in pathology, cognitive psychology, and VR psychology have shown that the sense of body ownership can be induced by integrating multisensory information (e.g., visual and tactile stimulation) (see Fig.10) [22].

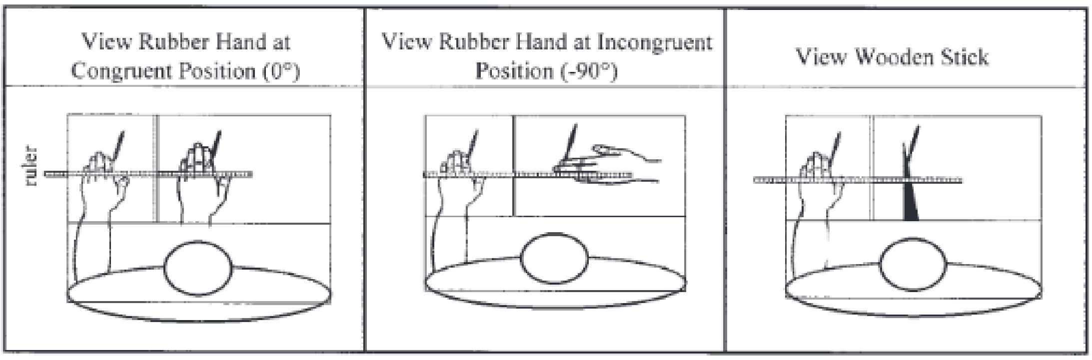


Fig.10 Visuo-tactile stimulation [22]

Additionally, VR psychology has also reported that it can be induced through an experimental process that provides a specific stimulus between a virtual body and a user's body (see Fig.11) [23]. This phenomenon that the sense of body ownership is induced over a virtual body is refers to as the Illusion of Virtual Body Ownership (IVBO) [24].

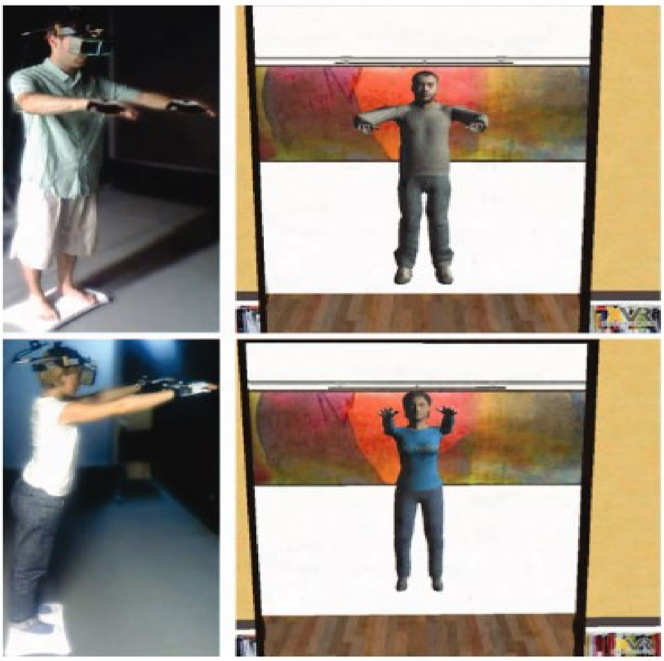


Fig.11 Visuomotor synchronization stimulus [31].

The human brain processes the integration of multisensory information continuously and unconsciously when a stimulus is synchronously provided spatially and temporally [25]. At the same time, our body representations (i.e., body position and posture) are updated by this integration and comparison to pre-existing body representations. However, typical drone systems do not satisfy a condition for inducing IVBO on flight experience, because they do not depict a user's body. It can be expected that users interact with environments (i.e., obstacle avoidance and approach to targets) rapidly and unconsciously by constructing the physicality on the flight experience.

Tsakiris et al. summarize two processes of inducing the sense of body ownership as a top-down and a bottom-up factor (see Fig. 12) [26]. As mentioned, it can be induced when somatosensory and visual information are synchronized. In contrast, it cannot be induced when a visual form of a body part has not innated shape, and an artificial body is not consistent with a user's physical body part direction [22]. The process of inducing body ownership caused by integrating multisensory information inputs (i.e., visuotactile information) is referred to as the bottom-up factor. The process of inducing it caused by the consistency with the pre-existing body representation (i.e., humans can understand their body states such as position and rotation) and visual form of a body is referred to as the top-down factor. Previous works have reported that visual form and pre-existing representation affect the intensity of a body ownership (e.g., perspective, appearance, personalization, and discontinuity [28-30,38]).

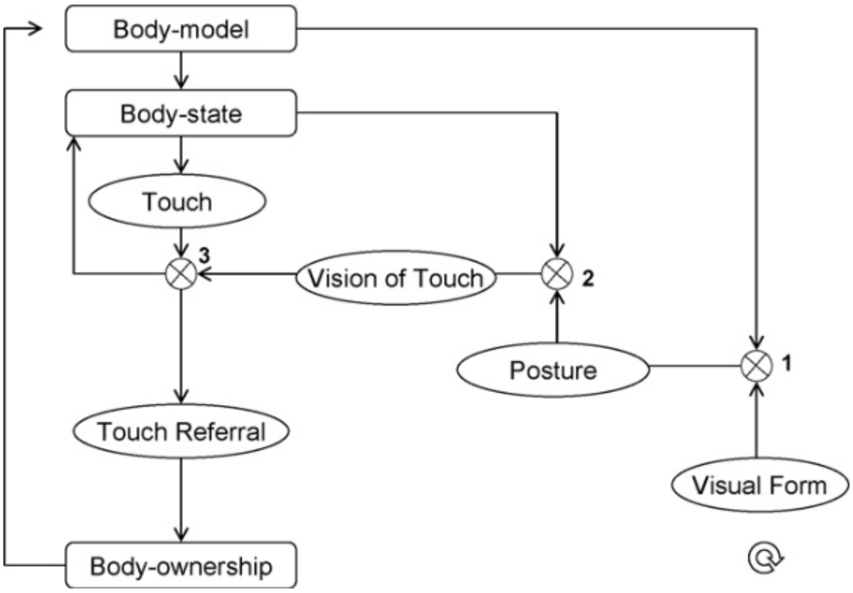


Fig.12 Neuro cognitive model of body ownership [25]

Additionally, it can be induced with visuomotor synchronization as well as visuo-tactile stimulus (see Fig.11). When a human moves a body part, they can predict a result of sensory information caused by its motion, because of an efference copy (a human sends a motor command copy to the brain of the sensory region). The sense of body ownership can be induced when the motor intention corresponds with an actual motor result. There is the study using a robot arm as a proof of eliciting the recognition between its self and others. Blakemore et al. developed a robot arm device enabled to tickle its own body [31, 32]. Participants can feel a tickling when there is temporal delay and shifted trajectory between their movement and the robot arm. A tickling stimulation elicited by self is canceled because it is not more ecologically important than other's one. Thus, consistency between the prediction of our body movement and the actual sensory result is important to inducing recognition of other and self (See Fig. 13). Additionally, the inverse model for motor control is accumulated in the process of learning. It was used for calculating how we move for expected results. Hence, we can learn how to move even an artificial body part that differs from human body shape, and the sense of body ownership can be induced by the above mechanism (i.e., it is not an innate body part such as a tail [35]).

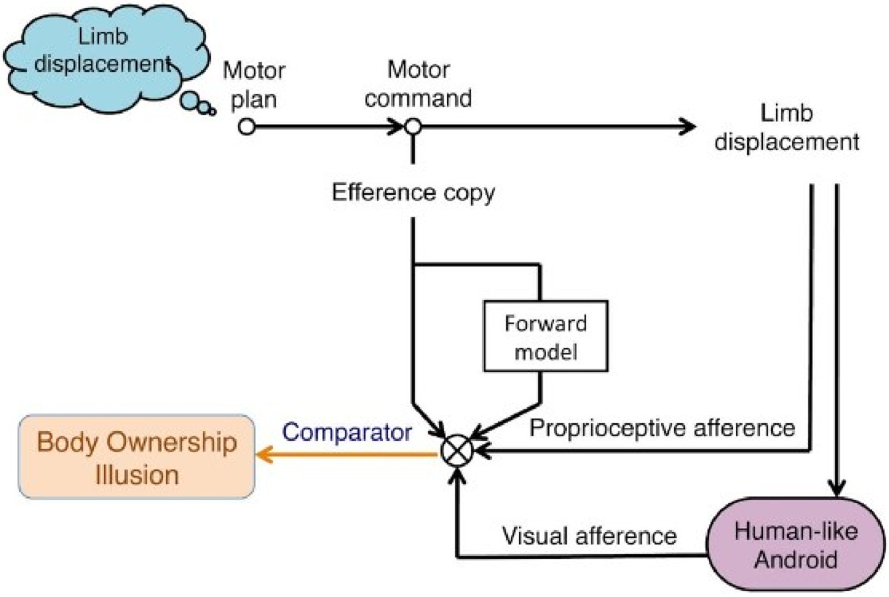


Fig.13 Body ownership arousal mechanism using visuomotor synchronization [33]

In recent years, many studies have used a full-body avatar because an avatar can be manipulated to correspond to a user's body using a motion capture system. Motion synchronization between a user's body movement and an avatar's movement can induce the sense of body ownership even if there are apparent differences in terms of shape and appearance between a real body and an avatar's body. They have been using various avatars because it is possible to modify an avatar's appearance and shape in VR environments (e.g., gender, age, robot, and race [36-39]). Furthermore, it can be induced even if an avatar's body construction differs from human body construction; a previous study, for instance, has reported the induction of the sense of body ownership over an un-humanlike avatar (e.g., an avatar attached with tail [35], very long arm [40] and a balloon that can be deformed by user's breath [41]). It can also be induced over un-humanlike full-body avatar (i.e., an animal avatar such as a bat, bird, or scorpion) [42].

IVBO improves spatial awareness. Human brain can recognize states of the body representation and depict a spatial representation of environments surrounding us. Hence, we can predict approaching threats and understand how to interact with environments (e.g., obstacles, buildings, and pedestrians) swiftly and unconsciously. That is, humans have mechanisms that represent our states of body and space and realize these functions. However, generally, our body is distorted when we are immersed in a virtual environment.

Conversely, a previous study has reported that the sense of body ownership improves the sense of distance and spatial awareness [43,44]. We propose that spatial awareness can be explained by peripersonal space (PPS). The human body region includes not only the body part, but also the space extended from specific body parts, trunk, hands, and head. In cognitive neuroscience, this space is regarded as a body region, referred to as PPS [45]. Humans can feel tactile information when visual threats enter the space, even though it does not present a tactile stimulus as if they are touched because the human brain has a neural population that simultaneously process visual and somatosensory information. The tactile information is fired at the same time as the visual information (i.e., bimodal neuron). It has been argued that PPS is important in defense mechanisms, such as expressing the space between itself and surrounding objects and avoiding obstacles [46].

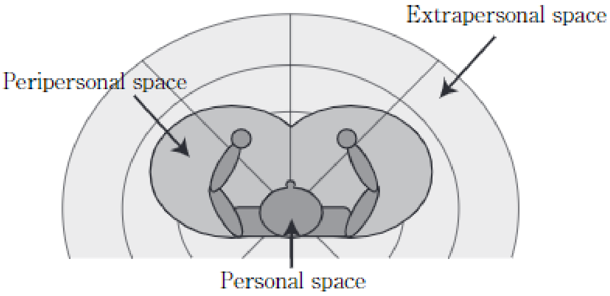


Fig.14 Specific spaces that surround a human [45].

The size of PPS has plasticity, e.g., previous study has reported that the size of PPS is spread toward tools by using a tool such as rakes [47]. Additionally, PPS can be modulated depending on the sense of body ownership. A previous study has reported the out of body experience (OBE) that gives participants a feeling of transferring their body in front of them [48]. In this experiment, participants see their back via HMD using a web camera located behind them. The experimenter strokes on their back. Thus, participants can see their back is stroked. As a result, it induces the sense of body ownership over the front of the body. Interestingly, it reveals PPS, which is important for spatial awareness, is transferred forward [49]. PPS can also be significantly extended using a large-body avatar [50]. Thus, it is believed that PPS is related to the sense of body ownership.

Previous studies have reported that an intensity of the sense of body ownership and an avatar's appearance affects spatial awareness. Specifically, in the case of a third-person perspective, task performances that evaluate spatial awareness are more improved using scanned body avatar (in this study, the participant's body was scanned by depth cameras and depicted as point clouds) than other conditions (i.e., mesh-based avatars) [51]. It has also been reported that the sense of size and distance are modified depending on the size of an avatar [37, 52]. For example, inducing the sense of body ownership over a small doll leds to overestimate the size of object [52]. Thus, it can be expected that the sense of body ownership can construct PPS, and it improves spatial awareness on a flight experience. Additionally, it needs to consider body appearance, shape, and size to improve spatial awareness.

2.3. The Proteus effect

A disadvantage of the sense of body ownership is fear of heights caused by enhancing the sense of presence over the flight experience. Thus, in comparison to a typical drone system, it has the potential to induce fear of heights by the sense of body ownership over a drone. In this section, we explain the Proteus Effect to support emotional control on the tactical level.

As mentioned, IVBO can be induced over various avatars. Interestingly, previous studies have reported that an avatar's appearance affects a user's behavior. The psychological phenomenon caused by the visual and behavioral characteristics of an avatar is referred to as the *Proteus-Effect* [53]. The proteus effect affects users' action, size estimation, and their mental condition. For instance, participants play a percussion instrument more rhythmically when manipulating an avatar with casual cloth and tanned skin in comparison to an office worker avatar [54]. Furthermore, Peck et al. have reported that toned skin avatar can significantly reduce implicit association test (See Fig.15) [39]. Banakou et al. have reported that participants overestimate the size of objects when inducing the sense of body ownership over the child avatar [37] (See Fig.16). Additionally, they have also reported that inducing the sense of body ownership over the Einstein avatar can lead to improving the score of cognitive exams in the case of a participant with low self-affirmation [55]. These findings indicate that the impression of the avatar affects our body image when inducing the sense of body ownership.

Fig.15 Changing mind by changing user's body [40]

Fig.16 When a sense of body ownership over child avatar is induced, user's preference becomes more childish [38].

