# Immersive Eating: Evaluating the Use of Head-Mounted Displays for Mixed Reality Meal sessions


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### ABSTRACT

This paper documents a pilot study evaluating a simple approach allowing users to eat real food while exploring a virtual environment (VE) through a head-mounted display (HMD). Two cameras mounted on the HMD allowed for video-based stereoscopic see-through when the user's head orientation pointed toward the food, and the VE would appear when the user turned elsewhere. The pilot study revealed that all participants were able to eat their meals using the system, and a number of potential challenges relevant to immersive eating scenarios were identified.



**Keywords**: Virtual reality, mixed-reality, augmented reality, head-mounted display, food, eating, usability.

**Index Terms**: H.1.2 [Information Systems]: User/Machine Systems—Human factors; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality


## 1 INTRODUCTION

The ability to eat while being immersed in virtual reality (VR) opens many possibilities such as sensory manipulation [1], [2], investigation of food consumption in new environments, and the creation of extraordinary restaurant experiences [2], [3]. It could ultimately enable a user to enjoy a meal anywhere and together with anyone. Aside from benefiting the average consumer, eating in VR may also benefit individuals with special needs, such as the isolated or immobile elderly [4] struggling with underweight, by letting them eat with others [5] in environments that increase consumption volume [6]. The recent development in the area of head-mounted displays (HMD) has made them widely available among consumers and researchers. Food studies already applying HMDs [1], seem to take for granted that the act of eating while wearing an HMD might be unnatural or almost impossible and might ruin the sensation of "being there" in the virtual world (also referred to as *presence* [7]). From what we have found, the area of natural interaction with real food items while being immersed in VR through HMDs appears to be unexplored in the literature.

In this paper, we describe the development and initial evaluation of a novel interface for interacting with real food items while being immersed in a virtual environment (VE). The interface consists of an HMD equipped with two cameras on the front. The image of each camera is displayed to each eye, allowing the wearer of the display to experience video-based stereoscopic see-through. Taking advantage of the fact that we usually perceive our environments from a distance, while interacting with food in close proximity, head orientation is used to control when the user will see real surroundings versus the VE. When the head is orientated in the direction where food items are kept (usually placed in a downward angle directly in front of the eater on a table), the signal from the two cameras will be passed through. However, if the user looks straight ahead and away from the food, the VE will become visible.

This approach may not provide optimal user immersion, but it provides unaltered visibility of the food (while wearing an HMD) to the extent currently possible with commercially accessible hardware. It also avoids dependency on a particular lighting setup or image color composition, as is often the case when applying more advanced image-processing techniques for creating mixed reality [8].

## 2 METHOD AND MATERIALS

The aim of this study was to gain initial insights on the user experience and the usability of eating while using the described interface. Following the philosophy of "discount usability engineering" [9], the study mainly applied qualitative interviews to evaluate the prototype with the purpose of identifying usability problems and areas of improvement for future design iterations. Performance and psychological aspects, such as the level of comfort and presence, were considered equally important in the evaluation. To ensure that participants could fully indulge in the experience, the traditional use of think-aloud techniques in usability testing was replaced with a post-experience interview.

### 2.1 Hardware

To allow the eater to handle food items, an OVRvision PRO with two cameras was mounted on the front of an Oculus Rift CV1. The stereo camera provides each eye with a 960x950 picture 60 times a second and features lenses with a wide field of view (115° horizontally and 105° vertically). To protect the equipment without interfering with the infrared tracking, a transparent plastic bag was placed over the HMD (Figure 1). The HMD and the stereo camera were powered and provided a signal through USB 3.0 cables and an HDMI cable plugged into a VRReady PC (i5-4670K, 8 GB RAM, GTX 970). In addition, an Oculus Touch motion controller was used for mapping the area in which food was placed. Two positional Oculus sensors tracked both the controller and the HMD.


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Figure 1: The HMD without and with the plastic bag.

