



Evaluation of visual, auditory, and olfactory stimulus-based attractors for intermittent reorientation in virtual reality locomotion

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Abstract

In virtual reality, redirected walking (RDW) enables users to stay within the tracking area while feeling that they are traveling in a virtual space that is larger than the physical space. RDW uses a visual attractor to the user's sight and scene manipulation for intermittent reorientation. However, repeated usage can hinder the virtual world immersion and weaken the reorientation performance. In this study, we propose using sounds and smells as alternative stimuli to draw the user's attention implicitly and sustain the attractor's performance for intermittent reorientation. To achieve this, we integrated visual, auditory, and olfactory attractors into an all-in-one stimulation system. Experiments revealed that the auditory attractor caused the fastest reorientation, the olfactory attractor induced the widest angular difference, and the attractor with the combined auditory and olfactory stimuli induced the largest angular speed, keeping users from noticing the manipulation. The findings demonstrate the potential of nonvisual attractors to reorient users in situations requiring intermittent reorientation.

Keywords Virtual reality · Redirected walking · Attractor · Auditory · Olfactory · Multi-modality

1 Introduction

Locomotion is a natural human behavior to navigate and avoid obstacles, even in a virtual environment (Cardoso and Perrotta 2019). Virtual reality (VR) systems, however, restrict the users' walkable space as the tracking area (safe area) in the real world and limit their movements to prevent collisions (Nilsson et al. 2018). VR systems use redirected walking (RDW), a locomotion technique that physically confines VR users to a limited tracking area to ensure their safety without interrupting their current locomotion

(Steinicke et al. 2008; Sun et al. 2020). Particularly, RDW techniques control the user's translation, curvature, bending, and rotation locomotion (Bruder et al. 2009; Interrante et al. 2006; Langbehn et al. 2017; Steinicke et al. 2009). Subtle RDW redirects the user's walking trajectory in a direction that is comfortable or minimal (Razzaque et al. 2001), whereas overt RDW interventions changing the walking direction of the user are easily noticeable (Suma et al. 2012). VR systems with overt RDW halt the user's movement and then reset or reorient the virtual scene or change its direction. The resetting technique intervenes and controls the VR user's heading when the user needs to change orientation, such as reaching the boundaries of the physical space (Suma et al. 2012; Williams et al. 2007). This effectively protects the user from risks, such as encountering virtual or physical boundaries and obstacles or getting stuck in a corner (Chen and Fuchs 2017; Cools and Simeone 2019).

Rotational RDW with an attractor (also called a distractor that acts as part of the user's activity, providing interactive and engaging experiences) is an overt continuous RDW technique that uses the reorientation-and-resetting method (Peck et al. 2009; Sra et al. 2018; Suma et al. 2012). This technique manipulates the user's trajectory by generating a rotational difference between the virtual and real worlds

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while the user concentrates on a visual object that emerges in front of them to draw their attention. Recently, scenario- or narrative-based attractors have been proposed to prevent breaks in presence and stop users while subtly reorienting them (Chen and Fuchs 2017; Sra et al. 2018). The attractor continuously demands attention from the user, by requesting eye contact or following the visual attractor, until the user reorients to the desired orientation. Thus, frequent interventions with increasing reorientation time impede the user's awareness (Peck et al. 2009, 2011). Therefore, to induce reorientation effectively and without disruption, it is necessary to broaden the difference between virtual and real orientations, allowing the user's direction to alter swiftly when an attractor appears. The angular difference represents the difference between the accumulated virtual orientation (i.e., the product of the rotational gain and the real direction changing per second) and the real orientation from the moment the attractor appears until the participant is aligned in the direction they should move.

Visual effects are popular as attractors. Such effects always appear in the user's field of view (FOV), and their reorientation performance varies with the shape, size, naturalness, and design of the animation (Cools and Simeone 2019; Gao et al. 2020; Peck et al. 2010). As the tracking area is constrained, the attractor can frequently reappear to reorient the user. However, this intervention could not only reduce the reorientation performance but also decrease

presence in the virtual space. Users who lose concentration in the virtual environment become disinterested and collide with objects in the physical space (Chen and Fuchs 2017; Nilsson et al. 2018; Sra et al. 2018). When users encounter the attractor frequently, they may either become accustomed and exhibit reduced attentiveness toward the attractor, or swiftly comprehend and predict its reorientation pattern. In the latter case, they might rely on their own predictions rather than the attractor's actual objective, which could potentially diminish its impact on reorientation. Here, an attractor capable of maintaining the user's presence without reducing its performance is required even with repeated attractor usage (Figs. 1 and 2),

A combination of a visual attractor and sound effect was designed to enhance the naturalness of the attractor, proving preferable over the visual attractor alone (Peck et al. 2009). In particular, an auditory attractor, which reorients the user solely by sound, provides a greater sensation of presence and naturalness than a visual attractor. The auditory attractor does not require appearance design or presence in the FOV of the VR user. Therefore, little time and effort are required to fabricate a wide variety of these attractors to perform RDW experiments. However, the rotational gain values causing the virtual and real directional inconsistencies of auditory attractors are smaller than those of visual attractors; thus, they still appear frequently and increase the reorientation time required to achieve the desired reorientation,

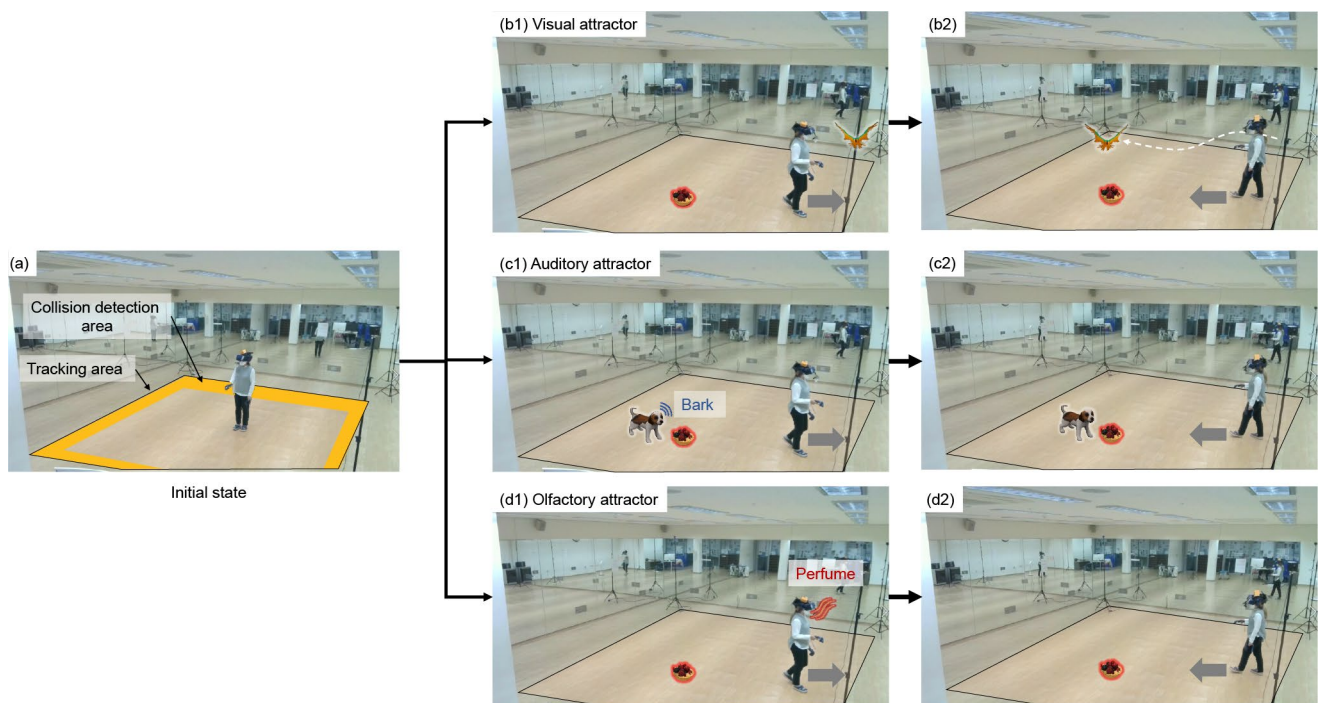


Fig. 1 Schematics of visual, auditory, and olfactory attractors. **a.** Initial state of the participant. When the user nears the collision-detection area and requires redirected walking (RDW) (**b1**), a visual attractor and target (snack) appear as the participant's destination appear in

front of and behind the user, respectively. **c1.** Auditory attractor and target are behind the user. **d1.** Olfactory attractor is perfumed from an all-in-one system, where the target is behind the user. (**b2**), (**c2**), and (**d2**) the user leaves the collision-detection area