As mentioned, the sense of body ownership can be induced even in the case of an un-humanoid avatar such as an animal [42]. Hence, in recent years, some previous works have reported the proteus effect with an un-humanoid avatar. For example, Ahn et al. have reported that the sense of body ownership over a coral avatar and a cow avatar affect natural sustainability [56]. Charbonneau et al. have reported that participant's gait was modified by inducing the sense of body ownership over a giant monster [57]. However, almost all previous works have not focused on a special ability such as a bird's flight ability. It may be possible to obtain the proteus effect, which cannot be induced by humanoid avatar, using animal avatars because animals have special abilities, such as a bird’s flight ability. Specifically, it can be expected that the proteus effect of a bird avatar reduces fear of heights in in-flight experiences because flight ability gives us an impression of safety because of wings, even though users may fall. In fact, it has already been clarified that the proteus effect reduce the fear of heights. Lugrin et al. have reported that inducing IVBO over a robot avatar can reduce the fear of height [58]. Here, we should discuss the methodology to simultaneously resolve PPS and the proteus effect.

2.4. Summary

Considered together, previous studies have proposed NUI, a special camera, and an alert function (e.g., haptic feedback system). NUI corresponds to the operational level (i.e., manipulation skill based on a full understanding of manipulation methods, such as acceleration and brake) on the cognitive process for driving a vehicle. A special camera and an alert system correspond to the sensory information system and visual-search ability on the tactical level. However, there are no support systems for tactical levels, such as attention, visuospatial ability, concentration (we referred to these functions as spatial awareness), and emotional control. Thus, we aim to develop a support system to resolve these issues. Operators need to feedback to action based on visual information. In contrast, the sense of the size of a vehicle is an innate ability to interact with environments unconsciously and autonomically. Thus, it is assumed that its sense corresponds to spatial awareness and it is important to build the sense of the size of a vehicle to pre-existing issues.

First, we propose the sense of body ownership to obtain the sense of the size of a vehicle. The sense of body ownership indicates the feeling of self-recognition and self-attribution caused by integrating multi-sensory information (visuo-motor and visuo-tactile stimulations). This inducing process is similar to the peripersonal space that is the mechanism of the sense of the size of a vehicle. Additionally, previous works have reported that the sense of body ownership can improve spatial awareness, which can be modified depending on the avatar appearance [51, 52]. Hence, in comparison to general drone systems that do not present an avatar, it can be expected that spatial awareness for flight experience can be improved by inducing the sense of body ownership.

Second, a disadvantage of the sense of body ownership is a fear of heights because it enhances the sense of presence at heights. Previous work has reported that fear of heights distorts the sense of distance. Thus, there is a risk of hitting buildings due to the distortion. We propose the proteus effect to simultaneously improve spatial awareness and reduce fear of heights. Previous works have reported that the sense of body ownership affects the user's attitude, behavior, and psychological state depending on avatar appearance [53]. Its psychological effect is referred to as the proteus effect and it is expected to reduce fear of heights while maintaining the sense of body ownership.

Therefore, it is assumed that the support system that covers all cognitive functions for driving a vehicle can be completed by developing the system based on the sense of body ownership. In the following section, we consider the proper avatar for applying the sense of body ownership to flight tele-existence. Then, we investigate the effectiveness of the sense of body ownership and summarize these results.

3. Proposal method: Inducing the sense of body ownership over a non-humanoid avatar

As mentioned in the second chapter, it can be expected that the sense of the size of a vehicle and emotional control are improved by IVBO and the proteus effect. However, it is assumed that it is difficult to induce IVBO over a drone because there are significant differences in terms of body construction between a human and a drone. Thus, it needs to depict an avatar on a drone of view instead of a drone body to induce IVBO. Furthermore, PPS, which is supposed to be a defense mechanism, has also been reported to modify with the size of the avatar []. The Proteus effect, which we thought was effective for the fear of heights, is also important because of the impressions and preconceived notions we have of an avatar appearance. Thus, it needs to investigate a proper avatar for the flight experience. In this chapter, we argue a useful avatar for the flight experience.

3.1. Inducing the sense of body ownership over a bird avatar (a dragon)

We aim to improve the sense of the size of a vehicle and reduce the fear of heights by inducing the sense of body ownership over a drone. As mentioned, previous work has reported that PPS that works as a defensive mechanism can be modified depending on an avatar's properties (shape, size, and appearance). Hence, if PPS could be extended to a drone, it can be expected that operators can predict danger and understand positional relationship introspectively. Thus, a human avatar is useful for obtaining a sense of the size of a vehicle. However, wide PPS hit buildings because a drone has to enter a narrow space. It is assumed that it leads to a high workload. On the other hand, it can be expected that operators can interact with environments while maintaining a corrected sense of distance and the sense of the size of a drone, by obtaining PPS that is deformed a drone shape. It is assumed that it is effective to change an avatar according to a specific scene for obtaining introspective spatial awareness. It needs to induce the sense of body ownership over an un-humanoid avatar to achieve this purpose.

It can be expected that inducing IVBO over a drone-shaped avatar can help humans interact with environments while recognizing the drone's size. However, previous studies have reported that a difference in posture between a user's body and an avatar's body causes stress and a high workload, and it is not suitable for the user experience [59]. We propose a bird avatar to resolve this issue. There are two mechanisms the Top-down factor and Bottom-up factor to induce the sense of body ownership [26, 27]. A bird avatar that has limbs satisfy the bottom-up condition that integrates multi-sensory information. In consideration of the top-down factor that consistency with pre-existing body representation and visual form of a virtual body, a non-humanoid avatar that has a human appearance leads to reduce an intensity of the sense of body ownership because a human see visual form elaborately. On the other hand, it is assumed that it cannot lead to reduce the intensity of the sense of body ownership over a non-humanoid avatar because a bird is not a human appearance. Furthermore, it can be expected that a bird avatar is effective for obtaining the proteus effect to reduce the fear of height because a bird has a flight ability. It can be expected that its preconception and impression reduce the Anxiety to a fall. We describe 3 steps to examine the effectiveness of IVBO over an non-humanoid avatar at the following section.

We introduce the following three themes: 1) " investigation of conditions for inducing IVBO over non-humanoid avatar, 2) “improving the sense of the size of a vehicle with IVBO," and 3) " reducing the fear of heights using the Proteus effect of a dragon avatar." For the first theme, we examined the possibility of inducing IVBO over a non-humanoid avatar to utilize the effectiveness of IVBO to improve both the sense of the size of a vehicle and emotional control. In the second theme, we aimed to indicate the need to consider avatar properties, such as size and appearance, for improving the cognitive functions of the sense of the size of a vehicle. Finally, in the third theme, we aimed to overcome the disadvantages of the sense of body ownership, i.e., the fear of heights, by utilizing the proteus effect of a dragon avatar for improving emotional control. This result serves as the principal for the sense of the size of a vehicle in the domain of flight tele-existence. In future, it is expected that better avatars will be investigated to improve spatial awareness on the basis of this study.

3.2. Investigation of conditions for inducing IVBO over non-humanoid avatar

Our first purpose is to induce IVBO over a non-humanoid avatar to improve the sense of the size of a vehicle and reduce the fear of heights. We propose a bird avatar for this purpose to resolve these issues simultaneously. A deformed human appearance is creepy for almost persons. The previous study has reported that human appearance influences the sense of body ownership, and a robot avatar can enhance body ownership [38]. It is considered that fidelity of appearance is an important factor in the case of human shape from the evidence of the top-down factor. A bird shape is similar to a deformed human avatar, and it has limbs that are a necessary condition for inducing the sense of body ownership. Hence, the sense of body ownership can be induced even in the case of a bird avatar. Additionally, it can be expected that it induces the proteus effect for reducing the fear of heights, as stated below. However, it has not been clarified whether the sense of body ownership can be induced over an animal avatar that full-body is un-humanlike body construction, at the time of writing. An animal's body construction and appearance differ from humans. Thus, we aim to investigate the possibility of inducing the sense of body ownership over a bird avatar for investigating how an un-humanlike avatar's appearance influences spatial awareness and psychological effect (i.e., reducing the fear of heights) as a first step.

3.3. Improving the sense of the size of a vehicle with IVBO

It can be expected that the sense of the size of a vehicle is improved by inducing IVBO over a non-humanoid avatar, which is deformed into a drone size. Furthermore, other previous works have reported that PPS can be modified depending on an avatar's appearance [47, 49, 50]; PPS can be spread by using a tool [47]. it can also be significantly extended using a large-body avatar [49]. Additionally, previous study has reported that PPS shifts toward a virtual body that located front of a physical body by inducing OBE [50].

We make a hypothesis as follows: Inducing IVBO into a drone shaped avatar can enhance the sense of the size of a vehicle in comparison to other conditions (i.e., a regular size avatar and only drone). Specifically, it helps us to interact with the environment, such as obstacle avoidance, entering into narrow space, approach to targets, and understanding the size of a drone. Especially, we can pass through spaces by obtaining a sense of the size of a drone. Our second purpose is an investigation about how IVBO over a non-humanoid avatar impact on the spatial awareness task. We examine tasks to investigate how IVBO impacts on understanding the size of an avatar and interacting with the environment. In this experiment, we are instructed to aim for the destination while passing through rings that located in virtual environments. We compare some conditions using the accuracy of judgment, required time to judge, collision time, and the count of collisions when they pass through rings to evaluate the ability that they can understand the size of a collision detector size. We hypothesize that a drone shaped avatar can easily to interact with environments, i.e., IVBO over a non-humanoid avatar improves task performances.

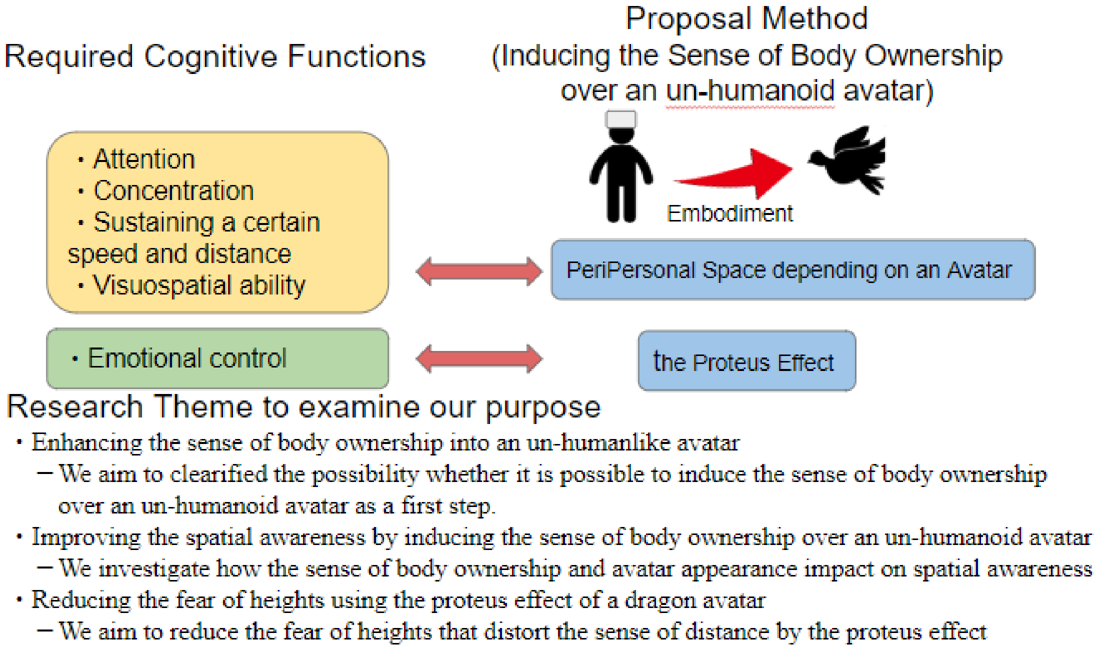
3.4. Reducing the fear of heights using the Proteus effect of a dragon avatar

Almost human feel the fear of height when they encounter the heights. Additionally, it can be induced even in 3D Games and, the previous study has reported the fear of heights to distort the sense of distance [60, 61]. There is a possibility to cause an accident due to the fear of heights. Furthermore, it is assumed that the sense of body ownership influences the fear of heights in comparison to other systems because it can enhance the sense of presence in a flight experience. Hence, we aim to reduce the height of fear using the proteus effect. It is considered that humans feel the fear of heights potentially because humans do not have a flight ability. Contrary to this, our body image that we are a human can be changed into an avatar by the Proteus effect. In fact, the previous study has reported that inducing the sense of body ownership over the robot avatar can reduce the fear of heights comparing with a human avatar [57]. Thus, it can be expected that the pre-existing body image that humans cannot fly in the sky is changed by inducing the sense of body ownership into an avatar that has a flight ability. It can be expected that the proteus effect reduces the fear of heights and enhance the sense of presence on flight experience by inducing the sense of body ownership over an avatar that has flight ability such as a bird and a dragon. In this research, we aim to reduce the fear of heights by inducing the proteus effect of a dragon avatar that has a flight ability and a strong body. Based on the previous study, the sense of body ownership is not only important, but an experimental scenario is also important to induce the proteus effect [62]. Therefore, in the experiment, we prepared two experimental conditions, a dragon condition to behave as a dragon by operating a dragon avatar, and a condition to behave like a human by operating a human avatar. We evaluate the reaction of fear when they encounter heights. There are drones that explore not only the air but also the deep sea and the universe, where humans are prone to feel the fear. If the hypothesis of this research is clarified, it can be applied to a technique that can overcome the fear that occurs when manipulating a drone in the first person and moving to a high place. Additionally, it is considered that the research area will be expanded to the investigation of an animal type avatar to obtain the psychological effect applied to various environments.

3.5. Summary

We show summary of our research in Fig.17. Pre-existing support systems have not focused on some cognitive functions on tactical level, such as attention, concentration, sustaining a certain speed and distance, visuo-spatial ability, and emotional control. Previous works have reported that the sense of body ownership can improve spatial awareness [43,44]. Additionally, Other works have also reported that PPS that is important factor for spatial awareness can be modified depending on avatar's properties (i.e., size, shape, and appearance). Additionally, the proteus effect caused by the sense of body ownership affects user's behavior and attitude. Hence, we focused on inducing the sense of body ownership over an un-humanoid avatar such as a dragon avatar and a bird avatar to improve spatial awareness and reduce the fear of height. It can be expected that participants can interact with environments while keeping the sense of the size of a drone, and the corrected sense of distance by inducing the sense of body ownership over an un-humanoid avatar that its shape is deformed a drone body construction, because of changes in user's PPS. Additionally, the proteus effect of a bird avatar that has a flight ability affects attitudes on heights because of its preconception that I do not fall by wings and flight ability. An improvement of spatial awareness corresponds to cognitive function for spatial awareness (i.e., attention, concentration, visuospatial ability, and sustaining speed and distance).