## 2.2 Software

The OVRvision SDK (version 1.81) was used to interface with the stereo camera, and a Unity 5 application was created using the Oculus Utilities (version 1.10.0) to present the VE in the HMD. A VE demo from the asset package named “Autumnal Nature Pack”[1] by Manufactura K4 was used for the virtual experience. The VE portrayed a park in autumn. A bench in the park was selected to be the point of view for the user, and a virtual table was placed in front of it. The view from the bench included colorful trees and flowers and a small fountain on the left-hand side. An ambient soundscape featuring birds singing was played back in stereo (no spatialization was used).

To enable see-through, two vertical planes were placed in front of the virtual cameras, rendering the park environment into images for, respectively, the left and right eye. Each plane used a custom shader displaying the video signal from, respectively, the left and right front-mounted camera. The shader also allowed the transparency of the planes to be changed, making it possible to fade smoothly between seeing the stereo camera feed and seeing the virtual park (Figure 2). This transition was mapped to the angle between the current viewing direction and the “food-and-head” vector pointing from the food to the location of the HMD. An angle below 25 degrees would make the stereo camera feed fully visible. Increasing the angle would linearly increase the transparency of the planes displaying the camera feed and ultimately show the VE only when the angle exceeded 30 degrees.

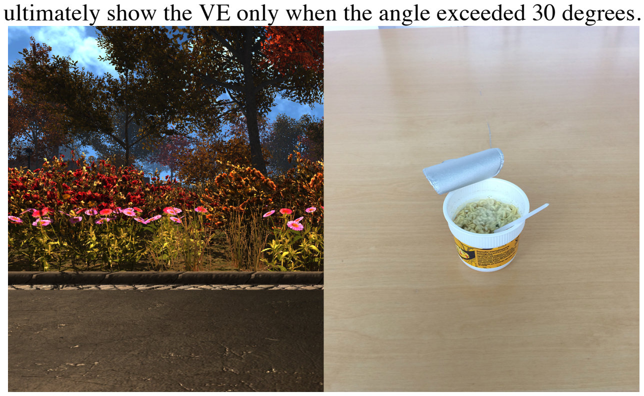

Figure 2: Left: The virtual park environment. Right: The visible image from the mounted camera.

## 2.3 Test setup and food selection

A table in a small meeting room was used for the experiment over a period of two days. The two positional sensors were placed on the table a meter apart and in front of the participant who was to wear the HMD. The investigator took a seat at the end of the table to guide the participant through the experiment.

Cup noodles were served as the main dish, supplemented by a small piece of cake and a cardboard juice. Noodles and cake were chosen, as we assumed different eating strategies would be applied to consume them, such as using a fork versus the hands, blowing on the surface of the food to cool it down versus not considering the temperature, eating a mouthful at a time versus taking small bites, etc. During pre-testing, we experienced problems with drinking from glasses, as they collided with the HMD. Therefore a drink consumed through a straw was chosen.

## 2.4 Procedure and recordings

The participant was then guided chronologically through five parts of the experiment: (1) an initial interview session asking about previous experiences, (2) a hand-eye coordination test without wearing the HMD, (3) the same hand-eye coordination test while wearing the HMD, (4) a mixed-reality meal session wearing the HMD and (5) a concluding interview session focusing on the meal experience.

During the initial interview, the participant was asked to describe his or her previous experiences with HMD-mediated VR (including the tendency of cyber- and motion sickness), how often he or she eats alone, and questions investigating what he or she eats and where he or she would usually eat when eating alone.

The hand-eye coordination test performed by the participant was a modified version of the alternative hand wall toss test [10], which allowed the participants to remain seated and eliminated the need for a wall. The participant was asked to throw a small purple plastic ball (with a radius of approximately 3 cm) in a curved trajectory from the right hand to the left and then back from the left to the right hand. After a small rehearsal session, the number of successful transfers from one hand to the other was recorded during a period of 30 seconds together with the number of failed attempts. This was done both without and with the participant wearing the HMD (set in see-through mode).