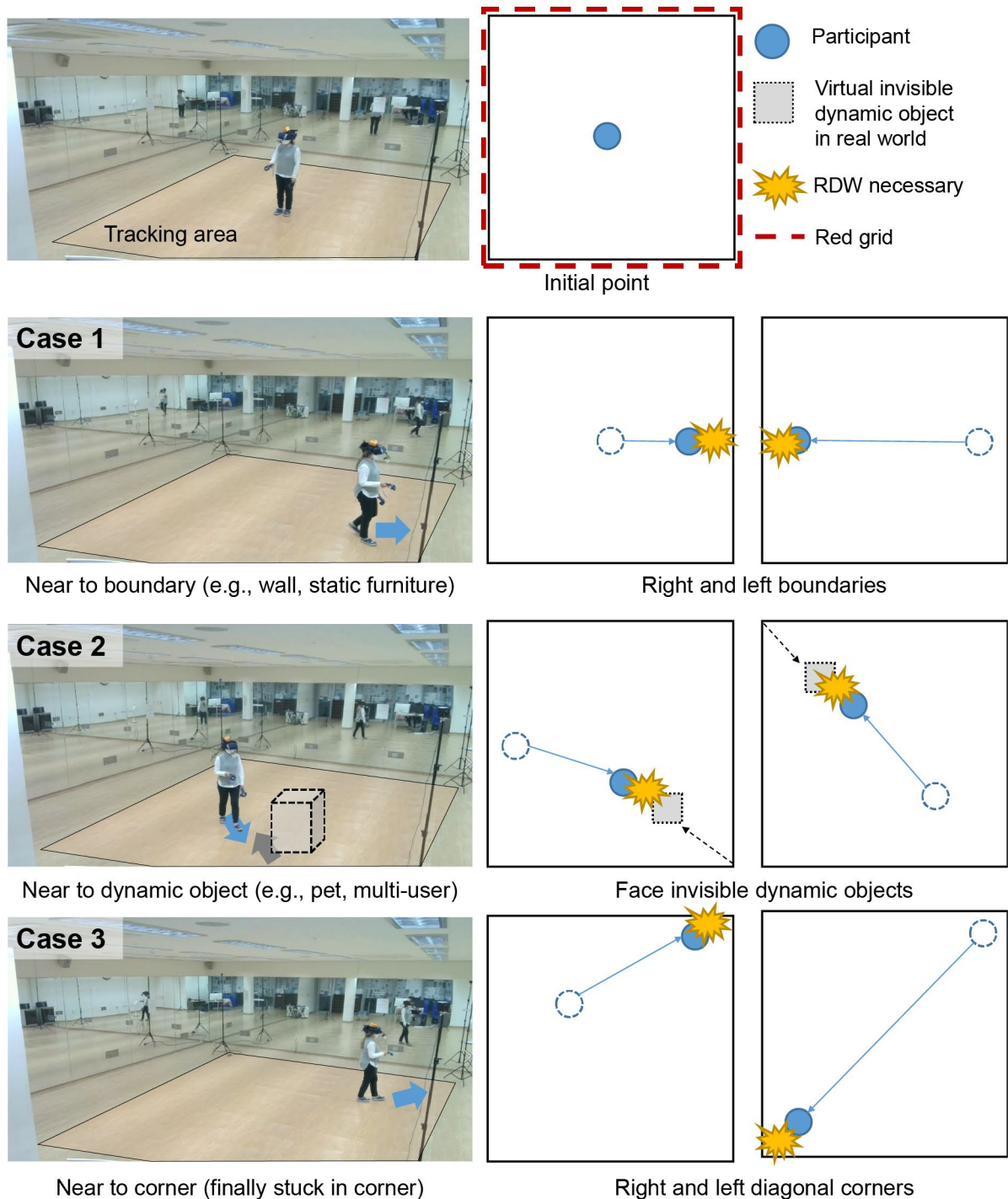


Fig. 2 Snapshots and schematic of the intermittent reorientation-necessary cases in which the participant nears the boundary, an invisible dynamic object, and a corner

as in the case of visual attractors (Junker et al. 2021; Serafin et al. 2013).

Scent can also reorient the user without changing the appearance of the stimulus, similar to the auditory stimulus. Sounds and scents can offer spatial information about the stimulus location, even if the source is behind the user or in

an ambiguous visual situation, without requiring continuous visual attention (Gao et al. 2020; Maggioni et al. 2020). Humans can navigate space based on cues from perceived olfactory stimuli (Hamburger and Knauff 2019; Jacobs et al. 2015), in particular stereoscopic olfactory cues perceived through both nostrils affected to determine the heading

direction (Wu et al. 2020). Interestingly, the user tends to gaze more widely to find the source of an olfactory stimulus than that of a visual or auditory stimulus, because the human ability to locate the source of an olfactory stimulus is inferior compared to that of an auditory or visual stimulus (Patnaik et al. 2018). When people smell and track a scent, they exhibit characteristic behaviors around the scent trail. When human participants performed a scent-tracking task using only smelling while other senses were limited, they did so by sampling scent signals by freely moving their noses and pathing in a zigzag pattern (Porter et al. 2007). In addition, in our previous study, we offered olfactory stimuli on the left- or right-hand sides of the participants' VR HMD earphones (refer to Fig. 3(a). Surprisingly, approximately 75% of the participants did not actually turn toward the olfactory stimulus; instead, they turned randomly and then looked around (Lee et al. 2022). Wandering behavior of the users causes them to frequently rotate their heads, which in turn provides the opportunity to accumulate rotational gain. In other words, if an olfactory stimulus is used as an attractor in VR locomotion, it should increase the rotational disparity between the virtual and real worlds, thereby contributing to broader user reorientation. Particularly, if significant reorientation needs to be induced intermittently in situations where visual attention cannot be continuously elicited from the user, these nonvisual attractors can help or replace visual attractors in a less explicit manner.

In this study, we considered four types of attractors that stimulate the visual, auditory, and olfactory senses; visual

(V), auditory (A), olfactory (O), and multi (AO)-attractors; in particular, the AO attractor used auditory and olfactory stimuli together (Fig. 1). The sensory stimulus was co-presented with a target object that the participant should find in the virtual space, and the target object was created rearward of the participant in the virtual space. The V stimulus was displayed within the participant's FOV, and the A stimulus was provided at the target object's location. Considering the randomly turning behavior (Lee et al. 2022), we then attached the olfactory stimulation system to the VR HMD to deliver an O stimulus in front of the participant. O stimulus provided a cue that encouraged participants to look around and reorient. The objectives were to increase the angular difference between virtual and real orientations and to decrease the reorientation time compared to that of the V attractor. A substantial angular difference requires minimal intervention and a brief reorientation time to effectively reorient the user in the desired direction. It was also necessary to study whether repeated usage of the attractors degraded the reorientation performance. Presence, VR sickness, and manipulation perception for the proposed attractors were assessed to prevent degradation of the VR experience. The research questions (RQs) were as follows:

RQ1. To help VR users avoid colliding with objects in physical space, which attractor can best induce a shorter reorientation time and larger angular difference between the virtual and real orientations? Additionally, can they sustain reorientation performance regardless of repeated usage?

RQ2. Does the look-around behavior induced by the proposed attractors make the user aware of visual scene manipulations during RDW? Does it reduce presence in virtual space or increase VR sickness?

We considered the following research hypotheses (RH):

RH1. A and O stimuli-based attractors induce larger angular differences between the virtual and real orientations, and longer attractor reorientation times than the V attractor. Given that the users frequently change their head orientation to search for the A or O stimulus (Patnaik et al. 2018), the angular difference increases, causing an increase in the reorientation time. We formulated the following hypotheses depending on the repetition of the use of the attractor: Participants will adapt to the V cues of the V attractor, quickly grasping its purpose, resulting in smaller angular differences and shorter reorientation times. The A and O stimuli used in our study serve as cues that induce the participants to reorient, in particular, the A stimuli also invisibly provide information about the location of the stimulus. In simpler terms, compared to interactions with V cues, participants have more opportunities to look around when interacting with A and O stimuli. Given that, the angular difference and reorientation time remain unaffected even when the attractor offering the A or O stimulus is used repeatedly.

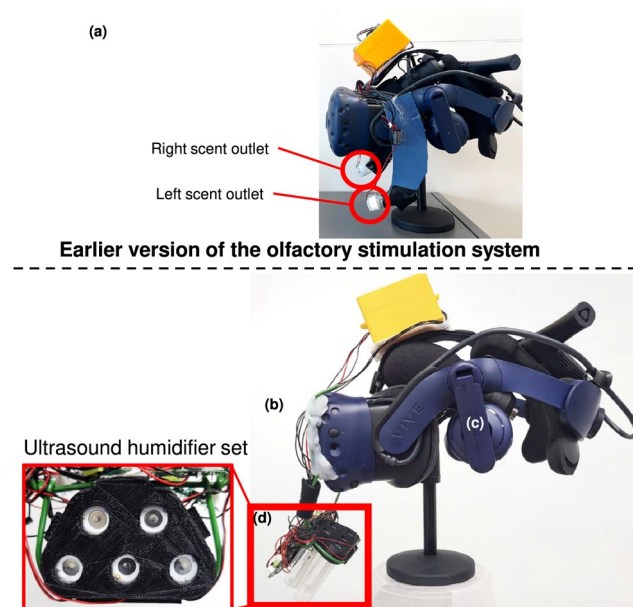


Fig. 3 Earlier version of the olfactory stimulation system (a). All-in-one visual, auditory, and olfactory stimulation system displays (b) visual attractor on the VR HMD, (c) auditory attractor sounded by the headset, and (d) olfactory attractor device attached to the VR HMD diffuses scents through an ultrasound humidifier setting

RH2. The user is more likely to perceive reorientation manipulation and experience higher levels of VR sickness when interacting with nonvisual attractors than the V attractor. We hypothesized that nonvisual attractors would encourage the participants to frequently look around and change their head orientation (RH1), resulting in increased exposure to manipulated VR scenes (i.e., virtual environments with RDW technology) compared to the V attractor. These VR scenes may induce discrepancies in visual-vestibular cues, which have been shown to contribute to VR sickness and manipulation perception (Peck et al. 2011). Therefore, we hypothesized that the use of nonvisual attractors increases the levels of manipulation perception and VR sickness, as these attractors allow for wider and longer visual observation of the manipulated virtual scenes. In addition, our use of a rotation gain above the threshold level reported in previous studies on redirected walking using audio stimulation (Junker et al. 2021; Nilsson et al. 2016) may also contribute to VR sickness and manipulation perception. However, our V, A, and O stimuli were matched to the task context and snack object characteristics that the user seeks. Therefore, nonvisual attractors do not diminish the user's sense of presence compared to the V attractor.