We carry out some experiments to examine above effectiveness. First, we investigate possibility for inducing the sense of body ownership over an un-humanoid avatar to apply the effectiveness of its effect for a flight experience. Then, we investigate how avatar appearance and the sense of body ownership impact on spatial awareness. Finally, we investigate the proteus effect of a dragon avatar impacts on the fear of heights. We show our proposal method at Fig.17.



Research Theme to examine our purpose

- Enhancing the sense of body ownership into an un-humanlike avatar
  - We aim to clearified the possibility whether it is possible to induce the sense of body ownership over an un-humanoid avatar as a first step.
- Improving the spatial awareness by inducing the sense of body ownership over an un-humanoid avatar
  - We investigate how the sense of body ownership and avatar appearance impact on spatial awareness
- Reducing the fear of heights using the proteus effect of a dragon avatar
  - We aim to reduce the fear of heights that distort the sense of distance by the proteus effect

Fig.17 Proposal method overview

4. Exp1: Investigation of the condition for inducing IVBO over a non-humanoid avatar

4.1. Exp1-1

4.1.1. Purpose

We treat a bird avatar to obtain the proper proteus effect for flight experience. However, it needs to investigate the possibility that the sense of body ownership is induced into a bird avatar because its body construction clearly differs from human's body construction. Furthermore, it has not been clarified that the proteus effect of an animal avatar can be induced as far as we know. Thus, we investigate the possibility of whether the sense of body ownership is induced even in a bird avatar, and the possibility of whether the proteus effect of an animal avatar is induced.

4.1.2. Apparatus

We used a VR HMD Oculus DK2 (960x1080 pixels and 110deg Field of View) to embody the virtual environment. Participants viewed the VR space via this device. The participant's motion was captured by Microsoft Kinect V2 and reflected the avatar's movements. The experimental program ran on a PC with a 4.0 GHz CPU, GeForce 970 Ti GPU, and 16GB RAM. The experimental program was implemented by Unity Game Engine 5.3.4. This program was run with approximate 80 FPS.

4.1.3. Condition

In experiment 1, we investigated the possibility of inducing the sense of ownership into a bird avatar. Especially, we investigated how the consistency between the bird avatar and a bird's features impacts on the sense of ownership into the bird avatar and the sense of flight. We setup avatar factors (human avatar and bird avatar), movement factors (asynchronous, synchronous) and character factors (size of avatar and sound of flapping) as experimental conditions. Participants manipulate the virtual body 3min under the combination of each condition (Fig 18). The experiment was designed as mixed 2x3x2 conditions.

We setup avatar factors (human, bird), motion factors (asynchronous versus synchronous versus flying) and character factors (human features, bird features) as within-subjects variables. Avatar factors are composed of two conditions that embody participants as either a human avatar or a bird avatar to investigate the possibility of inducing the sense of body ownership over the bird avatar (see Fig.18 (a)).

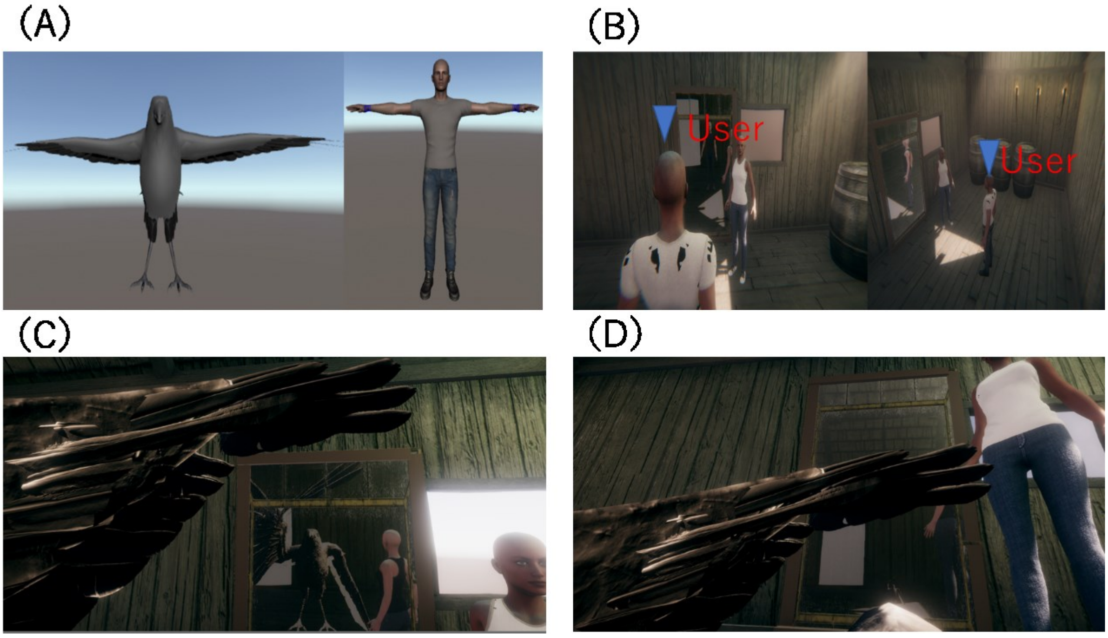


Fig.18 VR Programs: (a)Avatar (b) Virtual room (c) perspective from human size avatar (d) perspective from bird size avatar

Motion factors are composed of three conditions concerning the mapping of movement between the subject's body and an avatar's body to investigate whether motion synchronization is valid even with a bird avatar. Character factors are composed of two conditions where a virtual body resembles either a human or a bird to investigate how consistency between the bird avatar and a bird's features impact on the sense of ownership and the impression of virtual reality. In avatar factors, we set up the human avatar condition and the bird avatar condition. A bird body is not compatible with a human avatar body completely. Thus, we map a human's body part to a bird body part as shown in Fig.19 (left). In motion factors, we setup the asynchronous condition, the synchronous condition, and the flying condition. In the asynchronous condition, a virtual body moves independently of participants in accordance with prepared animations (stretch a virtual body, twist a virtual body and walk). In the synchronous condition, the virtual body's motion is synchronized with that of the participants. In the flying condition, the virtual body can fly when participants perform a flying action gesture. When they flap their arms, the virtual body can rise upward. They can also move the avatar in the same direction that their body leans. The flying speed is the same for all conditions. Participants' movement can be tracked in a playable space of 2m square using Microsoft Kinect v2 (See Fig.19 (right)).

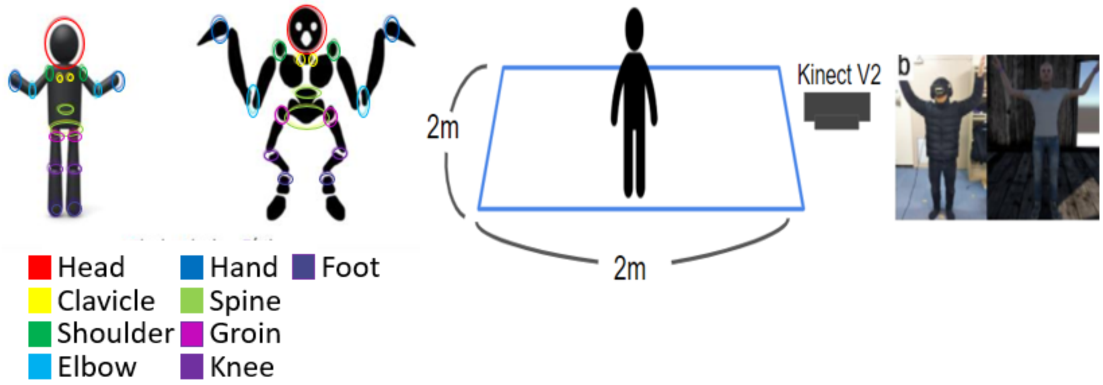


Fig.19 Correspondence table between a bird body construction and a human body construction and tracking space for experience

In character factors, we setup the human-features condition and the bird-features condition. In the human-features condition, the virtual body resembles a human (an avatar is the size of an average human (180cm), and when participants flap the sound of flapping is not produced). In the bird-features condition, the virtual body possesses bird features (the avatar is the size of a bird (20cm)), and when participants flap the sound of flapping is produced). Participants carry out 12 conditions that are combined with each of the conditions (see Table.2.)

Table.2 Combination of experimental factor

<table>
<tr><td colspan="4">Avatar Factor</td></tr>
<tr><td>Human</td><td colspan="3">Participants manipulate a human avatar (Fig.18(a) right)</td></tr>
<tr><td>Bird</td><td colspan="3">Participants manipulate a bird avatar (Fig.18(a) left)</td></tr>
<tr><td colspan="4">Motion Factor</td></tr>
<tr><td>Asynchronous</td><td colspan="3">An avatar moves independently in accordingly to prepared animations</td></tr>
<tr><td>Synchronous</td><td colspan="3">An Avatar's movement correspond with participant's movement</td></tr>
<tr><td>Flying</td><td colspan="3">In addition to synchronous condition, participants can fly in the sky by taking specific gesture.</td></tr>
<tr><td colspan="4">Character Factor</td></tr>
<tr><td>Human-Feature</td><td colspan="3">Size of an avatar is human size (180cm), and sound of flapping do not play</td></tr>
<tr><td>Bird-Feature</td><td colspan="3">Size of an avatar in bird size(10cm), and sound of flapping play</td></tr>
<tr><td colspan="4">Combination of Experimental Factors</td></tr>
<tr><td>Avatar Factor
Human/Bird</td><td colspan="3">Movement Factor</td></tr>
<tr><td>Character Factor</td><td>Asynchronous</td><td>Synchronous</td><td>Flying</td></tr>
<tr><td>Human-Feature</td><td>Asynchronous x Human-Feature</td><td>Synchronous x Human-Feature</td><td>Flying x Human-Feature</td></tr>
<tr><td>Bird-Feature</td><td>Asynchronous x Bird-Feature</td><td>Synchronous x Bird-Feature</td><td>Flying x Bird-Feature</td></tr>
</table>

4.1.4. Procedure

We used a VR space as shown in Fig.19(b). Participants observe VR space via an HMD from the avatar's perspective. The previous study that used an avatar where the appearance differed from the participant used a virtual mirror making it possible to observe the entire avatar's body and motion synchronization [23]. This present paper sets a virtual mirror as used with those studies. The participants could observe the avatar's body by looking toward their actual body directly. Additionally, they could indirectly observe the avatar's body via a virtual mirror that was located in front of the avatar (Fig. 18(b)). Additionally, we set a female character to the VR space as a cue of the avatar's height. Participants perceive the size of the avatar's body by comparing the female character with an avatar. This character factor changes the participant's perspective. In the human-features condition, participants obtain perspective as shown in Fig.18(c). In the bird-features condition, participants obtain the perspective as shown in Fig.18(d). We also present the sounds of a burning torch in the virtual room as auditory stimulation for shutting out noises in the experiment room. 33 students who did not know our experimental purpose participated in experiment 1. The experiment was conducted over two days. We changed the avatars type each day. The 2nd experimental day had an interval of more than three days from the 1st day in order to reduce the effect of the 1st-day score. Each experiment had a training session and a trial session. The training session's purpose was learning pre-decided actions, and getting used to the virtual environment. We instructed participants to perform pre-decided actions, then to move freely. We also instructed them to observe the virtual body for each action through their subjective perspective and a virtual mirror. Participants used a human avatar during the training session. Pre-decided actions were as follows:

1. Put both hands forward.
2. Raise hands respectively.

3. Look down at their own bodies.
4. Raise legs respectively.
5. Pose a bent posture.
6. Move around the virtual room.
7. Flap.

The previous work has reported that the sense of body ownership can be induced within 90 seconds [63]. Additionally, another work has reported that the sense of body ownership can be induced highly under whatever conditions, and the inconsistency with multi-sensory information leads to reduce its intensity [64]. Thus, it is assumed that this experience gives sufficient stimulation for inducing the sense of body ownership.

After the training session, the trial session was conducted. Either a bird avatar or a human avatar was assigned randomly to participants. Another avatar was assigned on a later experimental day. We instructed them to perform the same actions as in the training session under each condition. Each trial was 3min. At the end of each condition, the HMD visual was blacked out and participants were asked to answer a questionnaire. Participants participated for about 50 min for the entire experiment on one day. We show the entire experimental flow in Fig.20.

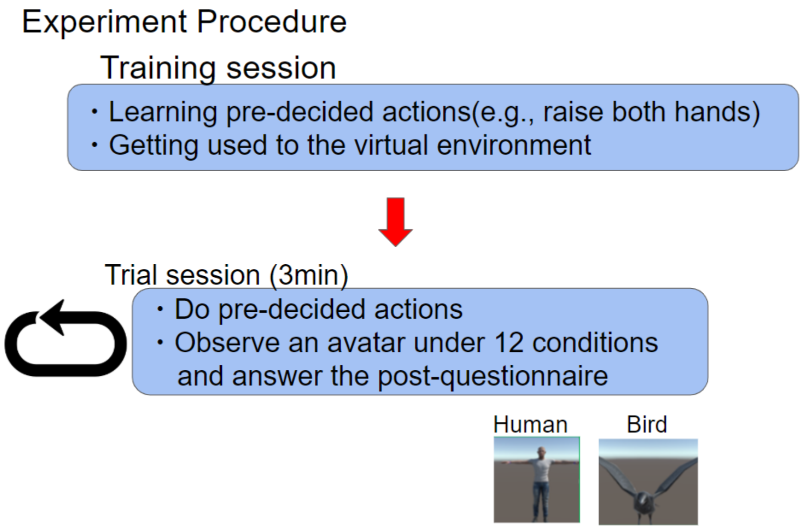


Fig.20 Experiment procedure

4.1.5. Evaluation

We use questionnaire show in Table.3 to investigate an intensity of the sense of body ownership. This the sense of body ownership item is based on the pre-existing work [37]. Furthermore, we also use Flying and Realness items to investigate how an avatar appearance affects user's experience. We made the Flying items that indicates the sense of flight, as if they fly in the sky. If there are significant difference in terms of the Flying item in the case of a bird avatar condition, this result imply a user's behavior can be affected even in an animal avatar.