Conversation was discouraged during the mixed-reality meal session, and the participant was told that the investigator would attend other activities while still being available in case the participant should encounter problems or discomfort during the experiment. After the participant had arranged the food items on the table in front of him or her, the tracked controller was used to mark the approximate center of the area in which the food was located. The participant was then instructed to eat as much or as little as he or she wanted but that all of the food items had to be tasted during the wearing of the HMD. The amount of time was logged during which the participant saw the VE, the food, and the time where the participant saw the transition between the two states. When the participant indicated that he/she was done, a concluding interview was held with the participant. The interview was semi-structured [11] and revolved around the following key questions:

- Q1. How would you compare this meal experience to your everyday-eating-alone experiences?
- Q2. How would you describe the visuals, texture, taste, and smell of the food served during the meal session?
- Q3. How consistent or disconnected was the information from your senses during the meal session?
- Q4. Did you experience any problems during the eating session?
- Q5. Did you feel sick during any part of the test?
- Q6. Which of the two realities presented in this prototype would you characterize as the dominant one?
- Q7. Could you give an indication in percentage of how much time you spend in each of the two realities presented in this prototype?
- Q8. Could you rate the extent to which you felt like being in the park on a scale from 0 to 10 (where 0 is *“I did not*

[1] https://www.assetstore.unity3d.com/en/#!/content/3649

*feel like being there" and 10 is "I did feel like being there"*)?

Q9. Could you rate the extent to which you felt like being in this room on a scale from 0 to 10 (where 0 is *"I did not feel like being there" and 10 is "I did feel like being there"*)?

Q10. How would you describe the transition from one reality to the other?

Q11. Do you see yourself eating with this type of setup in the future?

Follow-up questions where asked whenever clarification or more detail was needed.

## 3 FINDINGS

Six people (three males and three females), aged between 28 and 56 years, took part in the pilot study. When asked what meal they most often ate alone, four responded "breakfast" and two "lunch". All participants had prior experience with VR (the participant with the least experience had tried VR three times, and the participant with the most experience considered himself a VR professional). Four of the participants reported that the eating was done concurrently with other activities, such as instant messaging or watching video content online. The results of the hand-eye coordination test are given in Table 1 below. Participant 6 did not complete the test while wearing the HMD due to discomfort.

Table 1. Results from the hand-eye coordination test with and without HMD: participant (P), successful transfers (ST), and failed attempts (FA)

| | ST | FA | ST (HMD) | FA (HMD) |
|---|---|---|---|---|
| P1 | 45 | 0 | 19 | 4 |
| P2 | 35 | 0 | 17 | 4 |
| P3 | 26 | 0 | 13 | 4 |
| P4 | 33 | 0 | 16 | 4 |
| P5 | 29 | 0 | 20 | 3 |
| P6 | 30 | 0 | - | - |

### 3.1 The new eating context (Q1, Q10)

Two of the participants highlighted the novelty of the situation as being the main difference between this experience and an ordinary alone meal. A slower pace of eating was also brought up by three of the participants: "When I was looking in front it was actually comforting to sit there… I didn't expect that actually… but the sounds and the visuals, I think I ate slower than I would do normally" (P1). Most participants said that they found the act of switching reality to be logical: "It worked really well with my intentions. When I had an intention about finding food then it worked and it didn't happen at times when it wasn't intentional" (P2). However, the transition was described more as functional rather than realistic or comfortable: "It was necessary to switch to perform the action, but I didn't want to do it. If I could I would stay in virtual reality but I couldn't" (P1); "Looking down on the food was a necessary evil that I had to do and when I sat there and champed and chewed then I could sit and enjoy the park. It work fairly well and was fun" (P5).

### 3.2 Food sensation (Q2)

All participants reported that the texture, taste, and smell of the food were as they expected. The visuals were described as being believable and representative of the food that was being displayed but that it was of a lower resolution and of a color that was darker and in contrast with the vibrantly colored VE: "It was degraded by the camera and everything became a little more grey and flat, but it still tasted fine when it came inside" (P2); "The texture of the noodle was hard to see and the individual noodle from each other. Here the cake was easier as it had a more uniform surface both on the side and on the top. I did not have any impression of when or if I hit a piece of chicken or which type of vegetable I eat, but I could see the noodles" (P5). Another participant went on to describe how some of the food items were perceived as better suited than others for the virtual park environment: "The juice was particularly good in this setting, but it also depends on what one is used to eat. But it [the juice] was fresh, while this [the noodles] was more heavy" (P3).