We analyzed the reorientation performance of attractors and their effects on presence, VR sickness, and manipulation perception. To the best of our knowledge, this is the first study to explore A, O, and AO attractors in the reorientation-and-resetting technique (Williams et al. 2007). In this study, we investigated whether the A, O, and AO stimuli as attractors can achieve better reorientation performance than the V attractor in the case of repeated attractor usage. Further, we discuss the considerations to prioritize when adopting or designing a human-sensory stimulating attractor.

2 Related work

We review RDW methods such as overt reorientation, and the potential of visual, auditory, and olfactory stimuli as attractors to change the user's walking trajectory in the intermittent reorientation-required situation.

2.1 RDW techniques

VR locomotion methods, such as walking in place, arm swinging, walking by cycling, and RDW (Freiwald et al. 2020; McCullough et al. 2015; Razzaque et al. 2001; Williams et al. 2011; Wilson et al. 2016), allow users to navigate virtual space while physically remaining in the tracking area. RDW, which supports real walking, is considered a more natural and immersive virtual locomotion interface than walking-in-place, flying, and joystick input interfaces

(Rewkowski et al. 2019; Wilson et al. 2016). RDW is a software-based technology that alters the user's walking trajectory by modifying the visual scene in the virtual world while walking in the physical space (Peck et al. 2011). It controls the user's movement path or direction without the user's awareness and prevents him/her from wandering outside the VR tracking areas (Nilsson et al. 2018). When simultaneously presented with auditory and other stimuli, visual stimuli tend to dominate awareness (Gao et al. 2020; Rothacher et al. 2018), causing users to rely on visual information in their FOV to interpret the space around them and make locomotion decisions (Dichgans and Brandt 1978). Early RDW technology scaled the user's rotation in the virtual space differently from the user's physical rotation. This resulted in the user commuting a zigzag path in the virtual space while actually walking in a straight line between one spot and another (Razzaque et al. 2001, 2002). These RDW techniques manipulated the translational and rotational gains in rendering visual scenes that changed every moment according to the user's movement, thereby modulating his/her walking speed and angular degree of trajectory. They conveyed the feeling of walking a different distance in the virtual space from that in the physical space (Interrante et al. 2006; Steinicke et al. 2008, 2009). They led users to believe that they were walking on a straight or slightly curved path in the virtual world even though they were walking along relatively larger curved paths in the real world (Bruder et al. 2009; Langbehn et al. 2017). This type of RDW technology has been effective in providing a continuous redirection experience so that users felt that they were traveling in virtual spaces wider than the corresponding physical spaces (Chen and Fuchs 2017; Razzaque et al. 2001). However, keeping users within the VR environment tracking areas without colliding with objects or walls in the respective physical spaces remains a challenge. There could be a limit to eliciting a considerably wide rotation in a relatively short time by relying on the visual dominance effect to manipulate translational, curvature, and rotational gains subtly. This approach also increased the incidence of visual-vestibular mismatch, causing users to suffer from dizziness triggered by moving visual stimuli or the relative motion of the visual surroundings associated with body movement (Sra et al. 2018). To address this, we investigated an intermittent redirection method for situations requiring users to redirect at considerably large angles to avoid colliding with the tracking area boundaries or moving objects in the physical space (Nilsson et al. 2018).

2.2 Overt reorientation techniques

The subtle reorientation techniques prevent the user from being aware of their interventions while moving; therefore,

they have the advantage of not degrading presence or stopping the user's current movement (Nilsson et al. 2018). Overt reorientation techniques cause the user to notice the manipulation interventions easily by openly intervening to change the user's orientation (Suma et al. 2012). This method can safely redirect users in circumstances where they will soon reach boundaries or are in danger of colliding with objects (Fan et al. 2022; Peck et al. 2011). These techniques can be divided into discrete and continuous methods. Overt discrete reorientation technology artificially resets the user's orientation. For example, the freeze-backup technique intentionally stops the user's current movement and then guides the user to move to the center of the area, and the freeze-turn technique drives the user to turn to avoid a collision-risk area (Williams et al. 2007). Overt continuous reorientation technology applies a rotation gain while the user rotates, leading to a mismatch in the user's walking direction between the virtual and physical worlds (Suma et al. 2012). The 2:1 turn method makes the virtual rotation twice the physical rotation, causing the user to rotate 360° in the virtual world but 180° in the real world to face the center of the tracking area (Williams et al. 2007). However, these overt reorientation techniques increase the likelihood of a break in presence, which attenuates the immersive nature of the experience.

A visual object that reorients the VR user without impairing the VR experience was proposed as part of an attractor-based reorientation and reset technique (Nilsson et al. 2018; Peck et al. 2009). In this scenario, the VR system creates an angular difference between the real and virtual orientations while the user focuses on and follows a specific virtual object, known as an attractor or a distractor, which inconspicuously steers the user in the required direction. The user focuses on the attractor and cannot detect the rotation manipulation. This follows from the phenomenon of inattention blindness, in which humans do not notice changes in the area around them when they focus on a specific object (Simons and Chabris 1999; Suma et al. 2011). Although the visual attractor overtly intervenes in the virtual environment and the user's current awareness, it is designed to appear in the context of the virtual environment, so that the user does not notice the manipulation and reorients naturally (Nilsson et al. 2018). Therefore, to exploit visual attractors for direction change, it is crucial that they do not interfere with the scenario and context flow (Sra et al. 2018).

Naturalness is the key to attractor success; for example, butterflies and hummingbirds were reportedly more effective in turning than ball-shaped objects in a virtual forest environment and are preferred by participants (Peck et al. 2009). However, the user's immersive experience can be disrupted when the attractor repeatedly emerges to direct the user to move in the desired direction (Engel et al. 2008; Peck et al.

2011). Context-friendly attractors have been introduced to avoid interference with the immersive nature of the experience and to prevent the user from noticing the reorientation manipulation (Chen and Fuchs 2017; Cools and Simeone 2019). An attractor was developed as an interactive object similar to an antagonist fire-spitting dragon, which directed the user to orient the center of the tracking area while they followed the dragon to shoot at it using a gun while dodging the fire (Chen and Fuchs 2017). The visual attractor (i.e., enemy dragon) consistently appeared in the user's FOV for approximately 45% of the experimental duration, and its ability to rearrange itself decreased in a second experiment from 31° to 26°, but most participants considered the dragon as a game element supporting immersion (Chen and Fuchs 2017). In another case, users were directed to look at an attractor and click on it as it moved around them or changed color. The users preferred the complex interactivity-based attractor to the reorientation method without an attractor; this simple interactivity-based attractor could draw attention longer but was slow in reorienting the users (Cools and Simeone 2019). Additionally, role-playing-based attractors that request interactions to control the user's vision ability (e.g., reducing the FOV using binoculars and a shallow depth of field owing to character emergence) changed the user's direction, while interacting with the attractors in the virtual world (Sra et al. 2018). The VR users assumed the role of a naturalist who used binoculars to observe birds or conversed with a virtual character. The attractors boosted presence, minimized dizziness, and made the participants oblivious to the virtual world rotations.

However, one limitation of visual attractors is that they can only draw the user's attention within the 120° viewing angle range allowed by the VR head-mounted display (HMD) (HTC 2022). In other words, visual attractors that appear outside the FOV, such as behind the user, cannot change the users' directions. Moreover, the visual attractor may have different reorientation effects depending on the individual's capability to process visual information; at the limited 40° FOV, the attractor has a narrower rotational detection threshold range than that at the sizable 110° FOV (Williams and Peck 2019). To achieve the required reorientation performance, even when the user's visual ability is insufficient, the V attractor should be altered or complemented with an alternative attractor. To this end, we proposed alternative modalities to draw attention without visual appearance to guide users forward and backward.