Table.3 Questionnaire in Exp1

No	Label	Question
Q1	MyBody	How much did you feel that the virtual body you saw when looked at a virtual body as your body?
Q2	Mirror	How much did you feel that the virtual body you saw when looked at a mirror as your body?
Q3	Flying	How much did you feel as if you were flying in the sky?
Q4	Realness	Did you accept the virtual reality as a real experience?

4.1.6. Results

Our results show that the sense of ownership equal to a human avatar can be induced even in the bird avatar since equivalence was confirmed by TOST between those avatars. This result was the same as with many previous works [37-40]. Thus, our results suggested that a bird avatar can enhance the sense of flight. 33 Toyohashi University of Technology students who do not know our purpose participated this experiment with informed consent.

We scored the sense of body ownership by MyBody(Q1) and Mirror(Q2) of the questionnaire shown in Table 2. MyBody(Q1) and Mirror(Q2) directly related to the sense of body ownership. We show results in Fig.21. An error bar was shown as the standard error. There was a significant difference between motion factors in terms of MyBody ($F(2,64)=329.7235$, $p<0.0000$). We conducted multiple-comparisons concerning motion factors. It showed that the synchronous condition and the flying condition were significantly higher than the asynchronous condition ($p<0.0000$; $p<0.0000$). In contrast, there was no significant difference in avatar factors and character factors. Likewise, there was a significant difference between motion factors in terms of Mirror(Q2) ($F(2,64)=340.3169$,$p<0.0000$). We conducted multiple-comparisons concerning motion factors. Consequently, the synchronous condition and the flying condition were significantly higher than the asynchronous condition ($p<.0000$;$p<.0000$). There was no significant difference in avatar factors and character factors in terms of Mirror(Q2). Furthermore, there was no interaction between each condition in terms of both MyBody(Q1) and Mirror(Q2). Results of MyBody(Q1) and Mirror(Q2) indicate that the synchronous condition can enhance the sense of ownership. This result is the same as in previous works [37-40]. However, it did not indicate that the bird-features condition cannot enhance the sense of ownership. We used the TOST test at a significance level of 5% and a confidence interval of ±0.8 in order to analyze an equivalence of the sense of ownership between a human avatar and a bird avatar. As a result, equivalence was accepted. Therefore, the bird avatar can induce a sense of body ownership equivalent to a human avatar ($p=0.019$).

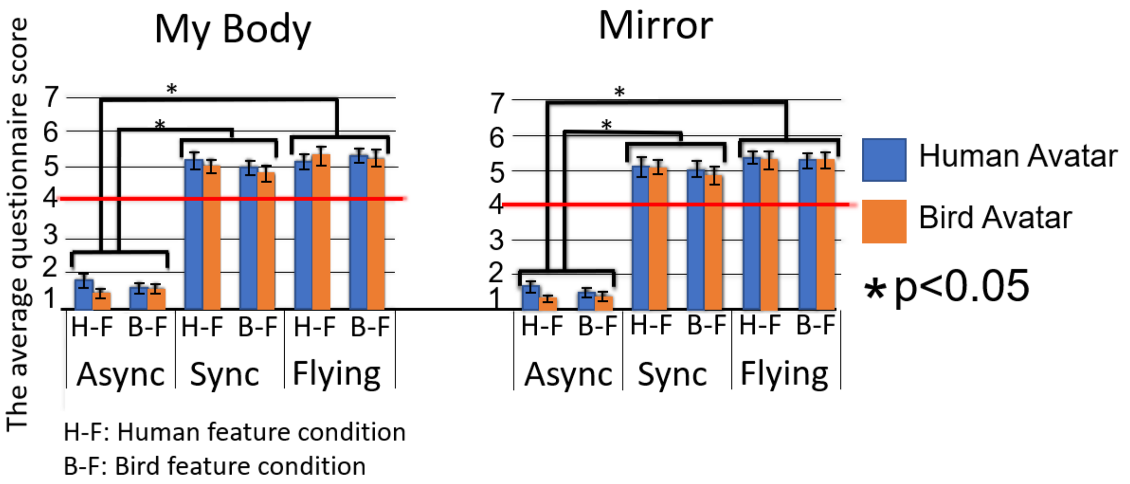


Fig.21 Rating MyBody(Q1) and Rating Mirror(Q2) (Error bar was shown as standard error)

We scored the sense of immersion in flying experience by Flying(Q3) and Realness(Q4) of the questionnaire shown in Table.2. We show results in Fig.22-23. Flying(Q3) represents the sense of flying. Realness(Q4) represents the sense in which it gives us a feeling of realness in the virtual experience. As a result of Flying(Q3), there was an interaction between avatar factors and motion factors (F(2,64) =7.2292, p=0.0015) in the rating Flying (Q3). There was a simple main effect between avatar factors under the flying condition (F(1,32=13.5106), p=0.0009). As a result of multiple comparisons, a bird avatar was significantly higher than a human avatar under the flying condition (p=0.0009). There was an interaction between movement factors and character factors (F (2,64) = 5.9435, p=0.0043). There was a simple main effect between character factors under the flying condition (F (1,32=6.7222), p=0.0142). The bird-features condition was significantly higher than the human-features condition(p=0.0142). Results of Flying(Q3) indicate that bird appearance and birds feature (the small size and the sound of flapping) can enhance the sense of flying.

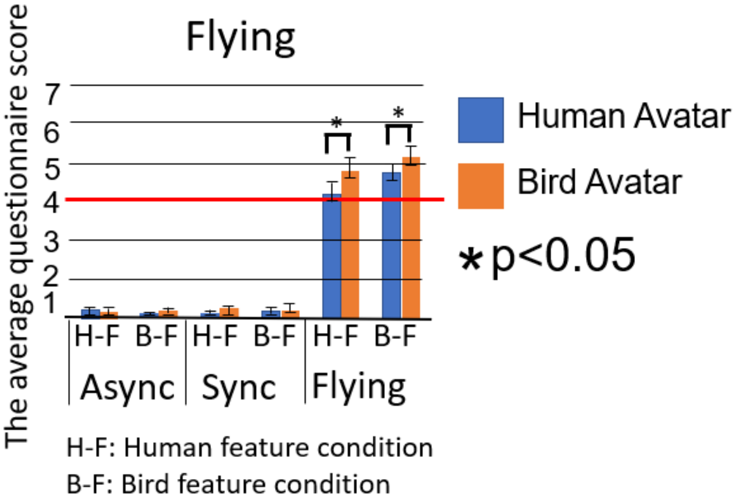


Fig.22 Rating Flying(Q3) (Error bar was shown as standard error)

As a result of Realness(Q4), there was an interaction between avatar factors and motion factors (F (2,64) =12.8987, p<0.0000). There was a simple main effect between avatar factors under the synchronous condition (F (1,32) = 14.7601, p=0.0005). As a result of multiple-comparison, A human avatar was significantly higher than a bird avatar under the synchronous condition (p=0.0005). However, there was no simple effect between avatar factors under the flying condition. We used the TOST test at a significance level of 5% and a confidence interval of ±0.8 in order to confirm an equivalence between a bird avatar and a human avatar under the combination of the flying condition and the human-features condition. As a result of the TOST-test, an equivalence between a human avatar and a bird avatar was confirmed(p=0.0340). Therefore, the results of Realness(Q4) indicate that the kinds of an avatar cannot affect Realness(Q4). However, there was a simple main effect between motion factors when participants operate a bird avatar(F(2,64)=77.7834, p<0.0000). As a result of multiple-comparison, the flying condition was significantly higher than the asynchronous condition and the synchronous condition (p<0.0000, p<0.0000). Therefore, this result indicates that the flying condition can enhance the sense of Realness(Q4) in the case of a bird avatar. Additionally, there was an interaction between avatar factors and character factors in terms of Realness(Q4) (F(2,64)=11.0072, p=0.0023). There was a simple main effect between character factors when participants operated a human avatar(F(1,62)=18.9474, p=0.0001). As a result of multiple-comparison, the human features condition was significantly higher than the bird-features condition (p=0.0001).

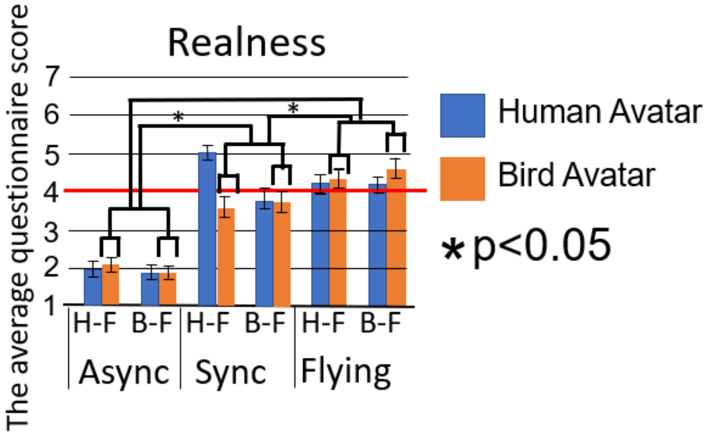


Fig.23 Rating Realness(Q4) (Error bar was shown as standard error)

4.1.7. Discussion

We discuss the possibility of inducing the sense of ownership by using the bird avatar from the results of MyBody(Q1) and Mirror(Q2) of experiment1. Our results indicated that the sense of ownership equal to a human avatar can be induced with the bird avatar since equivalence was confirmed by TOST between those avatars. Additionally, the synchronous condition and the flying condition can enhance the sense of body ownership even in a bird avatar, since these conditions were significantly higher than the asynchronous condition. This result was the same as with many previous works [37-40].

We now discuss the sense of immersion in the flying experience, from the score of Flying(Q3) and Realness(Q4) in experiment 1. The bird avatar was significantly higher than the human avatar in terms of the score of Flying. In contrast, in terms of Realness(Q4), a bird avatar is higher than a human avatar although there was no statistical difference between them. Thus, our results suggested that a bird avatar can enhance the sense of immersion in the flying experience. Here we discuss how consistency between the bird avatar and bird features (i.e. the flying condition and the bird-features condition (small size, the sound of flapping)) impacts the sense of ownership into a bird and the impression of virtual reality, from the questionnaire scores.

First of all, concerning the sense of ownership, there was no significant difference between the human-features condition and the bird-features condition from the scores of MyBody(Q1) and Mirror(Q2). Thus, our results indicate that consistency between a bird avatar and bird's features cannot enhance the sense of ownership into the bird avatar.

Next, concerning impressions of virtual reality, the bird-features condition was significantly higher than the human-features condition in terms of the score of Flying(Q3). However, there is no significant difference between a human avatar and a bird avatar on the score of Flying(Q3). Thereby, this indicates that the bird features condition can enhance the score of Flying(Q3) in both the human avatar and the bird avatar. In contrast, concerning the score of Realness(Q4), the flying condition is significantly higher than the synchronous condition in a bird avatar. It is assumed that consistency between the bird avatar and flying ability makes for greater realness in the flying experience. Likewise, the combination of a human avatar and the synchronous condition is significantly higher than other conditions in terms of the score of Realness(Q4). That is, flying ability, which is not an innate ability for a human, reduces the realness into the human avatar. However, the synchronous condition that is an innate ability for humans enhances realness for the human avatar. Taken together, our results indicated that consistency between avatars and an avatar's features (bird avatar and bird's features, human avatar and human-features) can enhance realness in a VR experience.

We now discuss the subjective impressions when operating a bird avatar from the interviews conducted in experiment 1. In the case of the combination of the flying condition and the bird features condition, there is a greater number of comments" I experience the bird as if I changed into the bird avatar" than for other conditions. This indicates that consistency between the bird avatar and a bird's features can change our body representation into a bird.

4.2. Exp1-2

4.2.1. Procedure

Pre-existing work has reported there is a process of comparison between our body representation and an avatar's visual form for inducing the sense of ownership [26, 27]. However, it is assumed that a deformed human avatar reduces the sense of ownership since the difference between the avatar's appearance and the user's body representation is remarkable. In experiment 2, we investigate the effects of the avatar's appearance to the sense of ownership.

In experiment 2, we used an avatar that had deformed body constructions such as arm size, pose, obese body and inverse leg as shown in Fig.24. We conducted the experiment the same as in the experiment 1 procedure. We set up only the synchronous condition and the flying condition in order to only focus on the avatar's appearance. Other experimental settings were the same as experiment 1. 16 out of 33 students who participated in experiment 1 participated in experiment 2 again. We compared to experiment 2 data with the result of experiment 1 data (i.e. among the same participant's data). We analyzed avatar factors (a human avatar versus a deformed human avatar versus a bird avatar) and motion factors (synchronous versus flying).

Fig.24 Deformed human avatar that resembles bird concerning pose and skeletal frame

4.2.2. Results

We show the results in Fig.25-26. These results compare between the result of experiment 1(a human avatar and a bird avatar) and a deformed human avatar with motion factor (the synchronous condition and the flying condition). We analyze results by ANOVA at a significance level of 5%. The error bar indicates standard error. 16 Toyohashi University of Technology students who do not know our purpose participated this experiment with informed consent.

There was an interaction between avatar factors and motion factors in terms of MyBody (Q1) (F(2,30)=12.7204, p=0.0001). There was a simple main effect between avatar factors under the flying condition (F (2, 30) =5.6540, p=0.0082). As a result of multiple comparisons, a human avatar and a bird avatar were significantly higher than a deformed human avatar (p=0.0011; p=0.0226). However, there was no significant difference between a bird avatar and a deformed human avatar under the synchronous condition. There was a main effect between avatar factors in terms of Mirror (Q2) (p<0.0000). As a result of multiple comparisons, a bird avatar and a human avatar were significantly higher than a deformed avatar under both the synchronous condition and the flying condition (p=0.0002; p=0.023). Taken together, the results of experiments 1 and 1-2 suggested that anatomical inconsistency reduces the sense of ownership for a human-like avatar.

