Investigating Neural Perception Signals under Virtual Reality Environment

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Abstract

Recent studies show a significant enhancement in visual neural signals related to motion during physical activity. However, the scope of theses studies is limited to humans interaction with the physical world. However, the study of human visual neural signals and motion is under-explored for user interactions with virtual environments, which is important for improving immersive user experiences in virtual environments. We propose a visual psychophysics study that investigates how physical movement affects neural signaling in humans, which is highly correlated with visual perceptions. Specifically, we use visual illusion contrast thresholding to measure the strength of human neural signaling perception in a virtual environment using a head-mount display (HDM). We conduct controlled experiments for four users across four illusion patterns under stationary and in-motion conditions on a treadmill. We aim to quantify the impact of movement on visual perception. Under our four-user study experiments, although we cannot make a conclusion that individuals in motion demonstrate a higher threshold for nullifying visual illusions, we do observe the pattern that all participated users need higher contrast thresholds to see illusions when in motion.

1 Introduction

The first evidence of increased motion perception was found in mice, which shows that neurons in the primary visual cortex of awake mice showed a significant increase in firing rate when the animals transitioned from standing still to running on a spherical treadmill [4]. (Liska et.al [5]) show that although primary visual cortex (V1) is strongly activated during running in mice, marmosets have an opposite pattern than mice– the V1 activity is slightly suppressed, suggesting the effect of locomotion on visual processing might differ between species. Contradictory findings between species lead to the question: does locomotion increase or suppress humans' neural signaling?

Thus the interaction between physical movement and visual perception has been explored in the context of human neurological studies. (Siliezai et al [6] and Saleem et al [7]) demonstrate that humans exhibit strong signals on visual neurons during movement, and there is a significant interaction between visual processing and physical activity. Cao et al. [8] investigated how walking influences visual perception in humans, particularly focusing on how these activities modulate attention and memory-related processes. Their findings suggest that the sensory enhancement seen in rodents might extend to cognitive domains in humans, potentially influenced by similar neural mechanisms [8]. These findings raise intriguing questions about the generalizability of this phenomenon to humans, particularly interacting through the lens of visual illusions.

While the above research has examined the interaction between locomotion and visual perception in both natural and controlled environments, less attention has been given to these interactions within the XR area– augmented reality (AR), virtual reality (VR), mixed reality (MR). Investigating human

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perception under XR settings is crucial because these technologies increasingly integrate into daily life, from training and education to therapy and entertainment [9] [10] [11].

To this end, we conduct a control experiment to measure the correlation between locomotion and visual perception under a virtual environment. Specifically, we use different illusion patterns to measure neural signals in perception in a virtual environment. We show users illusion patterns in two experiment conditions: standing still and walking on a treadmill. We measure users' responses to illusion patterns under the two conditions and observe that users need higher illusion threshold to see illusions when they are walking.

2 Method

To explore the relationship between neural activity and human locomotion, we designed a controlled psychophysics experiment. In this experiment, we compared the strength of visual illusions experienced in a virtual environment under two different conditions: when participants viewed illusion patterns while stationary and when they viewed them while in motion.

2.1 Illusion Patterns

We created three different sets of illusion patterns, but used two illusion sets for our user study to reduce user study mental load: Ouchi Illusion and Wheel Illusion. We give brief definition and methods to adjust contrast of illusion patterns to show to users.

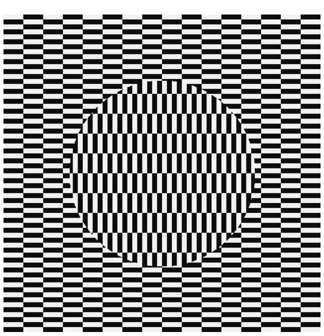
2.1.1 Ouchi Illusion

Ouchi Illusion is named after its creator Hajime Ouchi, characterized by black and white alternative patterns [12]. The inner pattern are in orthogonal direction with the outer pattern. The center disk seems floating above the background, creating a 3D effects on a 2D image.

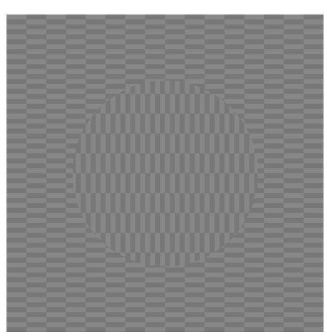
Ouchi illusion has the strongest effect when it's moving in diagonal direction, but the illusion is still visible when it's in still. The illusion displayed by non-moving ouchi illusion pattern is caused by involuntary movement. Specifically, the horizontal and vertical movements that are not aligned with the direction of the pattern.