2.3 Visual, auditory, and olfactory stimuli for intermittent reorientation

Visual information is the most dominant source of information for human perception of the environment and

significantly influences locomotive decision-making (Dichgans and Brandt 1978). Visual stimuli are preemptively used as attractors to accurately direct the user's walking trajectory. When a visual attractor and an auditory stimulus are provided together to redirect the user, the user tends to rely more on visual information to reorient. The rotational redirection detection threshold range of the visual attractor with the auditory stimulus is similar to that of the visual attractor (Nilsson et al. 2016). Even with visibility limited by dense fog, visual information still predominantly affects redirection performance, whereas auditory stimulus does not influence it (Junker et al. 2021). Additionally, when a scent and olfactory display coexisted under a directional mismatch, users could not distinguish the actual scent direction owing to visual information interference (Tsai et al. 2021). Humans use visual, rather than auditory and olfactory, information to acquire directional information. However, when the user's FOV narrows, limiting the area where the visual attractor can emerge, reorientation performance deteriorates (Williams and Peck 2019). The visual attractor demands that users focus on the attractor and then move along the path of the visual attractor; thus, the visual attractor must appear for extended periods or frequently when considerable reorientation is required (Peck et al. 2009, 2011).

Auditory stimuli can change the user's orientation even in the absence of a visual background, although the rotational redirection detection threshold range is narrower than that of the visual attractors (Serafin et al. 2013). Static and dynamic audio can shift the user's walking trajectory because the sound can express direction information, and the user can locate the origin of the sounds (Feigl et al. 2017). An auditory attractor exhibited lower rotational redirection performance and higher curvature redirection performance than the audio-visual attractor while reducing VR motion sickness (Meyer et al. 2016). In other words, the auditory attractor can draw the users' attention and change their walking trajectory similar to the visual attractor, regardless of its existence within the FOV, without the appearance or animation of the attractor.

Scents also offer directional information, thereby supporting the user's navigation (Maggioni et al. 2020), and convey positional information about the source stimuli located in space (e.g., the smell of basil in a basil stand, the smell of cocktails in a bar) (Kato et al. 2018; Narciso et al. 2020). The human olfactory ability allows location estimation of olfactory stimuli to a broader extent than visual and auditory abilities for the location of visual and sound stimuli, respectively (Moessnang et al. 2011; Porter et al. 2007), making the user gaze more frequently. Large-angle reorientation is possible because frequent looking around creates more opportunities for the intervention of reorientation manipulation techniques. However, scents are difficult

to handle as they easily dilute in the air (Maggioni et al. 2020); hence, they are mainly used to change the mood or increase the sense of immersion by reducing VR sickness (Amores et al. 2018; Baus and Bouchard 2017; Ranasinghe et al. 2019).

If the attractor intervenes frequently, the user may find it annoying and increasingly dull and becomes inattentive to the attractor (Chen and Fuchs 2017; Sra et al. 2018). Even when reorientation is urgently needed, the attractor may not react timeously (Cools and Simeone 2019). For example, when the attractor is triggered by two walls adjacent to the corner in the tracking area, the user cannot change the walking direction in time and hits the wall. Considering this, we investigated whether the initial RDW performance for each stimulus was maintained or changed with repeated use. We fabricated an all-in-one human-sense stimulation system that triggers an olfactory attractor in a VR HMD and experimented with repeated situations in which the attractor was triggered to avoid physical collisions.

3 Experiment design

We designed a virtual environment with intermittent reorientation-necessary cases and applied the attractor-based intermittent reorientation technique to reorient the participants forward in the desired direction. We developed an all-in-one olfactory delivery system attached to a VR HMD to design interactive human-sensory stimulating attractors stimulating V, A, and O.

3.1 Intermittent reorientation-necessary situations

We used a wireless VR HMD system (HTC Vive headset) with a tracking area of 5 m × 5 m and designed the virtual environment using Unity (HTC 2022; Unity 2022). The virtual environment was an open area with regularly spaced trees and grass in the center of a forest. The background sound was of birds tweeting to increase the immersive experience and eliminate the noise from the real world. When a participant ignored the attractor and neared the tracking area border, a red grid depicting the actual tracking area limit was displayed for safety reasons.

The intermittent reorientation-necessary cases assumed three situations when the participants approached the real-world boundaries: physical walls and static furniture, dynamic objects such as other people and pets, and corners (Fig. 2). This is because VR users wearing an HMD cannot perceive the current state of the physical space, which may increase the likelihood of them straying from the tracking area or colliding with obstacles when navigating a virtual space with a different scale or layout than the physical space

(Nilsson et al. 2018). When VR users leave the tracking area, the VR system loses the ability to adequately provide content and intervene to prevent potential collisions, as it cannot specify the user's location. In addition, a higher chance of physical boundary clashes exists in narrow spaces such as corners, forcing the VR system to intervene more frequently and break the user's immersion. For this reason, participants were required to turn sharply when approaching a corner to avoid getting stuck and stop the recurrence of attractors (Dao et al. 2021). The reorientation-and-resetting technique is required to help users avoid obstacles and stay within the tracking area, where the VR system can accurately detect their motions. This method should allow users to leave narrow areas without interfering with their current engagement with the VR experience. We set up a virtual rectangular tracking area and virtual boundaries to construct scenarios in which the participants approached a wall or fixed furniture (Case 1). In Case 2, we assumed that dynamic objects (e.g., pets or other users) coexisted in the real-world tracking area, and reorientation was triggered to help the participants avoid colliding with those objects. Because dynamic objects exist in the physical space, they need not appear in the virtual world. Thus, they were invisible from the perspective of VR participants. We created a dynamic object that moved toward the participants at a speed of 1 m/s from a corner, simulating a collision that activated the attractor (i.e., as soon as overlap occurred between the location in which the participants moved and that in which the box object representing the invisible dynamic object moved, as displayed in Fig. 2). In Case 3, as the participants moved to the corner, we used edges created as virtual boundaries.

3.2 Attractors with intermittent reorientation method

We designed the task of searching for snacks in a forest to build a house made of sweets for animals, inspired by the Hansel and Gretel fairytale. The participants had to decide how travel was started, continued, and stopped, as well as the direction in which to move, as part of the search assignment. As a result, the search task was appropriate for examining participants' behavior while walking in VR (Hodgson et al. 2008; Peck et al. 2010). The attractors induced reorientation when the participants encountered the case required for intermittent reorientation, a situation in which the participants entered a collision-detection area at 50 cm from the virtual boundaries and invisible dynamic objects. The attractors consisted of two parts: (1) the attractor using sense stimulation, and (2) the target that the participants should find in the task (Fig. 1(b1, c1, d1)). The attractor appeared in front of (V stimulus for V attractor, and O stimulus for O and AO attractors) or behind (A stimulus for A and AO

attractors) the participants, and the target of the task was positioned diagonally at 135° and 2 m away from the sight direction of the participants to indicate the reorientation-required position (Fig. 1(b2, c2, d2)). Fifteen different 3D objects were used as targets. We induced the participants to turn and gaze around by positioning the snacks behind them when sensory stimuli were provided. The attractor was cleared when the participants located the snack and clicked on it.

For the V attractor, we used a bird that appeared in the participants' FOVs to catch the attention of the user and point in the direction of the snack (Fig. 1(b1-b2)). In response to the participants' head movement, the bird moved to the left or right edge of the participants' FOVs, guiding the participants to reach the snack. The initial bird's head orientation was to the left, the same direction as the snack, but if the participants rotated and passed the snack, the bird's head turned to the right. We used an animation of a bird fluttering to create an immersive virtual world. The bird then hovered above the snack until the participants discovered it. The stereophonic barking of the dog and the scent of the snack served as the A and O attractors, respectively, as shown in Fig. 1(c1-c2) and Fig. 1(d1-d2). The spatiality of stimulus A was expressed using the ambisonic function provided by the Oculus Software Development Kit. To provide directional cues for stimulus A, we incorporated a dog barking audio source into a virtual animal object (a dog) in our 3D virtual environment. The dog object was positioned with a target behind the participant, allowing stimulus A to express the direction in which the participants should reorient themselves. Despite presenting the O stimulus in front of the participant, we strategically positioned a 3D snack object (target) corresponding to said stimulus behind the participant, creating the perception that the stimulus originates from that direction. In other words, the O attractor could serve as a motivational cue, guiding the participant to turn toward it.

We designed the all-in-one visual, auditory, and olfactory stimulation system by modifying the earlier olfactory stimulation system, offering scents from the left and right sides (Fig. 3(a)). The V and A attractors worked through the VR HMD and headset (Fig. 3(b) and (c)). An ultrasound humidifier was used to scent perfume systems as the olfactory interfaces (Lei et al. 2022). The system had five scent chambers and delivered the scent through a linked ultrasound humidifier controlled via Arduino, as displayed in Fig. 3(d). Snack objects, including an orange cake, a hazelnut cookie, a peach macaroon, two varieties of waffles (square and circle), and a mixed-berry tart were paired with citrus, java chip, peach, waffle, and currant scents. To prevent the participants from becoming accustomed to the aromas of comparable flavors, we alternated between the scents of fruit

and bread. Where intermittent reorientation was required, the VR system signaled the olfactory stimulation device via Bluetooth to release the appropriate scent once for 300 ms. The AO attractor operated the auditory and olfactory stimuli simultaneously.