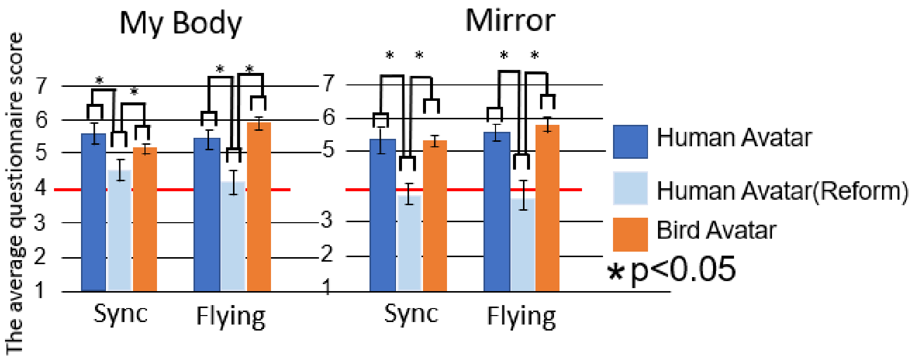


Fig.25 Rating MyBody(Q1) and rating Mirror(Q2) in Exp1-2

(Error bar was shown as standard error)

Concerning a sense of flight, there was significant difference between motion factors (F(2,30)=5.5601, p=0.0088). As a result of multiple comparisons, the bird avatar was significantly higher than the human avatar and the deformed human avatar under the flying condition (p=0.0005; p=0.0126). It suggested that the bird's appearance can enhance a sense of flying.

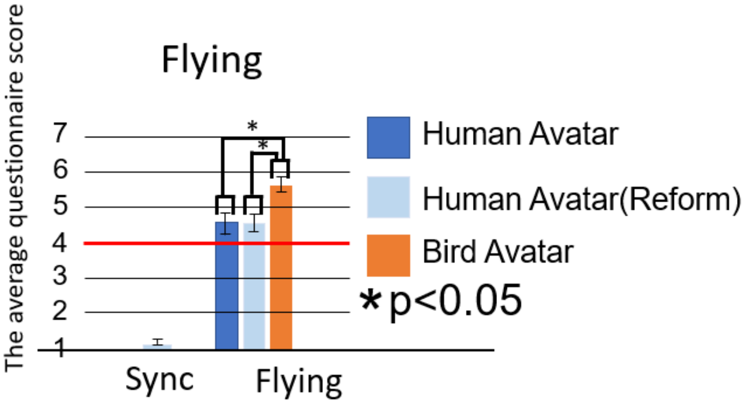


Fig.26 Rating Flying in Exp1-2

(Error bar was shown as standard error)

Concerning a sense of realness, there was an interaction between avatar factors and motion factors (F(2,30)=9.0304, p=0.0009) (See Fig.27). There was a simple main effect under both the synchronous condition and the flying condition (F(2,30)=9.0304, p=0.0003; F(2,30)=18.8539, p<0.0000). As a result of multiple comparisons, the human avatar was significantly higher than the deformed human avatar and bird avatar under the synchronous condition (p=0.0011; p=0.0120). There was no difference between the deformed human avatar and the bird avatar. Under the flying condition, the bird avatar was significantly higher than the human avatar and the deformed human avatar (p=0.0295; p=0.0002).

It suggested that a degree of similarity of experience between the avatar's appearance and that avatar's actual form gives more realness under the synchronous condition. That is, in the case of human avatar, the combination of the synchronous condition and the human-features condition gives a greater sense of realness. Contrary to this, in the case of the bird avatar, the flying condition gives a greater sense of realness. Considering the sense of flying, a bird avatar gives a greater sense of immersion in the flying experience than a human avatar.

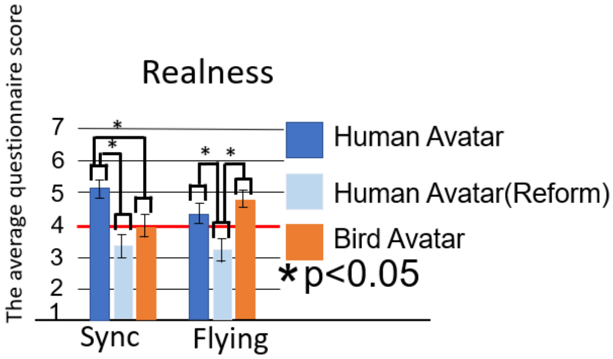


Fig.27 Rating Realness(Q4) in Exp1-2

Self-Report

After experiment 2, we asked participants to offer their subjective impressions of virtual reality when they operated a deformed human avatar. The following shows those comments which were characteristic and common.

Common comments among conditions:

・I felt that a deformed human avatar gives us the feeling of our arm becoming heavy.

・I did not find it possible to become an avatar, because I felt discomfort concerning the difference of body construction between the user’s body representation and the deformed human avatar’s appearance.

The synchronous condition:

・I do not feel creepy when I operate the bird avatar. Therefore, I can feel a feeling of becoming a bird avatar.

・I observed the differences concerning body construction in detail, though I did not feel discomfort from a subjective perspective.

The flying condition:

・In the case of a bird avatar, I felt the sense of flying, as if “A bird flying in the sky”. However, in the case of a deformed avatar, I felt the sense of flying, as if I fly in the sky like a glider.

・Discomfort in flying experience was emphasized since there was a stronger difference concerning body construction than a bird avatar.

・I felt becoming into a bird avatar since I can fly. However, there were some comments which referred changes in body representation into an avatar. On the other hand, many comments referred that participants felt discomfort and a decline in the sense of ownership to a deformed avatar since differences between a deformed human avatar and their body representation were more strongly notable than those with the bird avatar.

4.3. Discussion

Turning to the effects of the avatar's appearance for the sense of ownership from the results of experiment 2. There was no significant difference between a deformed human avatar and a bird avatar under a synchronous condition in terms of MyBody(Q1). In contrast, a deformed avatar was significantly lower than a bird avatar in terms of Mirror(Q2). Furthermore, a deformed human avatar is significantly lower than a bird avatar in terms of both MyBody(Q1) and Mirror(Q2) under the flying condition. Therefore, our results indicate that the appearance provided by the deformed human avatar significantly reduced the sense of ownership. It is assumed that the decline of the sense of ownership under the synchronous condition in terms of MyBody(Q1) is due to differences in how the questions were asked between MyBody(Q1) and Mirror(Q2). That is, participants can observe a difference between their own body construction and a deformed avatar in detail from the mirror. Furthermore, it is assumed that a deformed human avatar's appearance is the cause of decline in the sense of ownership, because a bird avatar can induce a sense of ownership at the equivalent of a human avatar and from the participant's comment " difference between own body and a deformed avatar's body are emphasized due to there being such a remarkable difference".

5. Exp2: Improving the sense of the size of a vehicle using IVBO

5.1. Purpose

In this research, we aim to improve the sense of the size of a vehicle by inducing IVBO. We hypothesize a drone shaped avatar can improve the sense of the size of a vehicle by obtaining IVBO. In Exp2, participants are instructed to aim for the destination while avoiding obstacles (See Fig.28). Specifically, we carry out an experiment that participants aim for a destination while passing through rings as practical situation.

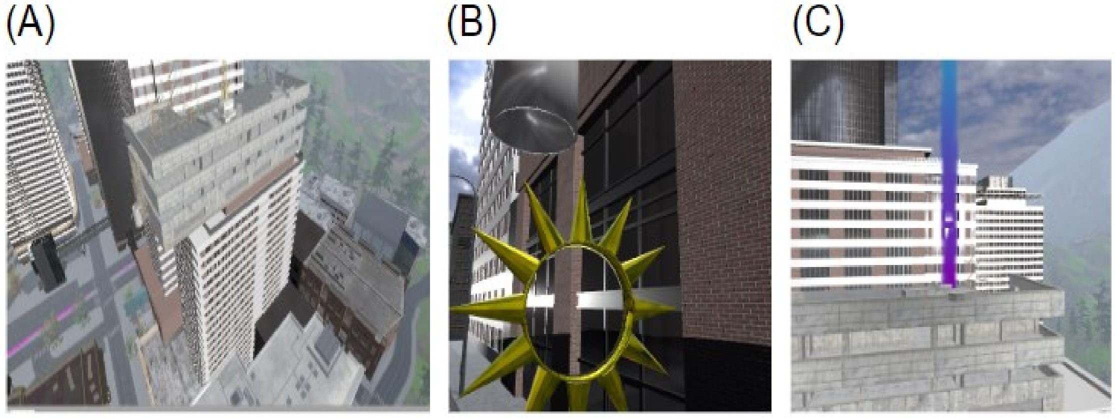


Fig.28 VR Environments

5.2. Condition

We set up 4 conditions the human avatar conditions, the dragon avatar condition, and the no-avatar condition. Participants are instructed to manipulate either a human avatar or a dragon avatar or a bird avatar or an invisible avatar（See Fig.29）. In the no avatar condition, we did not depict an avatar. We develop an experience that hang an avatar on a drone (See bottom picture in Fig.30) in consideration of practical application. We use DJI Phantom that is a popular drone as a drone

3D model. The size of drone was 50cm (width) x 50cm (length) x 30cm (height). We located a a collision detector at the drone body. We did not include an avatar as a collision detector. We calculated the number of hitting to rings and obstacles based on this collision. The virtual camera that is a user's perspective was located at an avatar's eye position (See right picture in Fig.39). In conditions that represents an avatar, participant can see an avatar body when they look down their own body and extend their arm forward (See Fig.38(A)～(E)). In the case of the no avatar condition, participants can see only drone's wings (these wings can be seen in other conditions). The size of a human avatar was modified depending on a participant height. Sizes of a dragon avatar and a bird avatar were changed to the size of a drone (See bottom picture in Fig.38). We show the picture that depicts avatars on the same location to be easy to understand sizes of avatars.

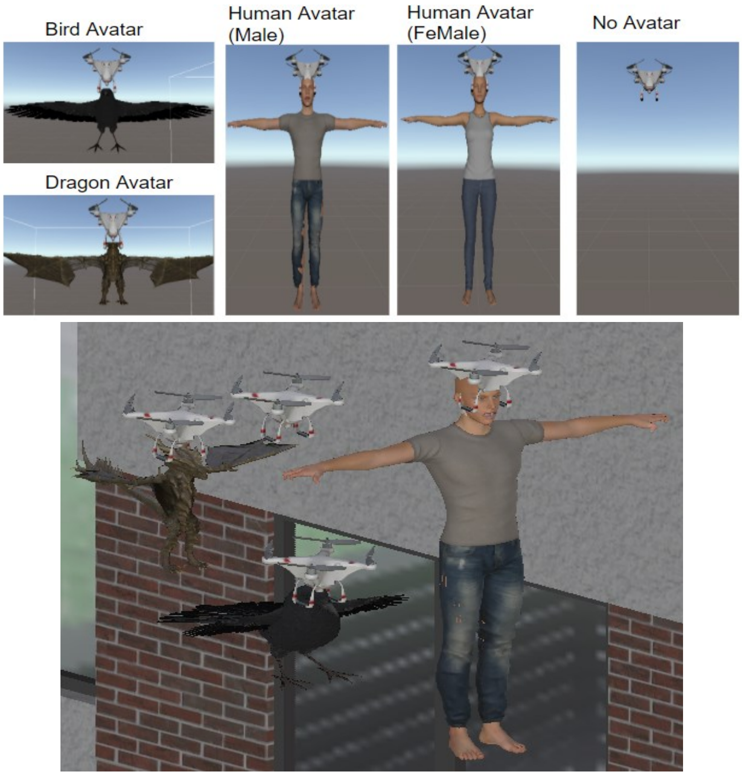


Fig.29 Avatars

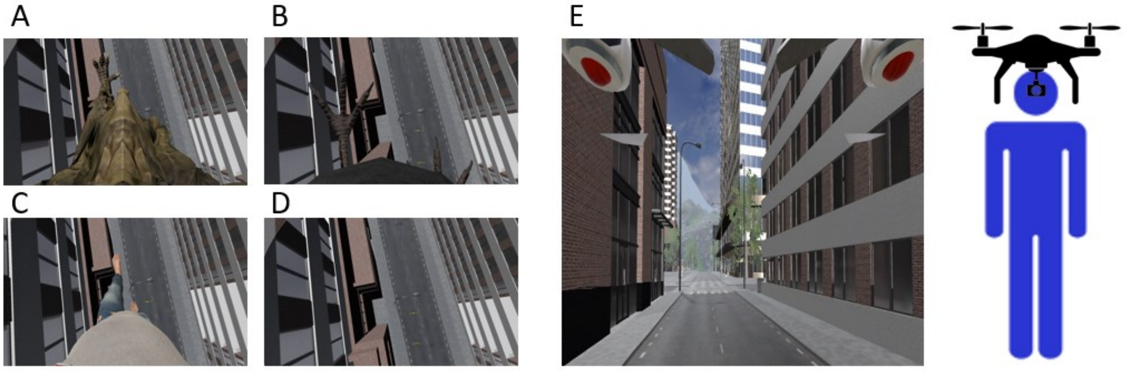


Fig.30 Perspectives from each avatar (A: dragon avatar B: bird avatar C: human avatar D: drone avatar E: perspective when a user looks forward)

5.3. Apparatus

Participant's movements are captured with HTC Vive wearable Trackers on 6 locations of body (both hands, both legs, hip, and head). Additionally, each avatar's body position was calculated using Final IK. Users participated by download this experimental application. FPS of this program was depended on participant's PC. This program was run with approximate 80 FPS on the experimenter's environment (GPU: GeForce RTX 2080, CPU: Intel Core i7-9750H).

5.4. Procedure

Upon arriving at the laboratory, participants are received an explanation of experiments by an experimenter. Once understanding the contents of experiments, participants put on equipment for experiments. Participants are instructed to aim for the destination while avoiding obstacles and passing through rings. It takes about 10 min for each condition. We describe entire experiment procedure in Fig.31.