To strengthen and weaken the illusion , we take two approaches – length contrast and color contrast:

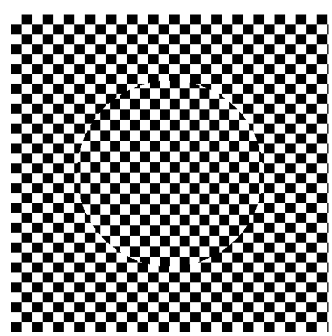
- *Length contrast* manipulates the pattern width/height ratio and the black/white color contrast. The illuion is strongest when the smallest block of the pattern is rectangular shown in Figure 1a, and weakest when it's a square shown in Figure 1c.
- *Color contrast* manipulates the color pattern, where the most obvious illusion happens when rectangles are pure black and white. Reducing the contrast between black and white reduces the illusion. Figure 1a shows the strongest ouchi color illusion and Figure 1b shows the weakest ouchi color illusion in our experiment.



(a) Strongest Ouchi illusion used in our experiment (ratio 1.0).



(b) Weakest Ouchi color illusion used in our experiment (ratio 0.0).



(c) Weakest Ouchi Length illusion used in our experiment (ratio 0.0).

Figure 1: The strongest and weakest Ouchi illusions are shown above.

Contrast ratio calculation: we define length contrast as follows:

$$Length\ Ratio = \frac{Length}{4 * Height} \tag{1}$$

Where the strongest length contrast has 4 times the length than the width and the least length contrast has the same length and width for all rectangles. We use a step size of 0.1 to increase/decrease the length ratio.

We define color contrast as:

$$\text{Blend}(c_1, c_2, r) = c_1 + (c_2 - c_1) \times (4 - r) \tag{2}$$

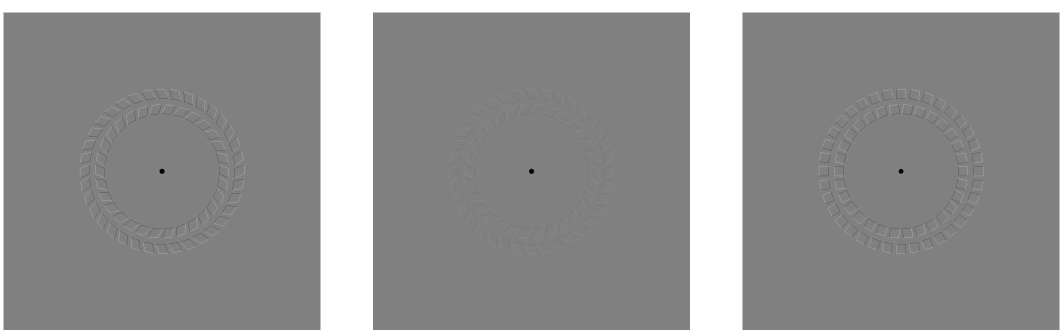
Where c_1 and c_2 RGB values of color1 and color2, respectively, and r is the blend ratio, a value between 0 and 4. Specifically, c_1 is black or white in the RGB space– ((0, 0, 0), (255, 255, 255)) and c_2 is the neutral grey color– (128, 128, 128). We apply the blending color ratio to black and white pixels to increase/decrease illusion contrast with a step size 0.1.

2.1.2 Wheel Illusion

The wheel illusion (also known as the rotating snakes illusion) produces the perception of motion in a static image [13]. This illusion is characterized by a series of concentric circles or spirals that appear to spontaneously rotate. The perceived motion in the wheel illusion is due to specific cognitive processes involved in how our brains interpret color, luminance, and geometric patterns. The interaction of these visual elements with the neural mechanisms of motion detection in the human visual cortex triggers the illusion of motion.

We use shift and color contrast to increase/reduce wheel illusion ratios to strengthen/weaken visual illusion effects. We use Equation 2 to adjust wheel illusion color contrast strengths with the same color range and step size as color Ouchi illusions shown in Figure 2a.

The wheel shift is how much the upper borders of the squares shift, where the outer squares shift in counterclockwise direction and the inner squares shift in clockwise direction. We use shifting values ranging from 0 to 4 (the normalized shift ratio is a shift value divided by 4), with a step size of 0.1. During shifting, we multiply the shift ratio by 10 to be able to visualize obvious shifts of the square borders (We do not directly use the range 0 to 40 to be consistent as Ouchi Illusion length ranges. The multiplication factor is dependent on the size and resolution of the canvas.).