In our experiment, the reorientation-and-resetting technique with attractors using a rotational gain of 15% was applied to the head rotation value when the attractor was triggered (Rewkowski et al. 2019; Sra et al. 2018). We used a 15% negative gain to induce a wider rotation when the participant made a left turn and a 15% positive gain to induce a narrower rotation in the opposite direction. The degree of virtual rotation was calculated as the product of the participant's head rotation degree per second and the rotation gain. Larger changes in the head rotation angle resulted in correspondingly larger virtual rotation angles, which in turn led to increased angular differences between the real and virtual orientations. For example, if the participants rotated left by 1° , the virtual rotation was 0.85° , and if the participants rotated right by 1° , the virtual rotation was 1.15° . If the participants rotated left and right by the same angle, the result of the virtual rotation was 0.3° , because the rotational gain was applied twice to the participants' rotation. When the participants arrived at the intermittent reorientation-necessary position and the attractor was activated, the rotational gain was applied to the participants' head rotation degree. As the participants turned their heads left or right to follow the stimulus or locate its source, the rotational gain was repeatedly multiplied according to the number of their head rotations, increasing the angular difference between their physical and virtual orientations. This approach aimed to make the participants unaware of the manipulation while increasing the angular difference. Following the discovery of a snack by the participants, the rotational gain was reset to one. The virtual direction was changed to match the

participants' actual direction because they had already left a situation where intermittent reorientation was necessary and no further rotation manipulation was required.

3.3 Experimentation

We instructed the participants to follow a guiding star in the sky and find target objects (snacks) that fell in the forest (Fig. 4(a)) before noticing visual, auditory, or olfactory stimuli triggered in the intermittent-reorientation-necessary cases (near walls or obstacles). Participants encountered cases requiring three intermittent reorientations in two iterations (for a total of six situations requiring intermittent turns) and experienced the attractor six times per experimental set (Fig. 2). If participants faced an intermittent-reorientation-necessary case, the attractor was activated to draw their attention and reorient their walking direction. If participants looked around and found and clicked on the snack object (Fig. 4(b-e)), the star reappeared and guided them to the next location (i.e., the next intermittent-reorientation-necessary case). Each participant participated in four test sets with various attractor conditions, and the Latin square was used to counterbalance the order of the experiment sets.

To evaluate our intermittent-reorientation-necessary situation setup for reorientation, we counted the number of collision detections when additional reorientation was required, but we did not trigger it more than twice to calculate the reorientation success rate of each attractor. If the participants ignored the attractor and could not find the snack, we interrupted the participants to guide them or ended that experiment. In a such case, we considered the reorientation a failure. We estimated the attractor's reorientation angular speed as the induced angular difference per reorientation time by measuring the angular difference the attractor caused and the amount of time it took the participants to find

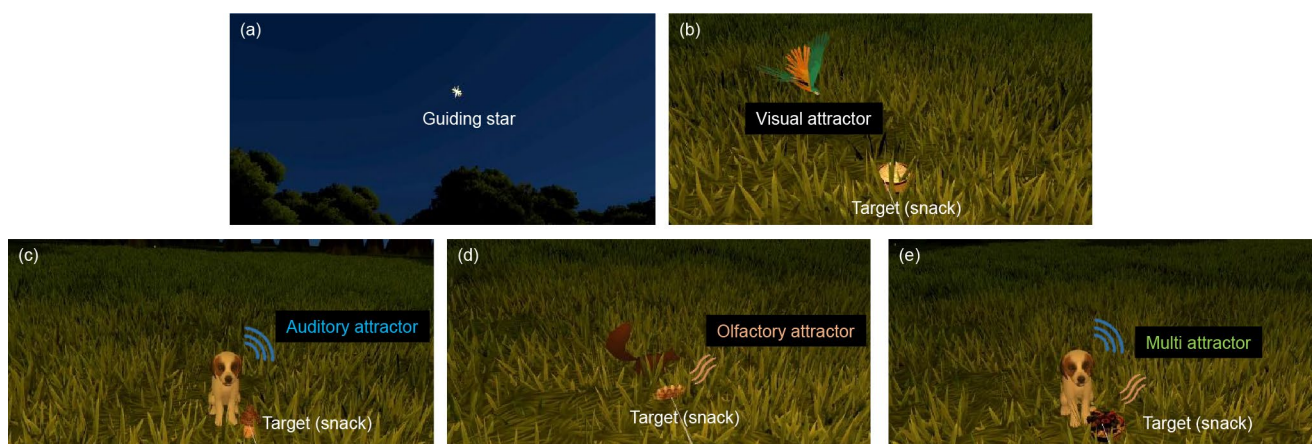


Fig. 4 Earlier version of the olfactory stimulation system (a). All-in-one visual, auditory, and olfactory stimulation system displays (b) visual attractor on the VR HMD, (c) auditory attractor sounded by the

headset, and (d) olfactory attractor device attached to the VR HMD diffuses scents through an ultrasound humidifier setting

the snack. Because of the significant angular difference, the attractor's high performance was required to move around the corner and avoid triggering two attractors simultaneously. Short reorientation times showed that the participants could quickly shift their paths with infrequent attractor interventions, which was necessary to prevent crashes. The reorientation angular speed of an attractor was used to evaluate its reorientation efficiency.

We also measured the presence, VR sickness, and perception of manipulation to evaluate the usability of the attractor. After completing one set of experiments, we asked participants to dismount their VR HMDs and answer to survey. The participants interacted with each attractor before completing a series of surveys about presence and VR sickness. We used the three-question version of the Slater-Usloh-Steed (SUS) questionnaire and VR Sickness Questionnaire (VRSQ) to evaluate presence and VR sickness on a seven- and four-point Likert scales, respectively (Kim et al. 2018; Slater et al. 1994). The three questions on the SUS (presence Q1, Q2, and Q3, respectively) were: "In the computer-generated world, I had a sense of being there"; "To what extent were there times during the experience when the computer-generated world became your reality, and you almost forgot about the real world outside?"; and "In retrospect, do you think of the computer-generated world more as an object you saw or more as a place that you visited?". Another question asked, "How much did the virtual map rotate while you interacted with each attractor?" on a seven-point Likert scale (1 = Not at all, 7 = Very much) to investigate the perception of manipulation (Hodgson et al. 2008; Sra et al. 2018).

The number of participants in the experiment was 32 (14 females, 18 males, age ($M = 23.41$, $SD = 2.21$)) and they had no VR-related sickness or auditory, olfactory, vision, or cognition problems. The experiment was approved by the Institutional Review Board (IRB No. 20,210,806-HR-62-01-02). The total duration of the experiment was approximately 1 h (15 min for each experiment set), and the participants were paid US\$20 as compensation for their time. The experiment design was a within-subject experiment with four conditions. In the experiment, even if the reorientation-necessary situations occurred sequentially and in various manners in the physical space, the participants walking in the virtual space could not distinguish the different reorientation-necessary situations, owing to them wearing VR HMDs and not being aware of the real world. That is, the participants could recognize a task that repeatedly performed the sequence, like interacting with an attractor after walking a certain distance.