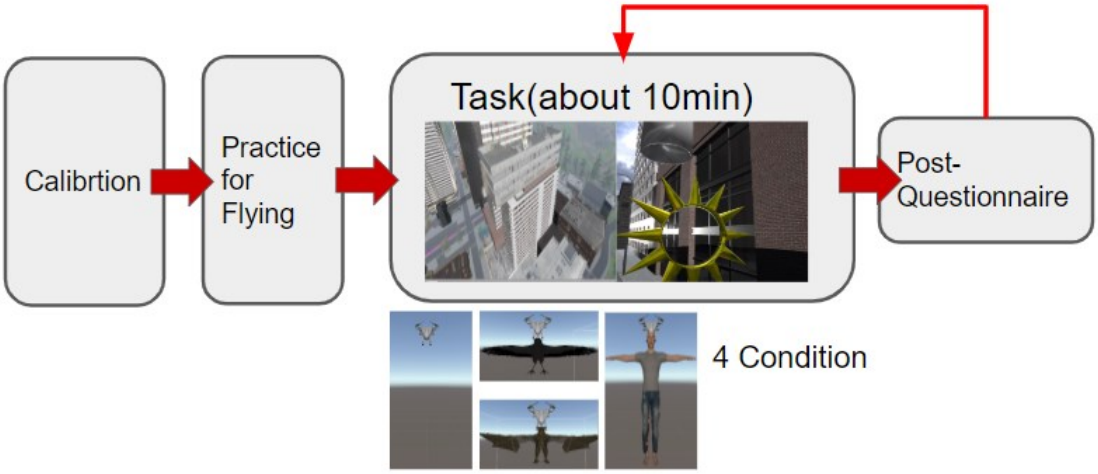
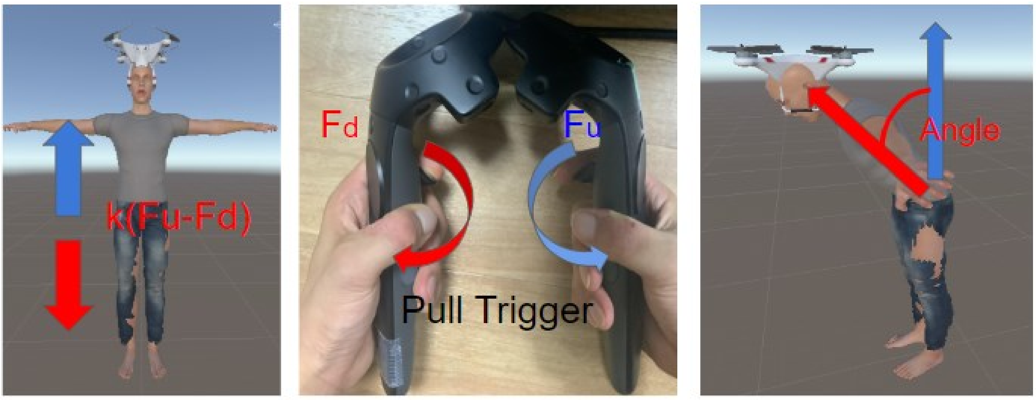


Fig.31 Experimental Flow

5.5. Flying manipulation scheme

We developed NUI flight system, because the sense of body ownership is a feeling depending on body movement. We reference the Fly jacket to make a NUI [11]. This system adds directional forces using a user's body tilt. For instance, participants can move forward when they take a forward - bent posture. Participants can also move to omni direction using this manner. Furthermore, move can be modified depending on a angle of body tilt. Participants can also move upward and downward by pulling a trigger of controllers. This system adds upward force **Fu** to a drone avatar by pulling a trigger of a left controller. It also adds downward force **Fd** to a drone avatar by pulling a trigger of a left controller. Finally, it adds summed these forces to a drone and move (coefficient k indicates move speed) (see Fig.32).



F=k(Fu-Fd)+MoveDirection*Angle
(※) A is the direction in which the subject leans

Fig.32 Manipulation Method

5.6. Evaluation

In this research, we use the frequency of collision with obstacles, the frequency of collision with obstacles, and time to achieve destination, as objective scores.

5.7. Results

33 online users participated in Exp2-2. Participants understood as informed. We show our results in Fig.33-34. We adapt normality test (Shapilowilk test) to examine normality. However, all scores were not normal distribution. Thus, we analyze our scores with the multiple comparison test holm method (significant level was 5%).

Our results show a dragon avatar significantly reduce the collision frequency to rings, in comparison to a drone condition. Furthermore, entirely, conditions that induce the sense of body ownership (i.e., a human avatar condition, a dragon avatar condition, and a bird avatar condition) improve task performances (i.e., the frequency of collision with rings, the frequency of collision with obstacles, and the time required to arrive at the destination). However, we point out that there are no significant differences between conditions.

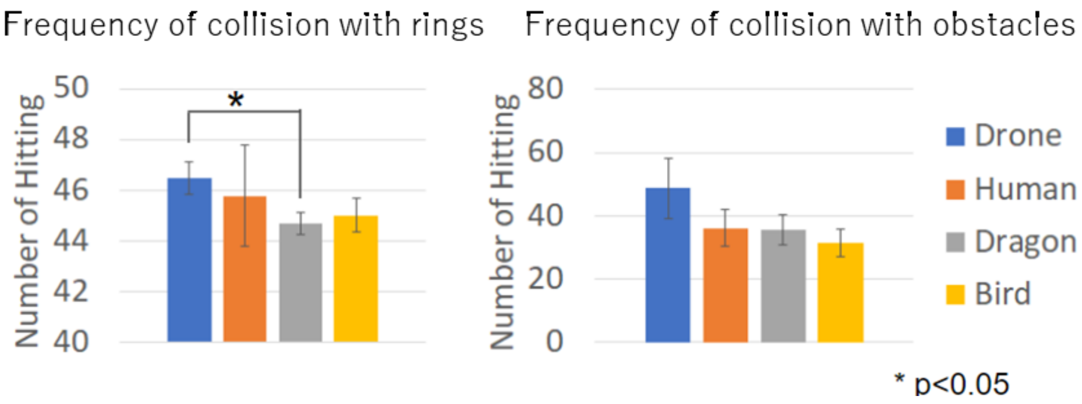


Fig.33 The collision frequency to rings and the collision frequency to obstacles

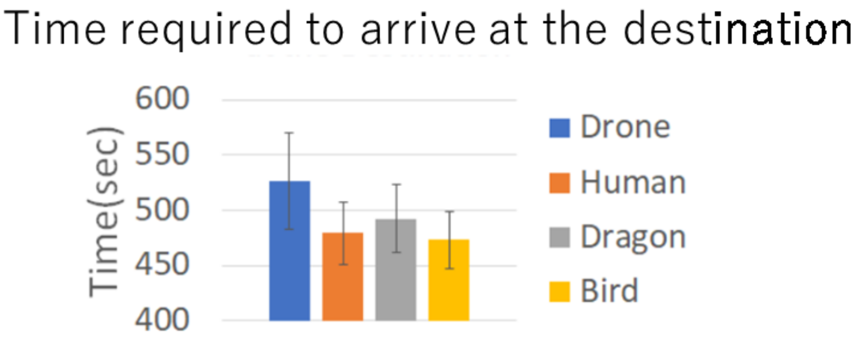


Fig.34 The required time for arriving at the destination

5.8. Discussion

Our results indicate that inducing the sense of body ownership can significantly improve task performances for spatial awareness. Especially, a dragon avatar can easily to interact with the environment (i.e., passing through rings). Previous work has reported that a peripersonal space that is important for spatial awareness can be modified depending on an avatar property (e.g., a shape and a size). Specifically, they have reported that inducing the sense of body ownership over a tall size avatar can extend a peripersonal space. Thus, there is possibility to shrink PPS to a drone shape by inducing the sense of body ownership over a dragon avatar. As a result, it can lead to easily to interact with the environment.

5.9. Conclusion

We carried out the experiment to examine the effectiveness of the sense of body ownership over a drone shaped avatar (i.e., a dragon avatar and a bird avatar). Additionally, we developed a practical task for manipulating a drone. We setup 4 conditions a drone condition, a human avatar condition, a bird avatar condition, and a dragon avatar condition. Participants are instructed to aim for the destination in virtual environment while passing through rings.

As results, a dragon avatar significantly reduces the collision frequency to rings. Furthermore, entirely, conditions that induce the sense of body ownership (i.e., a human avatar condition, a bird avatar condition, and a dragon avatar condition) could improve task performances (the collision frequency to rings, the collision frequency to obstacles, the required time for arriving at the destination). These results imply the sense of body ownership can construct the sense of the size of a vehicle. Furthermore, the sense of body ownership is effective for manipulating a drone, because we carried out a practical task. It can be expected the sense of body ownership improves our spatial awareness on the flight tele-existence. Especially, a drone shaped avatar can easily to interact with the environment (e.g., dodge obstacle, entering to narrow space, approach to targets, and adjustment a fine position).

6. Exp3: Reducing the fear of heights using the Proteus effect of a dragon avatar

6.1. Purpose

Results of Exp1 indicate that the sense of body ownership can be induced even in an un-humanlike avatar such as an animal. We aim to reduce the fear of heights using the proteus effect of an animal avatar. We choose a dragon avatar, because it has a flight ability and a strong body. In this experiment, we examine how a dragon avatar affects

6.2. Apparatus

The experimental program was developed using Unity 2018.3. We run this program with the computer installed with CPU (Intel(R) Core(TM) i7-7700K (4.20GHz， 4.20GHz)), and GPU(GeForce GTX1080), and memory(16.0GB). This program was run with approximate 80 FPS. We used HTC Vive Pro for presenting visual information (resolution per eye:2880 x 1600, refresh rate 90Hz, filed of view 110 deg). User’s entire body motions were captured by MVN X-Sense (latency 20ms).

6.3. Conditions

Results of previous study shows that it is important to induce the proteus effect. Thus, we setup the dragon scenario condition and the human scenario condition. Participants manipulate avatars shown in Fig.43. In the dragon scenario condition, participants manipulate the dragon avatar (Fig.35(upper left)). In the human scenario condition, participants manipulate the human avatar (Fig.35(lower left)).

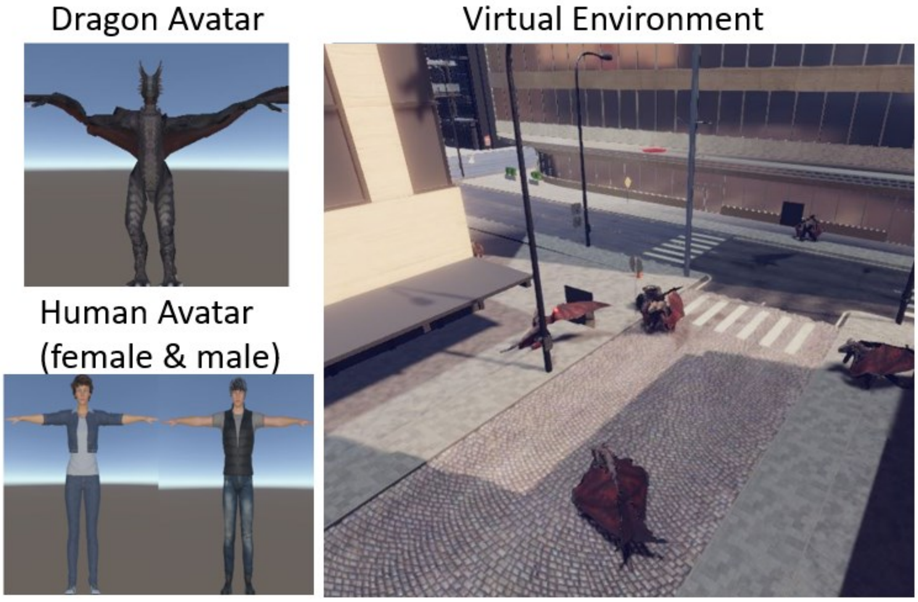


Fig.35 Conditions: Dragon Avatar, Human Avatar and Virtual Environment.

6.4. Procedure

Upon arrival at laboratory, participants understood as informed consent. Participant wear MVN-XSense and Vive Pro, and experimenter conducted on calibration for motion capture suit.

VR environment shown in Fig 35(right) were presented on VR HMD. There were Mirror in front of an avatar in VR environment. Participants could confirm motion synchronization between their self and an avatar via this mirror and from the first-person perspective. Participants were instructed to do following procedure on starting program.

1. Raising each hand respectively and checking that situation through the first person perspective and mirror.
2. Looking down their own body and putting each leg respectively. Participants are instructed to see this situation through the first-person perspective and mirror.
3. Taking a forward leaning posture and checking their posture via mirror.
4. Sitting there and checking this situation via mirror.

5. Walking in all directions and Turning to right direction and left direction.
6. Checking the motion synchronization between an avatar's movement and user's movement by moving their own body freely for 20 seconds.

After done above procedure, participants were instructed to spread both hands. The experimenter stroke participant's hands. We also represented the red cube at an avatar's body parts corresponding with participant 's body parts at the same time (See Fig. 36(right)). The red cube was moved depending on amounts of pulling trigger between joints. After confirming visuo-motion synchronization and visuo-tactile synchronization, participants were instructed to move toward characters located in VR environment by taking flight gesture. They are also instructed to interact with those character. After interacting with 5 characters, participants were instructed to move front of the lift shown in Fig. 37(left). Then, an experimenter putted a board in front of a participant in the physical environment. Once an experimenter puts a bord, participants were instructed to ride a lift (i.e., a board were depicted as a lift in virtual environment). The lift on which the subject rides move upward in steps of 5 meters. Participants were instructed to looks around heights and evaluate the subjective fear of heights, when a lift stop (see Fig. 45(right)).

Fig.36 Synchronous Stimulus. Regarding visuo-tactile synchronization, the red cube moves depending on amounts of pulling trigger between the position of a to the position of b in right figure.

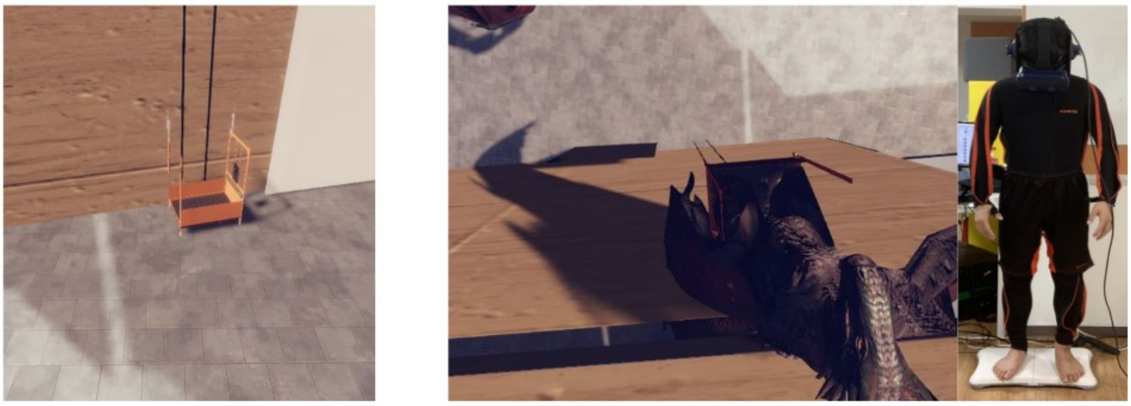


Fig.37 Locomote to upward using a lift

Previous study has reported that the fear of heights is saturated at 40m [65]. Based on this finding, the lift was raised from the ground (0m) to an altitude of 40m. After assessing fear at 40m, the trial was finished, and participants were instructed to answer questionnaires (see table4-5). Then, the same experiment was performed under different conditions.