(a) Strongest Wheel illusion used in our experiment (Shift 1.0).

(b) Weakest Wheel color illusion used in our experiment (ratio 0.0).

(c) Weakest Wheel shift used in our experiment (shift 0.0).

Figure 2: The strongest and weakest Wheel illusions are shown above.

2.2 Eye Tracking

We also implemented eye tracking for left and right eyes to record participants' eye coordinate on the xy 2D plane with (0, 0) as the absolute center coordinate. Each time participants' eye movement or vibration is detected, we record the time passed since the study, and the x and y coordinate values.

2.3 Virtual Environment Movement

We implemented a Canvas to display illusion patterns to users in the virtual space. Under the stationary condition, participants will see a static illusion pattern on the canvas shown in Figure 3. Under the walking condition, the illusion pattern canvas also simulates moving backward at a constant speed, but the users' visual distance to the canvas remains the same.

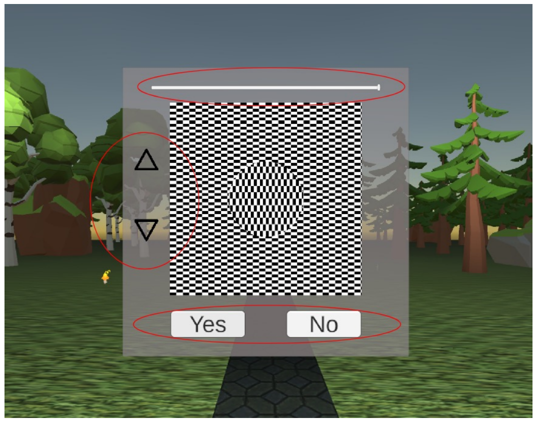


Figure 3: User study illusion pattern viewing scene. Under walking condition, the canvas will move at a preset speed. Participants click 'yes' if they see the described illusion and 'no' vice versa.

3 Experiment Procedure/Setup

Participants will go through a brief orientation session to familiarize with the HDM and the virtual environment in the beginning. They will be randomly assigned to one of two experimental conditions: walking on a treadmill or standing stationary. Following a standardized break, participants will experience the alternate condition. In each condition, they will view the same sequence of visual illusions and will be instructed to adjust the settings to determine their illusion threshold. Before moving the to the moving scene, the participant will be asked to take off the head-mount display and step on a treadmill with protective equipment.

3.1 Determining Illusion Threshold

We use staircase method to evaluate illusion threshold to effectively measure the illusion threshold and prevent habituation error and anticipation error in illusion patterns with algorithm 1. We are capable of manipulating the strength of the illusion by either changing the difference between foreground/background color or changing the height/width ratio of pattern size. When a visual illusion is presented to a participant, we will decrease the strength (thus decreasing the stimulus) until the subject report not seeing the stimuli. This intensity value is recorded, and we will increase the strength of illusion to the point where the illusion is visible again. Then, we repeats this process one more time. In other words, we will record four threshold value: two threshold for just not seeing the illusion and two threshold for barley seeing the illusion. The final illusion threshold is the average of the four recorded values.

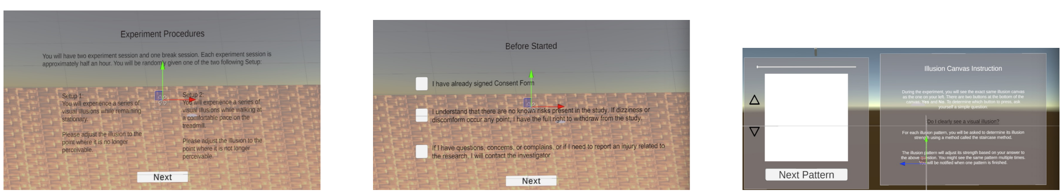
3.2 Virtual Environment

We design and implement virtual environments using Unity, which contains three scenes in Figure 4: Welcome Scene, Stationary Scene and Moving Scene. Welcome Scene is the first scene the user will enter. It serves as preparation and warm up room. This this space, user explores and familiarize the VR equipment as well as the virtual space. Given instructions, the scene also provides an opportunity for participants to practice tuning the illusion pattern. Both stationary and moving scenes contains a low-poly texture forest environment with a straight path in the middle of the scene. The main difference is that in the stationary scene, player (controlled by the participant) cannot move around.