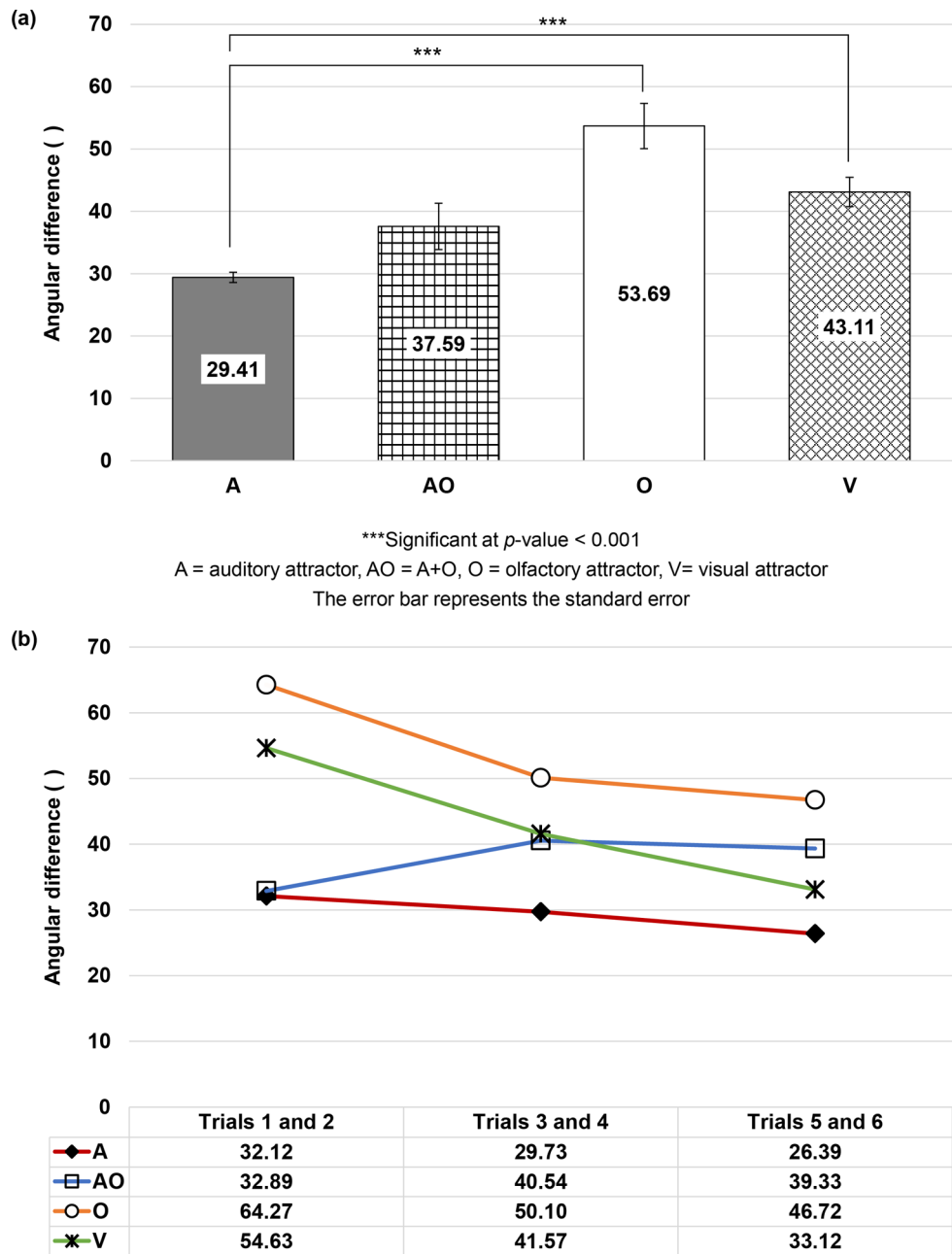
4 Results and discussion

We performed a two-way repeated measures analysis of variance (ANOVA) to compare the effects of different attractors on average reorientation performances and trends resulting from repeated application of attractors. The reorientation performances measured were (1) angular difference, (2) reorientation time, and (3) reorientation angular speed. We had three repeated usage groups by grouping six repetitions activated through the study protocol. The Kruskal-Wallis test was conducted to analyze average (1) presence, (2) VR sickness, and (3) perception of manipulation according to the type of attractor, and post hoc tests of the four attractors were conducted using Bonferroni-adjusted alpha levels of 0.012 per test (0.05/4). As data from one participant was noisy, the analysis was based on data from 31 participants.

4.1 Angular difference

The analysis revealed significant main effects of the attractor type ($F(2.018, 52.465) = 10.721$, $p < 0.001$) and number of trials ($F(1.959, 233.148) = 4.525$, $p = 0.012$) on the angular difference, with Greenhouse-Geisser correction ($\epsilon = 0.975$) applied to adjust for violations of sphericity. These effects were qualified by a significant interaction between the attractor type and number of trials, $F(6,232) = 2.441$, $p = 0.026$. Bonferroni-adjusted comparisons indicated that the O ($53.69^\circ \pm 3.64$) and V ($43.11^\circ \pm 2.36$) attractors induced wider angular differences than the A attractor (Fig. 5(a)). When comparing the AO and V attractors ($p = 1.000$) and the O and V attractors ($p = 0.082$), the angular difference was not significant. We examined the angular difference tendencies of the attractors considering their frequent applications. As shown in Fig. 5(b), on the first two attempts, in which the O attractor was used, it induced almost twice the angular difference of the A ($p = 0.002$) and AO attractors ($p = 0.003$), and the V attractor caused a higher angular difference than those of the A ($p < 0.001$) and AO attractors ($p = 0.014$). In the case of the overall angular difference, RH1 was not confirmed when comparing the average angular difference between the V attractor and the O attractor as it was insignificant. Concerning repetition, which we discussed in RH1, the angular difference of the V attractor exhibited a diminishing trend with increasing repetitions. In contrast to the earlier mentioned RH1, both the O and A attractors demonstrated a reduction in their angular differences. When used more than five times, the average angular difference of the AO attractor surpassed that of the V attractor. The starting point of an olfactory stimulus is sought more vaguely by the human sense of smell than the starting points of visual and auditory stimuli are sought by the senses of vision and hearing (Maggioni et al. 2020). Therefore, the participants

Fig. 5 a. Angular differences of the attractors and **(b)** trends with repeated use



would have looked around frequently, and their wandering behavior caused a greater angular difference in the situation in which they encountered the O attractor. After six applications, the O attractor showed a reduced degree of angular difference, although this degree was still higher than those of other attractors, particularly the A attractor ($p = 0.002$). The high angular difference compacts the users' physical walking trajectory, allowing the users to experience a wider virtual space while only moving in the tracking area. In other words, the angular difference induced by the O attractor allows the user to travel in a larger virtual space than that

allowed by other attractors; for example, when users enjoy VR travel content, they can visit more places by walking.

The average angle difference induced by the V attractor was more expansive than that of A and AO attractors, but it continued to decrease when it appeared more than three times. Our V attractor (bird object) increased the angular difference when used for the first or second time. Meanwhile, from the direction of the bird's head and flight as it repeatedly emerged, participants acquired a sense of the direction toward which they should turn, thus allowing them to decide the way to turn quickly without looking around. The V attractor will be effective for frequently turning around

the user until the user becomes accustomed to it. In other words, the V attractor is more useful for reorienting the user when the VR context changes (e.g., when the user enters a building or a genie suddenly appears from a magic lamp).

The A attractor induced a relatively constant angular difference of $29.41^\circ \pm 0.82^\circ$, even though it gradually decreased with repetition. It was more controllable than the other attractors, even if the A attractor had to be modulated to cause frequent head rotations adequate for redirection similar to the O attractor. In other words, the users could effectively reorient themselves when the A attractor induced the angular difference without unnecessary rotation. The A attractor can be used as a reorientation technology for indoor navigation or VR content such as real estate and interiors that require relatively accurate scale movements based on controllable functions. Only the angular difference of the AO attractor increased with repetition, as illustrated in Fig. 5(b). In the first two attempts, its angular difference was similar to that of the A attractor. The angular difference grew and surpassed those of the A and V attractors after six applications. The multiple modalities of the AO attractor demonstrated the benefits of the O attractor increasing the angular difference and A attractor with a constant reorientation time.

4.2 Reorientation time

The results of the analysis indicated significant main effects of both attractor type ($F(1.859, 50,186) = 40,762, p < 0.001$) and number of trials ($F(1.599, 191.931) = 24.256, p < 0.001$) on reorientation time. Additionally, there was a significant interaction between the attractor type and number of trials ($F(4.873, 190.062) = 3.106, p = 0.011$ with Huynh-Feldt correction ($\epsilon = 0.812$)), suggesting that the effect of attractor type on reorientation time may depend on the number of trials. The average reorientation times of the O (3.46 ± 0.22) and V (2.67 ± 0.18) attractors decreased with repeated use, as shown in Fig. 6(a)). The reorientation time of attractors, depending on said attractors' repeated use, was significantly different. The O and V attractors had longer reorientation times than the A and AO attractors even with repeated application, as shown in Fig. 6(b). The difference was statistically significant for all trials, as indicated for the A attractor (Trial 1 and 2: $p = 0.001$ and $p < 0.001$; Trial 3 and 4: $p < 0.001$ and $p = 0.005$; Trial 5 and 6: $p < 0.001$ in both) and the AO attractor (Trial 1 and 2: $p < 0.001$ in both; Trial 3 and 4: $p < 0.001$ and $p = 0.001$; Trial 5 and 6: $p = 0.002$ and $p = 0.004$). When comparing the A and AO attractors, there was no confirmation of the hypothesis (RH1) that nonvisual attractors would result in a longer attractor reorientation time than the V attractor. However, the O attractor demonstrated a longer reorientation time, supporting the hypothesis. Consistent with the angular difference conclusion, the