In this experiment, participants could fly in the sky in addition to actual walking. Here, we explain how to fly in the sky. First, participants should flap by their hand to land. First, participants should flap by their hand to take off. Participants could move upward 1m by taking flapping gesture. Furthermore, participants could move toward gaze direction by taking a forward leaning posture. The altitude that can be moved by flying is limited 3m to prevent getting used to the heights.5. We show the entire experimental flow at Fig.38.

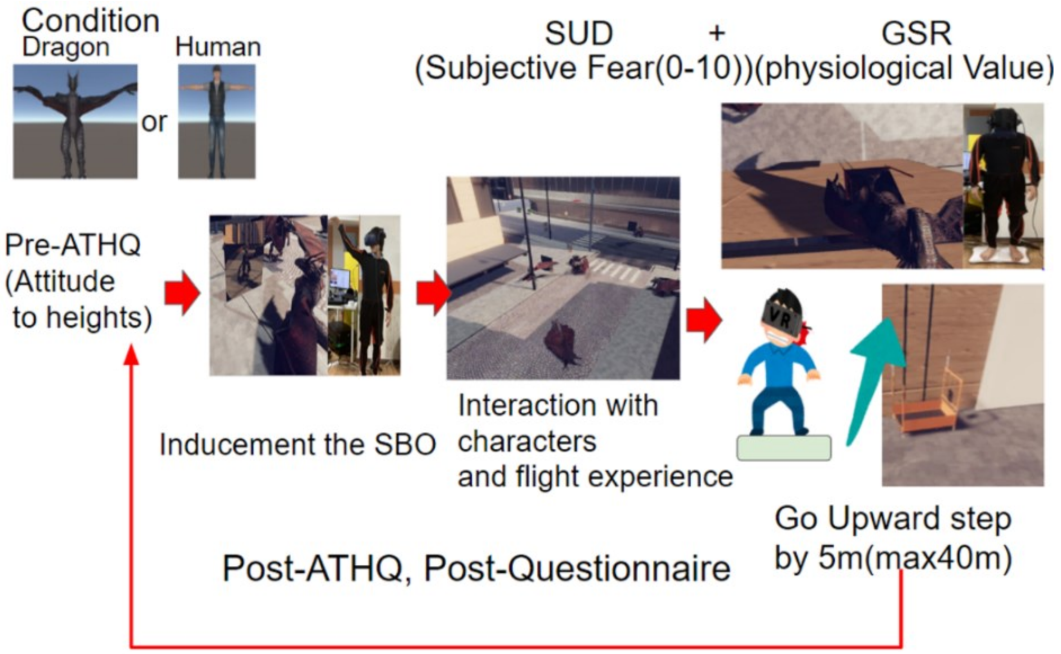


Fig.38 Precedure of Exp3

6.5. Evaluation method

6.5.1. Subjective score

Before the experiment began, participants were instructed to answer the prequestionnaire "Attitude Toward Height Questionnaire (ATHQ)" shown in Table 3 to evaluate the participant's impression of the height before the experiment [66]. ATHQ is a traditional questionnaire to assess an attitude toward the heights. ATHQ is composed of six questions about attitude to height based on the Semantic Differential (SD) method. The SD method evaluates the emotional image of a target on a scale of 5 or 7, using opposing adjective pairs (e.g., "light - dark", "artificial - natural"). For each question, we asked for answers in the range of 0 (positive attitude) to 10 (negative attitude). After completing one trial, they were instructed to answer a same questionnaire to investigate changes in attitude. We used the difference between the evaluation before and after experiment for the analysis.

Participants were instructed to answer "Subjective Unit of Disturbance (SUD)" from 0(not scary) to 10(very scary) every they participant stop at specific altitude [67]. SUD is a measure of subjective fear of heights. In addition, if a participant retires due to fear, we evaluated as 10(very-scary) for each SUD after retirement. After finishing each trial, participants were instructed to answer a questionnaire shown in Table. This questionnaire is composed of the sense of body-

Table.4 ATHQ

0	Good－Bad	10
0	Confort－Disconfort	10
0	Joy－Scary	10
0	Safe－Dangerous	10
0	Not Threat－Threat	10
0	Harmless－Harmfull	10

Table.5 Post Questionnaire in Exp2

No	Label	Question
Q1	Body Ownership	To what extent did you feel an avatar is your own body when you look down your body
Q2	Body Ownership (Mirror)	To what extent did you feel an avatar is your own body when you look at a mirror
Q3	The Sense of Transformation	To what extent did you feel as if you transform into an avatar
Q4	The Anxiety to a Fall	To what extent did you feel the anxiety of falling when you look down ground
Q5	The Fear of Heights	To what extent did you feel the fear of heights through entire experience
Q6	The Sense of Flight	To what extent did you feel the feelng of flight as if you fly in the sky
Q7	The Sense of being a Strong Body	To what extent did you feel being a strong body

ownership, the sense of flight1(i.e., a feeling as if they fly in the sky), the sense of transformation(i.e., a feeling as if they transform into an avatar), the sense of being a strong body, the anxiety for falling and the fear of heights through entire experiment. After finishing each trial, participants were instructed to answer a questionnaire shown in Table4. This questionnaire is composed of the sense of body ownership, the sense of flight1(i.e., a feeling as if they fly in the sky), the sense of transformation(i.e., a feeling as if they transform into an avatar), the sense of being a strong body, the anxiety for falling and the fear of heights through entire experiment. Each question item has a seven-step Likert scale, and "1" is not felt at all, and "7" is felt very strongly.

6.5.2. Objective score

Galvanic Skin Responses (GSR) are used as an assessment value to intensity of emotional state, because sweating increases when exposed to threats. Galvanic skin reaction is also used as an indicator of fear response in the task of measuring fear at height [65]. Thus, we use GSR as a reaction to the fear of heights. We used the GSR obtained by subtracting the average of the resting time when on the ground from the maximum value of the response value acquired from the time when they stop at a specific altitude.

6.6. Results

31 participants took informed consent and participate before participating in the experiment. One of them reported VR sickness and stopped the experiment. In addition, there were two participants who retired, because they could not endure the fear of heights. However, we started next condition, because they had intention to continue the experiment. The SUD of the retired participant was evaluated as 10(very scary) as described in Section 5.1.5.1. In addition, the GSR of the retired participants were not used for the analysis because they could not be compared.

6.6.1. Objective scores

In results of ATHQ (See Fig.39), regarding all items except "good-bad", the dragon scenario condition is significantly lower than the human scenario condition (“comfortable-uncomfortable”: $t = -3.462$, $p = 0.0020$, “fun-frightening” : $T = 3.2262$, $p = 0.0036$, "safe-dangerous": $t = -5.9167$, $p = 0.0000$, "non-threatening-threatening": $t = -3.8189$, $p = 0.0008$, "harmless-harmful ": $T = -5.4944$, $p = 0.0000$). This result show that manipulating the dragon avatar improved the attitude to altitude and changed it to a positive evaluation.

In post-questionnaires(See Fig.40), there were significant differences were observed between avatar conditions regarding anxiety of falling, the fear of heights, and the sense of being a strong body (anxiety of falling : $t = 3.7911$, $p = 0.0007$, the fear of height: $t = -5.5482$, $p = 0.0000$, the sense of being a strong body: $t = 5.2976$, $p = 0.0000$). This result show that manipulating the dragon avatar reduces the negative impression of the altitude compared to manipulating the human avatar. Regarding SUD(See Fig.41), there were significant differences between avatar conditions at all altitudes except 10m (5m: $t = -3.2625$, $p = 0.0033$, 15m: $t = 3.7039$, $p = 0.0011$, 20m: $t =- 3.4641$, $p = 0.0020$, 25m: $t = -4.3296$ $p = 0.0000$, 30m: $t = -4.8614$, $p = 0.0000$, 35m: $t = -5.5$ $p = 0.0000$, 40m: $t = -5.547$, $p = 0.000$). This result show that manipulating the dragon avatar suppressed subjective fear of heights.

Additionally, two participants retired because they could not endure the fear of heights. One of them retired at the stage of 20m in the human scenario condition, while the dragon avatar was able to continue the experiment to the end. The other person retired at 15m in the human scenario and retired at 30m in the dragon scenario.

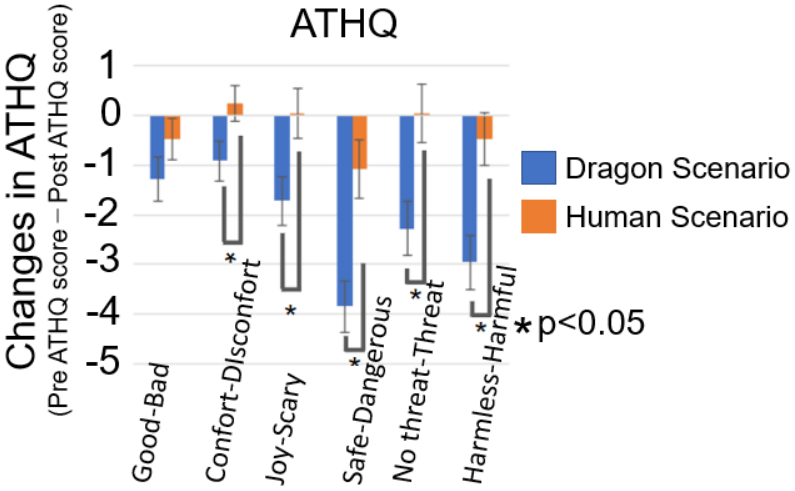


Fig.39 Results of ATHQ (Error bar shows standard error)

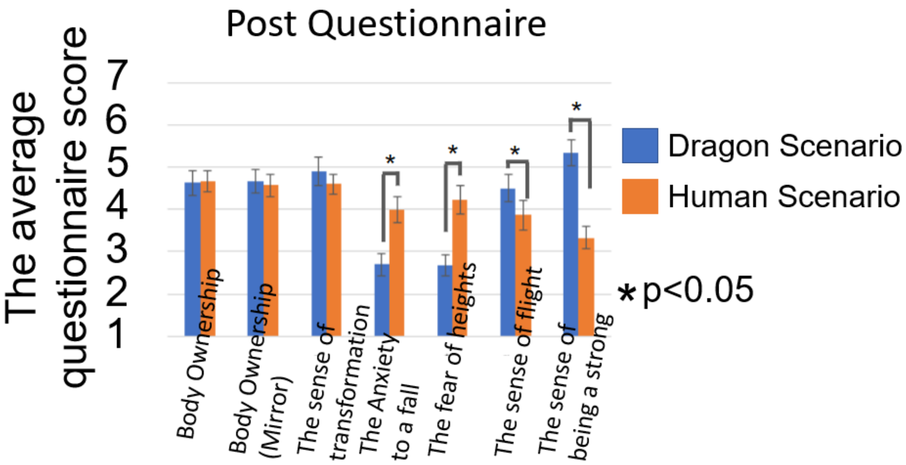


Fig.40 Results of post-questionnaire (Error bar shows standard error)

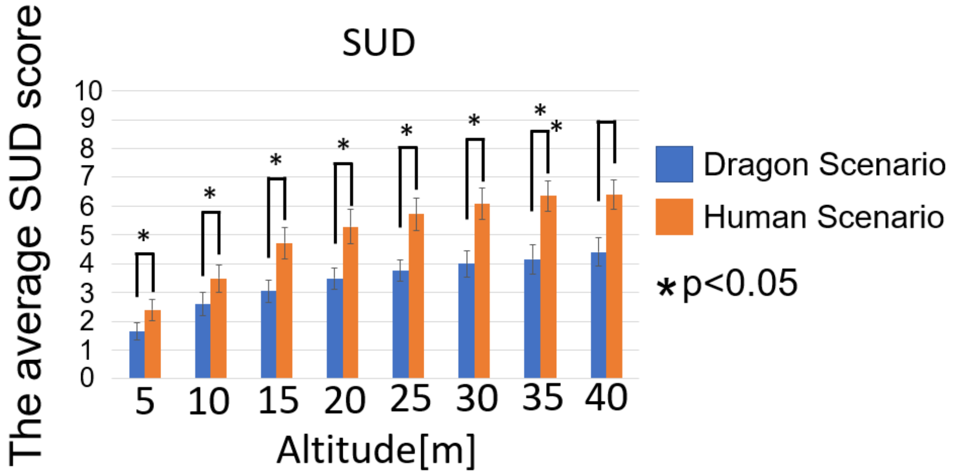


Fig.41 Results of SUD (Error bar shows standard error)

6.6.2. Subjective scores

We use 23 data that were subtracted corrupted data and retired participant's data to analysis. As a result of the analysis(See Fig.42), there were significant difference between avatars for GSR at 5m, 10m, 25m and 30m (5m: V = 61.5, p = 0.03356, 10m: V = 59.5 , p = 0.02815, 25m: V = 60, p = 0.03012, 30m: V = 55, p = 0.03426). This indicates that the use of dragon avatar can suppress the fear of heights felt at specific altitude (5m, 10m, 25m and 30m).