Algorithm 1 Staircase Method for Evaluating Illusion Thresholds

```
Initialize thresholds as an empty list
Set maxTrials to the maximum number of staircase steps
Initialize isVisible as false
for trial from 1 to maxTrials do
    Present illusion with current strength
    if isVisible then
        Decrease the strength of the illusion
        Ask participant if the illusion is still visible
        if participant says no then
            Record this strength in thresholds
            Set isVisible to false
        end if
    else
        Increase the strength of the illusion
        Ask participant if the illusion is now visible
        if participant says yes then
            Record this strength in thresholds
            Set isVisible to true
        end if
    end if
end for
finalThreshold ← average of all values in thresholds
return finalThreshold
```

The participant will view and manipulate the illusion in a standing condition. In the moving scene, the participates will be moving in a moving scene similar to the stationary one.



(a) Instruction scene (b) Consent scene (c) Tryout scene

Figure 4: Pre-user study scenes.

3.3 Hardware Setup

We took several steps to ensure the safety of participants using the treadmill in our VR setup. We built a harness system using PVC pipes, a gym rack, and a harness vest. Before starting, participants wear the harness vest, which helps protect them if they fall. PVC pipes are positioned to keep participants from walking too close to the edges of the treadmill. These pipes touch the participant's body if they move too far to the side, helping them stay centered on the treadmill. The treadmill also has a safety key attached to the participant's clothing that stops the treadmill if they fall or move too far backward. Additionally, we covered the gym rack with foam padding to prevent injuries from accidental contact, protecting both the participants and the VR equipment.

4 Results and Discussion

We conducted user study with four participants, and collected user thresholds for four illusion patterns. Each user undergoes a 25-35 minute user study session for four illusion patterns under stationary and walking scenes. We take the median of thresholds for each illusion pattern and present the threshold range values in Table 1. Considering the sample size of our participants, we do not make any conclusions on our collected data. Additionally, our eye-tracking equipment is unable to detect subtle eye movements during experiments, recording only coordinates with significantly different x and y values when larger eye movements occur. Thus we cannot use our eye tracking data as another factor to measure strengths of users' neuron signals. However, we do see a general trend that users need higher thresholds to visualize described illusion patterns when they are moving than when they are stationary. One hypothesis to explore in the future is that when humans are moving, their neural stimuli to trigger a perceptual response is stronger, and needs more intense perception stimuli to trigger illusion effects. Although not able to get concrete conclusion in our report, the pilot study feedback and issues provides us valuable insights for improving future large-scale user study experiences– adding more illusion patters, increasing illusion contrast range, let users take a break between patterns to reduce habituation or fatigue bias…

Illusion	Moving	Stationary
Ouchi Length	0.9-0.13	**0.9-0.11**
Ouchi Color	1-0.15	**1-0.11**
Wheel Shift	1-0.17	**1-0.13**
Wheel Color	**1-0.3**	1-0.37

Table 1: The table shows the illusion normalized threshold ranges where participants can see the described illusion effects. The values are taken from the median of all participants.

5 Limitation

Due to limited time and funding, we are only able to recruit four participants for our study, and our study data cannot be used to make any concrete conclusions. In addition, we used limited sets of illusion patterns to show to users (We have three sets but only used two sets), partly for reducing user mental loads and users are unpaid. Users also give the feedback that illusion patterns are stronger on a monitor than in a virtual environment, which suggests that we have not taken the visual difference between the monitor and HMD into account. Future experiments need to account for the resolution difference between monitor and HMD when generating illusion patterns.

6 Distribution of Workload

6.1 Siyuan

- Building of the stationary scene: low-poly assets and actually "plant" them (trees, rock, flowers) on the ground. Building of "the road", and lighting. Building of the Illusion canvas.
- Data saving functions.
- Order equipments. I drove to Rockville to purchase and carry the gym rack back to school. (got a 100 dollar citation for parking in lot GG1 when offloading the rack).
- Lab hardware setups.
- Demo video preparations.

6.2 Zongxia

- IRB initial draft and revision. Wrote initial draft for Consent form, Initial applications, recruitment letter.
- Illusion pattern and eye tracking implementations.
- Hire participants for user study and conduct user study, analyze user study data, feedback and results analysis.
- Paper abstract, experiment, pattern, diagram, data analysis, conclusion sections.
- Demo slides, website.

7 Reference

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