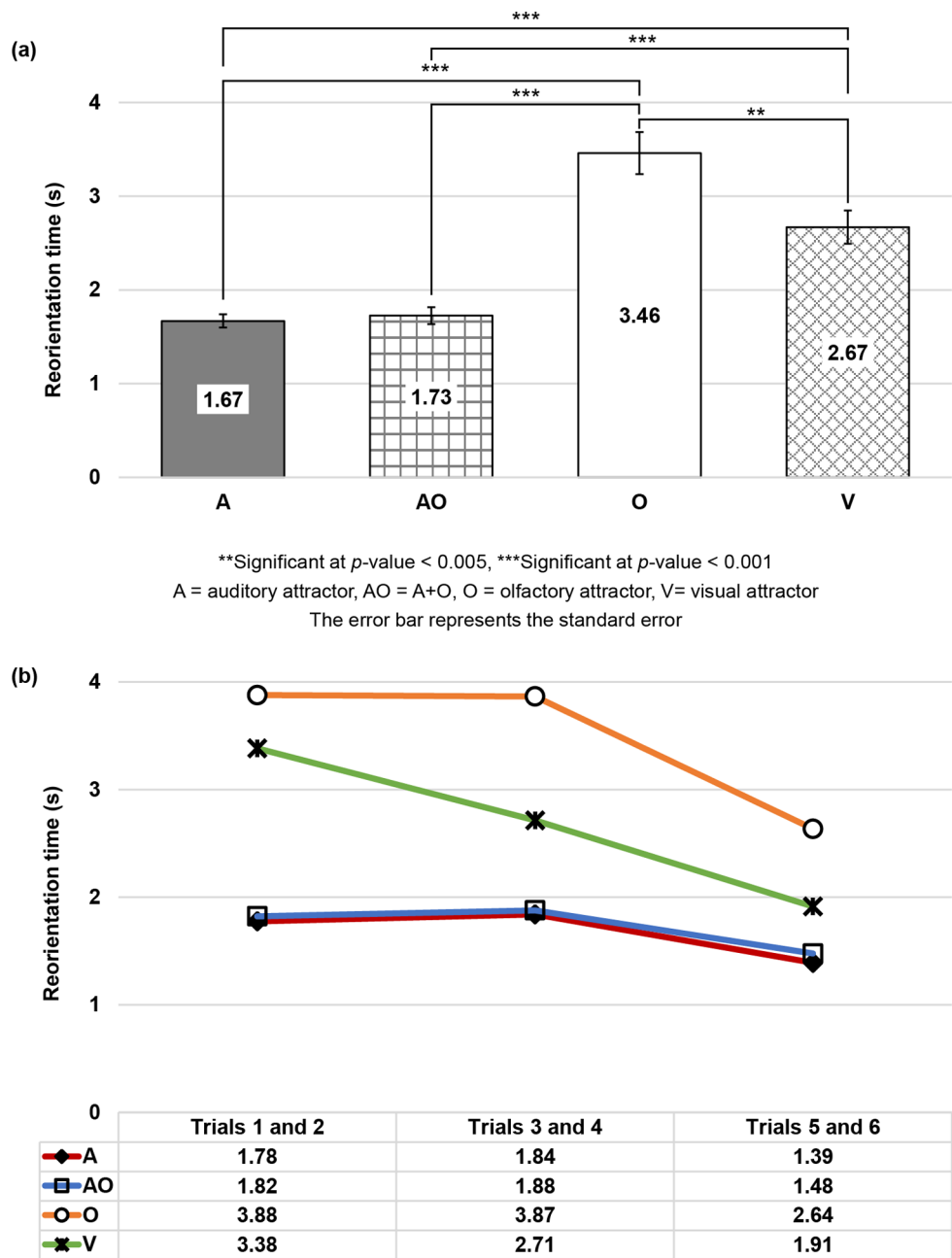
O and V attractors required more time to reorient than the A and AO attractors. Notably, the scent induced the participants' innate wandering tendency, causing them to swivel their heads more frequently and increase angular differences. However, this characteristic inevitably and occasionally added reorientation time, which was difficult to predict or control, such that the O attractor could not purposely reduce the reorientation time.

The A (1.67 ± 0.07) and AO (1.73 ± 0.09) attractors showed shorter reorientation times than the other attractors, taking approximately half the time of the O attractor despite repeated use (Fig. 6(a)). A comparison of the interruption modalities using V, A, and O stimuli revealed that the A stimuli were easier to be perceived than the others and were the most disruptive (Bodnar et al. 2004). In line with the previous study, our A and AO attractors were interpreted as quickly attracting participants' attention. Also, 18 participants (50% of participants) said they could easily recognize the dog sound of the A attractor. Therefore, when immediate reorientation is required, VR users can rapidly complete the reorientation by interacting with the A and AO attractors. Again, the AO attractor demonstrated the characteristics of both the A and O attractors; the O stimulus caused the participants to change their directions more frequently, yet the combined A stimulus preserved the rapid perception of the stimulus. When multiple VR users were in the same tracking area, or when someone other than the VR users stayed in the same space, A and AO attractors could rapidly change the direction of the users to prevent unexpected collisions. Moreover, A and AO attractors can enable users to participate in events expeditiously when used as a diegetic guidance tool that helps users experiencing cinematic VR not to miss key events in the content (Cao et al. 2020).

4.3 Reorientation angular speed

The reorientation angular speed is the angular difference per reorientation time. If the reorientation angular speed is high, the VR users can be reoriented swiftly with a wide angular difference, reducing the frequency of emergence of the attractor. We assumed that the reorientation angular speed of the four attractors would be similar because the angle difference and the reorientation time were mutually proportional (RH1); however, this could not be confirmed. Except for the AO attractor, all attractors resulted in similar levels of angular speed during reorientation, although some variability was present depending on repeated use. In contrast, the AO attractor showed an increase in reorientation angular speed with repeated use. A repeated measures ANOVA with Huynh-Feldt correction ($\epsilon = 0.905$) and post hoc tests using Bonferroni-adjustment were performed to compare the reorientation angular speed with respect to attractor type

Fig. 6 (a) Reorientation times of the attractors and (b) trends with repeated use

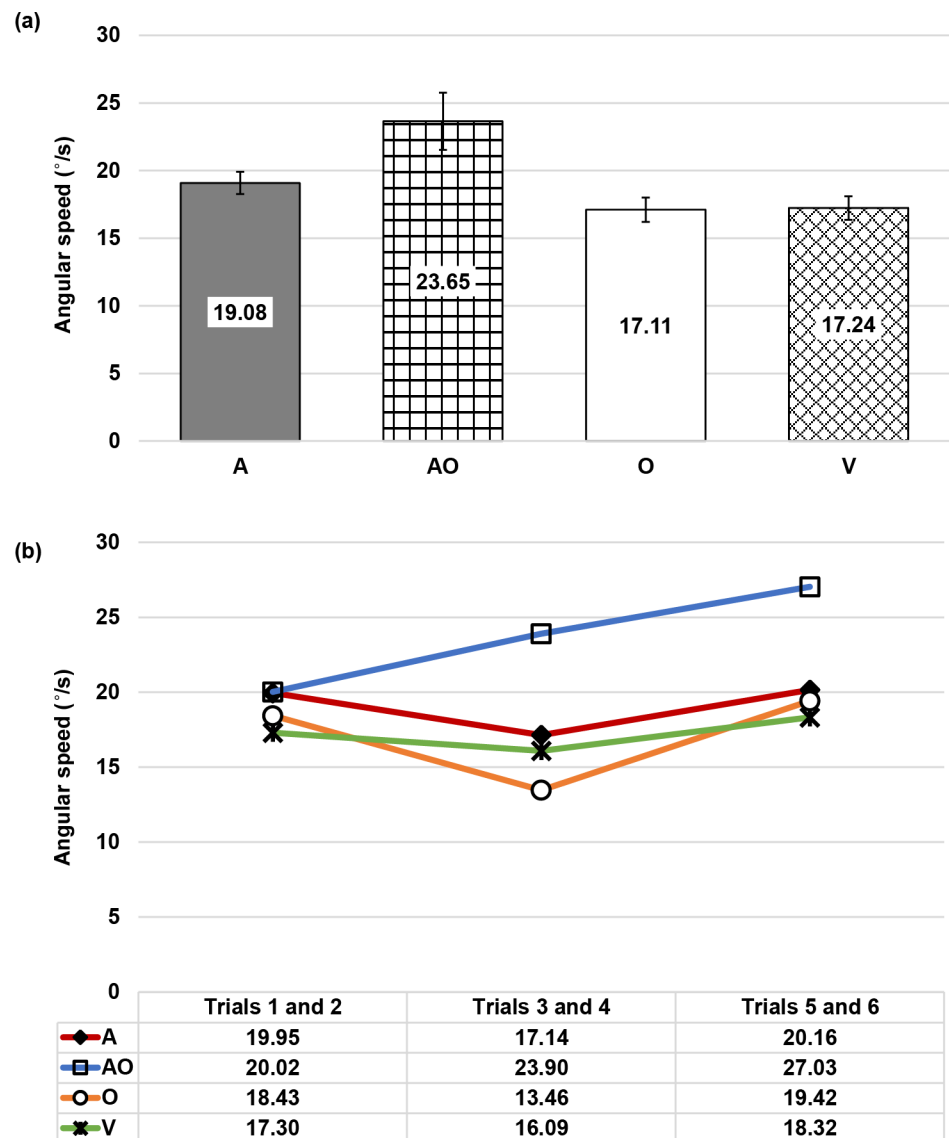


and number of trials. The results indicate that there was no significant interaction between the attractor type and number of trials on the reorientation angular speed ($F(5.433, 206.441) = 1.204, p = 0.307$). The average reorientation angular speed did not significantly differ between attractors, $F(1.874, 54.360) = 1.297, p = 0.281$. The AO (23.65 ± 2.11) attractor showed a higher average reorientation angular speed than the A (19.08 ± 0.82), O (17.11 ± 0.90), and V (17.24 ± 0.87) attractors, as displayed in Fig. 7(a). Likewise, the reorientation angular speed did not significantly differ between the number of trials. On the first two attempts, all attractors induced similar reorientation angular

speeds. However, with repeated use (after six applications), the AO attractor increased the reorientation angular speed more than the other attractors, as shown in Fig. 7(b).