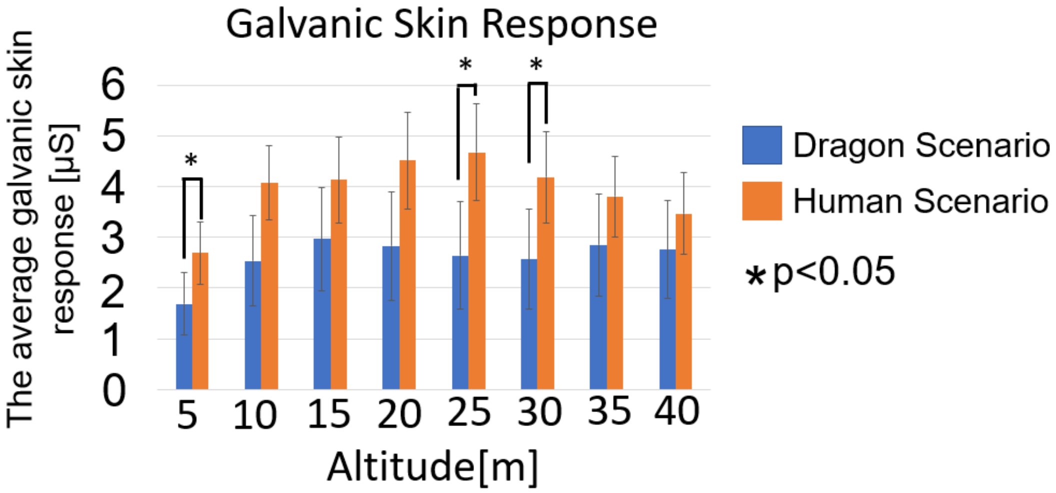


Fig.42 Results of Galvanic Skin-conductance Reaction (Error bar shows standard error)

6.6.3. Self-Reports

We could collect following comments.

・I could not think that it was okay in the case of the human avatar, even after flying … 11

・Even if I fell, I thought I should fly in the sky because of the wings, so I was not worried about the fall … 17

・I felt the VR experience was more real in the dragon avatar condition than the human avatar condition. … 6

・The VR experience of the dragon condition was as real as the human condition. … 6

・I felt the VR experience was more real in the human avatar condition than the dragon avatar condition. … 3

・I felt that I was not safe if I fell from a human avatar. …2

・When I manipulate a human avatar, I feel weak at the knees.

・In the human avatar condition, I'm getting scared of height.

・I could not look around, in the case of the human condition.

・The fear I felt when I ride a lift(at the ground) in the case of the human avatar was same the fear I felt when I go toward the highest place in the case of the dragon avatar.

・he dragon avatar reduce the fear of heights by about half compared to human Avatar.

6.7. Discussion

As a result of the ATHQ, all items except for "good-bad" showed improvement in the dragon scenario condition. SUD was also effective in suppressing fear except at an altitude of 10m. In the post- questionnaire, there were improvements in terms of anxiety of falling, fear of heights and the sense of being a strong body.

As a result of GSR, the dragon avatar significantly reduces the fear of heights at the specific altitude (5m, 10m, 25m and 30m). Thus, the dragon avatar can suppress the fear of height even in a potential parameter.

This suggests that even if users have an experience that they get a supernatural power in VR experience, if a user manipulates a normal human avatar, there is a possibility that users are influenced by human's mental models. On the other hands, in Dragon Avatar, it is possible that the mental model was not human even though he lived on the human body in his life and operated the avatar for a short time. In summary, his body image was corrected by the dragon's impression and strongly influenced his attitude toward heights.

7. Discussion and contributions

In this chapter, we discuss the experimental results and describe the contribution of this study. We aimed to develop a support system for the sense of the size of a vehicle and emotional control. We investigated how avatar properties (e.g., size, shape, and appearance) affect the sense of the size of a vehicle and emotional control. We hypothesized that a drone-shaped avatar can easily to interact with the environment, owning to modified the PPS. In addition, we also hypothesized that a non-humanoid avatar that has flight ability (e.g., a bird and a dragon) can reduce the fear of heights. However, almost all previous works have not utilized a non-humanoid avatar. Thus, in Exp1, we investigated the possibility of inducing IVBO over a non-humanoid avatar. In this experiment, participants manipulated either a bird avatar or a human avatar under particular conditions (the movement and feature factors) for approximately 3min. As a result of the ANOVA, in terms of body ownership, there were significant differences in the motion factor. In particular, the synchronous condition and the flying condition were significantly greater than the asynchronous condition. Furthermore, as a result of TOST, participants felt a sense of body ownership equivalent to that of a human avatar. These results show that IVBO can be induced by motion synchronization, even with a non-humanoid avatar (a bird avatar). These re1sults agree with those obtained in a previous work [37-40]. Furthermore, in Exp1, the deformed human avatar condition significantly reduced the intensity of the sense of body ownership, i.e., a human appearance is not suitable when using a non-humanoid avatar. It is assumed that the top-down factor that compares pre-existing body representation with the visual form reduces the intensity of the sense of body ownership because a deformed human avatar is unacceptable as our own physical body. In addition, our results also show that IVBO can be induced under the experience of flight. Thus, the results of Exp1 accomplished the first aim of the study. Furthermore, in terms of a sense of flight, there were significant differences between avatar conditions. The results show that a bird avatar provided a significantly greater sense of flight than a human avatar. This indicates that our mental model can be modified using an animal avatar. It also indicates that a sense of presence can be enhanced in a flight tele-existence; one purpose is to enhance the sense of presence at a distant location, even though a human does not have the ability to fly. It is assumed that a method that uses a non-humanoid avatar such as a bird is more effective than a human avatar. We could expand a flight tele-existence using the physicality.

In Exp2, we investigated how avatar properties (e.g., appearance, shape, and size) affect the sense of a vehicle. In this experiment, participants were instructed to aim for the destination as soon as possible while passing through rings of various diameters (from 30 to 80 cm). We set up 4 avatar conditions; a bird, a dragon, a human, and a no-avatar condition. The sizes of the dragon and bird avatars were changed to a drone shape, as much as possible. We hypothesized that IVBO over a drone-shaped avatar would help us interact with the environments, e.g., entering to narrow space, approach to desired targets, and obstacles avoidance, owning to the modified PPS. The results of multiple comparisons, there was significant difference between the dragon avatar condition and the no-avatar condition on the score of the collision frequency with rings. A dragon avatar could significantly reduce the collision frequency with the rings. Furthermore, entirely, conditions that induce IVBO (i.e., dragon avatar, bird avatar, and human avatars) improved task performance (time required to arrive at the destination, the collision frequency with the rings and obstacles). However, we note there were no statistical differences. These results indicate that IVBO can easily obtain a sense of the size of a vehicle. In addition, a dragon avatar can easily interact with the environment, i.e., passing through rings. There is no significant deferences between a bird avatar and a dragon avatar because of the intensity of the sense of body ownership. A bird avatar posture is more inconsistent with a user's body in comparison to a dragon avatar. Participants could not see the entire bird body when they looked down body because a bird's body is fat (a fat body prevents the user from seeing legs when they look down the body), which leads to a low IVBO.

Finally, we aimed to overcome the fear of heights for emotional control, using the Proteus effect of a dragon avatar. As result of the Wilcoxon rank sum test, regarding both subjective scores (ATHQ, post-questionnaire, and SUD) and objective factors (galvanic skin conductance), there were significant differences between a dragon avatar and a human avatar. A dragon avatar significantly reduced the fear of heights compared with a human avatar. ATHQ results show that the dragon scenario condition can improve a user's attitude towards heights. The results of the post-questionnaire (fear of heights and anxiety for a fall) and SUD show that the dragon scenario condition can significantly reduce the fear of heights. Furthermore, the dragon avatar condition can significantly reduce the objective fear of heights (galvanic skin conductance) at a specific altitude (25 m, 30 m). Post-questionnaire3e scores (a feeling of being a strong body and the sense of flight) and the self-report indicate that a dragon avatar can provide the feeling of being a strong body and the feeling of having the ability to fly. Additionally, it indicated that the reality of the experience of the dragon scenario condition was equivalent to that of a human avatar, i.e., these results were not led by a lack of the reality. Interestingly, in the case of a human avatar, participants could not imagine flying when they were exposed to heights, even though they experienced the ability to fly with either the dragon or the human. This implies that a dragon avatar facilitates the acquisition of the mental model of a specific experience that a human cannot experience, such as a flight. Hence, this result showed that some issues, such as the fear of heights, can be resolved by obtaining a mental model that differs from a human. Recently, drones that work in various fields, such as deep sea and space, have been increasingly developed [68, 69]. It is assumed that an environmental fear is caused even though the robots are tele-existent. The Proteus effect of a non-humanoid avatars is expected to be effective for emotional control, including those of non-humanoid tele-existence. In addition, the application possibility of the Proteus effect is expanded by using an animal avatar.

Our purpose is to develop a support system for the sense of the size of a vehicle and emotional control. Specifically, pre-existing support systems are insufficient, in terms of the sense of the size of a vehicle (i.e., maintaining a particular speed and distance between obstacles and a drone, danger prediction, and obstacle avoidance) and emotional control, at the tactical level of cognitive processes of driving a vehicle. Our results showed that the sense of the size of a vehicle and the fear of heights can be simultaneously improved by inducing IVBO over a non-humanoid avatar, such as a dragon. Typical support methodologies provide explicit information, e.g., a haptic feedback system and a stereoscopic camera. Therefore, the operators have to respond to the presented stimuli sequentially. In contrast, we have developed a novel methodology to support aspects of innate and psychological functions using IVBO, in which interoceptively exert actions.

8. Limitations and future works

We argued the cognitive process for a drone manipulation and identified that pre-existing systems are insufficient to support emotional control and the sense of the size of a vehicle. We aimed to resolve these issues by inducing IVBO over a non-humanoid avatar. Thus, in this study, we could construct novel IVBO-based manipulation for a drone.

In the discussion section, we noted that there was no significant difference between the bird condition and the drone condition because of insufficient intensity IVBO. In this study, we did not identify differences between a dragon avatar and a bird avatar. Thus, we need to investigate how intensity of IVBO affects task performances. Thereby, we can reveal the impact of IVBO over a non-humanoid avatar.

We could not deeply argue IVBO in this article. Previous works have reported that task performance for spatial awareness is modified depending on an avatar appearance. For example, Medeiros et al. have reported that a 3D-scanned avatar can improve task performance for the spatial awareness [51]. Additionally, we pointed out the importance of PPS as a mechanism to improve the sense of the size of a vehicle, however our results did not show how PPS affects the sense of the size of a vehicle. Furthermore, we did not investigate that modifying the size of an avatar could deformed PPS to a drone shape. Thus, we intend to investigate how PPS impacts the sense of the size of a vehicle, using Noel's methodology to evaluate the size of the PPS [70]. In their study, they assessed the distance of PPS by measuring the response time to a tactile stimulation corresponds in a looming sound after inducing the sense of body ownership to measure changes in PPS during the FBI. We can propose a novel framework and an effective index to create support systems for innate abilities by investigating these things.

Furthermore, the third-person perspective system is considered to be more effective than the first-person perspective, because users can experience a bird's eye view, using the third-person perspective. Patrick et al. reported that a third-person perspective can improve task performance [71-73]. Additionally, the sense of body ownership can be induced, even for an avatar that is viewed from a third-person perspective (i.e., out of body experience), and PPS can be transferred, based on the avatar position [22]. Suzuki et al. have already developed a system to manipulate a vehicle from a third person-perspective, using past pictures [74]. Thus, it may also be possible to develop IVBO-based system, from the third person perspective.

Furthermore, there are other way to build the physicality, such as galvanic vestibular stimulation and kinematic illusion. Additionally, Suzuki et al. reported that it is possible to obtain a body scheme over a common vehicle using transcutaneous electrical nerve stimulation [75]. Their study may effectively be applied to our work to obtain a sense of the size of a vehicle.

Taken together, we did not reveal the mechanisms for the IVBO based support system in this study. We intend to conduct experiments that change the avatar's properties (e.g., size, shape and appearance, and third-person perspective) to examine this. We will also investigate other method to construct the physicality, such as galvanic vestibular stimulation. Further studies are needed to reveal these factors.

9. Conclusions

We identified that there are no manipulation systems to support the sense of the size of a vehicle and emotional control. We hypothesized that IVBO, over a drone-shaped avatar, can easily interact with the environment. In addition, we also hypothesized that a dragon avatar, with the ability to fly, can reduce the fear of heights. Thus, we aimed to develop a support system for the sense of the size of a vehicle and emotional control using IVBO over a dragon avatar that is deformed to a drone shape avatar.

The results of Exp1 show that IVBO can be induced in a bird avatar. Furthermore, a human appearance significantly reduced the intensity of the sense of body ownership, i.e., a human appearance is not suitable when we use a non-humanoid avatar, owning to the top-down factor.

In Exp2, we examined how IVBO, over a non-humanoid avatar (i.e., a bird and a dragon), affects the sense of the size of a vehicle. As a result, entirely, IVBO can improve task performance, such as the time required to arrive at the destination, and the frequency of collisions with rings and obstacles). In particular, a dragon avatar significantly reduced the frequency of the collision with rings, in comparison to a no-avatar condition. Thus, IVBO is effective in obtaining the sense of the size of a vehicle. Additionally, our hypothesis that a drone-shaped avatar can easily to interact with environments was partly proved.

In Exp3, we examine how a dragon avatar affects the fear of heights. As a result, a dragon avatar can significantly reduce the fear of heights. Self-reports and post-questionnaire scores indicated that this result was led by the Proteus effect of a dragon avatar. A dragon avatar can induce the feeling of being a strong body. In addition, a dragon avatar is able to modify the user’s mental model and it provides the preconception that we have the ability to fly. Thus, our third purpose was accomplished.

Our results prove that hypotheses of this study (i.e., drone-shaped avatars enhance the ability of drones to interact, while dragon avatars suppress the fear of heights). Overall, the IVBO over Dragon avatar is effective in acquiring the sense of the size of a vehicle and emotional control, which are cognitive functions required in manipulating a vehicle. It is assumed that these findings become the principle of a support system using the physicality for the sense of the size of a vehicle and emotional control. However, in this study, we hypothesized that the PPS improves the task performance of drones by deforming an avatar into drone shapes, and conducted experiments that set up various conditions in terms of an avatar property (i.e., size and appearance). On the other hand, we have not conducted any experiments for the changes in PPS. Therefore, in the future work, we plan to conduct experiments that identify relationship between an avatar and the change in PPS to propose a novel manipulation reference framework using IVBO.

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Appendix

We describe video links of experiments below.

Exp1: https://youtu.be/FeHHuALhpGc

Exp2: https://youtu.be/yektFQZFbsM

Exp3: https://youtu.be/jLCKJXtzaZs