Almost all attractors in the experiment exhibited similar reorientation angular speeds in the first two attempts. However, as an exception, with repeated use, the AO attractor showed an increasing reorientation angular speed. Given the experimental results when the O attractor induced the widest angular difference and the A attractor exhibited the shortest reorientation time, we deduced that the A and O stimuli of the AO attractor interact to increase the reorientation angular speed without degrading reorientation performance

Fig. 7 (a) Reorientation angular speeds of the attractors and (b) trends with repeated use



even in repeated appearances. Frequent direction changes are required if the tracking area has an irregular shape. In this case, the AO attractor will change the VR users' direction more efficiently than other attractors without degrading reorientation angular speed. The A and V attractors displayed a relatively constant reorientation angular speed. Specifically, the A attractor induced a constant angular difference and reorientation time, and the V attractor showed a continuous decrease in angular difference and reorientation time. The O attractor exhibited fluctuating reorientation angular speeds, which were interpreted to have occurred while the participants spent time becoming acquainted with the O attractor.

4.4 Presence, VR sickness, and perception of manipulation

A Kruskal-Wallis test revealed that our attractors did not significantly affect the average presence ($H(3)=0.612$, $p=0.894$), as shown in Fig. 8(a). All attractors exhibited similar VR sickness values as we found no difference for any attractor ($H(3)=0.753$, $p=0.861$), as illustrated in Fig. 8(b). The participants' responses to the perception of manipulation were also not statistically different ($H(3)=1.942$, $p=0.584$) according to the attractor type (Fig. 8(c)). The results partially confirm RH2. Participants equally perceived the presence of all attractors as projecting and associating the RDW stimuli within the context of the presented virtual world rather than regarding them as having appeared haphazardly. This phenomenon was also observed in a study on the presence and naturalness

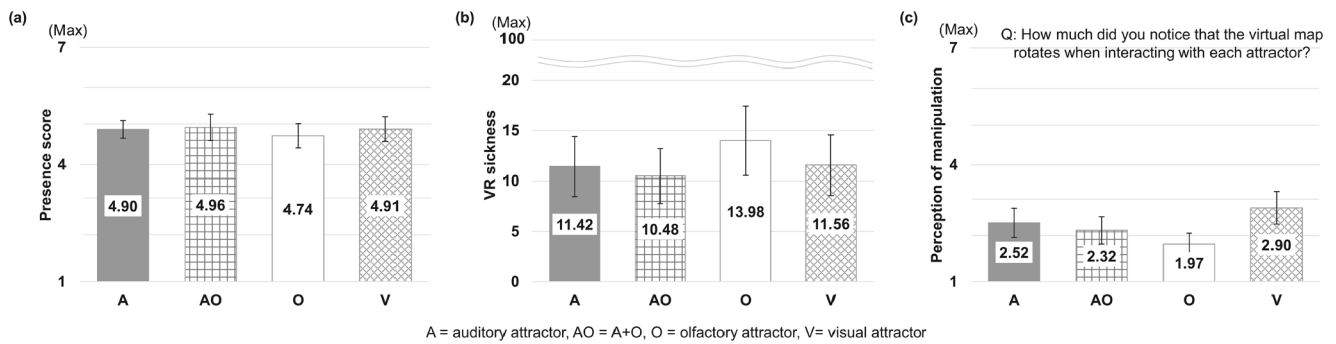


Fig. 8 (a) Presence, (b) VR sickness, and (c) perception of manipulation

of attractors (called distractors (Peck et al. 2009), in which the improved attractors showed a high presence. In contrast, unexpectedly, all attractors exhibited similar levels of VR sickness and manipulation perception as well as presence. This counters the RH2 prediction that the participants would readily notice the reorientation manipulations when interacting with nonvisual attractors, as the act of turning the head from side to side may help them readily recognize the virtual environment being manipulated, thereby increasing the experience of VR sickness. However, the nonvisual attractors did not increase VR sickness and manipulation perception. We attribute this to the increased workload on the participants' walking tasks. In previous studies (Meyer et al. 2016; Serafin et al. 2013), participants were assigned the task of walking along a virtually paved way. There was no further object search necessity. The studies primarily aimed to reveal the effectiveness of the proposed algorithms on RDW gains, along with the measure of the detection threshold. Conversely, our participants were required to locate the source of the RDW stimuli with no explicit path to follow; they had to decide the direction for themselves by relying on V, A, and O stimuli. Our participants' walking tasks entailed this additional workload. Indeed, some studies (Cools and Simeone 2019; Nguyen et al. 2020; Sra et al. 2018) showed that the users' perception of the manipulation level could weaken depending on the increased workload level of the task and interaction method for performing it. In the same vein, in our study, the workload and interaction method of the task of finding snacks by relying on sensory stimuli might have prevented participants from recognizing reorientation manipulation. Therefore, when creating A and O stimuli-based attractors, compromising on presence, VR sickness, and perception of manipulation need not be of concern.

To determine the components that require emphasis in the generation of attractors that stimulate the human senses, we examined the correlation of attractors with different modalities to user-perceived RDW experience. We calculated the Spearman's correlation coefficient. The efficacy of the attractor's reorientation was only weakly negatively

linked with the ease of perception of manipulation ($\rho = -0.20$, $p = 0.028$) (Akoglu 2018). The higher the reorientation angular speed of the attractor, the lower the perception of manipulation. We can increase the reorientation angular speed by increasing the angular difference, decreasing the reorientation, or both, to make users less aware of the visual scene manipulation for RDW. The reorientation angular speed of the AO attractor was the highest, and it increased with repeated usage, which might have lessened the perception of manipulation.

4.5 Reorientation success rate and number of collisions detected

We measured the reorientation success rates and the number of collisions detected to examine the reorientation effectiveness of our attractors. Nearly all the attractors successfully caused reorientation, with the lowest success rate being 0.97 (in the O attractor session). Our algorithm continuously tracked the distance between the collision area and the participant and activated the attractor when the participant was near a boundary, virtual dynamic object, or corner. The collisions detected with the A, AO, O, and V attractors were 1.43, 1.34, 1.80, and 1.49, respectively. Although not statistically significant, when the O attractor was triggered, marginally more collisions were detected because the participants looked around more in the collision-detection area.

5 Conclusion

RDW techniques adopt visual-stimulus-based attractors to draw the user's overt attention while manipulating the visual scene to reorient the user intermittently. However, the visual attractors, which attempt to induce redirection within the user's FOV or HMD's FOV, can reduce the possibility of sufficient reorientation. This may interfere with the user's in situ contexts of the VR experience and fail to prevent the user from colliding with objects in the physical space. To address this, we investigated nonvisual stimuli, such as

sounds and smells, to draw the users' attention and induce changes in the walking direction without weakening the reorientation performance with repeated use. We prototyped an all-in-one stimulation system connected to a VR headset to deliver V, A, and O stimuli. Further, we conducted a user study where a set of intermittent reorientation-demanded scenarios experimented with the repeated use of the human-sensory-stimulating attractors.

In this study, we demonstrated that the nonvisual attractors did not attenuate the perceived experience factors such as presence, VR sickness, and perception of manipulation. In terms of the reorientation performance, the A, O, and AO attractors induced rapid and wide reorientation with high angular speeds. The A attractor was the fastest and had a relatively constant angle difference, so it could steer the VR users in the desired direction without unnecessary reorientation. The O attractor retained the widest angular difference with repeated use, making it particularly effective for users who needed to escape from corners or were entrapped in spaces. Interestingly, the AO attractor rapidly reoriented the users like the A attractor with a broad angular difference like the O attractor. The participants reoriented with the auditory stimulus and were subsequently redirected with a larger angular difference with the continuous support of the olfactory stimulus. We found that the perception of visual scene manipulation was inversely correlated with the reorientation angular speed. The reorientation angular speed of the AO attractor was the highest across all attractors. That is, we hypothesized that the combined attractor could be most efficient in redirecting users in the desired walking direction while allowing them to remain unaware of the scene manipulation and without necessarily appearing in their FOV frequently. Although our study has provided insights into the effects of integrating the A and O stimuli (i.e., the AO attractor) on reorientation performance, it remains unclear whether other combinations of sensory stimuli would yield similar results, or whether the specific nature of the stimulus combination would influence reorientation performance. Additionally, future studies may investigate the potential for further enhancing reorientation performance by combining three or more sensory stimuli. These studies are expected to enhance our understanding of the properties of multi-stimulus combinations that improve reorientation performance, and help develop more effective reorientation techniques by leveraging the multi-stimulus combinations.

This study demonstrates that A and/or O stimuli can outperform the RDW performance of the V stimuli and that this performance is sustainable even under repeated usage, e.g., when escaping from irregularly shaped tracking areas or ambiguous backgrounds in which visual attractors cannot be used to intervene in VR environments. The unique characteristics of each stimulus as an attractor should lead

to the development of an attractor implementation automation strategy that is embedded into the context of the virtual environment, while considering the situational conditions that require redirection.

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Data availability The data that support the findings of this study are available upon reasonable request.

Declarations

Ethical approval The research was approved by the Institutional Review Board (IRB No. 20210806-HR-62-01-02).

Informed consent We informed and obtained consent from each participant prior to research engagement.

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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