### 3.3 Sensory coherence, problems, and sickness (Q3, Q4, Q5)

In all interviews, the sound and visuals of the VE were described as being consistent but with small errors, such as having stationary clouds while the wind was blowing. Several participants mentioned experiencing a mismatch between their proprioception and the visual input from the stereo camera when looking at their food: "There was a connection between what the camera saw and what I would have seen with my eye, but it still felt like something was off. I felt that I couldn't trust the location of my hands. Almost! But not quite" (P5).

Most participants said that the noodles were more difficult to eat compared to the cake and drinking the juice. One participant elaborated: "…everything was so lightweight… that the noodles so easily could fall off [the fork] and that the fork was entirely without weight made me insecure about whether I could hit my mouth..." (P5). Other factors mentioned as contributing to the difficulties were a limited field of view, the possibility of collision with the HMD, and a lower resolution and refresh rate of the cameras compared to viewing the food with the naked eye.

All participants expressed that they felt uncomfortable during the hand-eye coordination test performed while wearing the HMD in see-through mode. However, they also said that this was less prominent or disappeared during the meal session "the moment when I had to take the food was disturbing because you switch from one to the other, but I think I even got used to it at some point" (P1).

### 3.4 Dominant reality, time perception, and presence (Q6, Q7, Q8, Q9)

All participants stated that the VE was the most dominant reality, and they also estimated that they used more time in the VE. When comparing the participants' statements with the logs (Table 2), most of them slightly overestimated the amount of time they spent visually in the VE. One particular participant (P5), however, deviated from this pattern by spending almost half of the time in each reality. This could be explained by the fact that the participant worked professionally with VR and probably found the eating interface to be novel compared to the VE. Although this explains the recorded time, it does not explain why the participant felt that he spent more time in the park.

Table 2. Meal duration (MD) in minutes (m) / seconds (s), estimated percentage of time (ETD), and recorded percentage of time (RTD) of each participant (P)

| | MD | ETD (park) | ETD (room) | RTD (park) | RTD (transition) | RTD (room) |
|---|---|---|---|---|---|---|
| P1 | 8m 2s | 80 | 20 | 63.0 | 63.0 | 36.5 |
| P2 | 7m 11s | 80 | 20 | 74.5 | 74.5 | 25.0 |
| P3 | 6m 32s | 70 | 30 | 91.1 | 91.1 | 8.6 |
| P4 | 6m 18s | 95 | 5 | 81.6 | 81.6 | 17.3 |
| P5 | 4m 37s | 80 | 20 | 52.0 | 52.0 | 47.3 |
| P6 | 5m 42s | 95 | 5 | 89.5 | 89.5 | 10.0 |

All participants rated their sense of being in the park as 5 or above. In general, the participants expressed that they found the

VE to be compelling but that the need to return to the real room every time food had to be handled reminded them of where they were: “I don’t like being cheated, it has to be honest. If I sit there and are pulled in… then suddenly I have to find my noodles and then noo… [laughter]” (P3). The participants provided mixed ratings of their sense of being in the room. Two participants rated this as low and especially pointed to the fact that they forgot that the investigator was sitting next to them. Two others rated this question in the middle, stating that the realities were perceived as being mixed: “When I looked at the bench then I said it was a soft bench because I was setting on this soft chair [in the room] and looked at some wood [bench in park], so my body must have been aware that it wasn’t there, but I still thought the visuals were beautiful and the sounds... I don’t know… can one divide the senses?” (P3). The last two said they never doubted they were in the room and therefore gave high ratings.

### 3.5 Appeal (Q11)

Two participants quickly proclaimed that they were uninterested in the concept of VR in general: “I think it would be unpleasant if something had fallen off the shelf or somebody had broken down the door or the world had ended while I sat there in the park” (P3). The ability of VR to transport the user to new locations or events was the main reason why two other participants expressed their enthusiasm about the concept: “Then you could sit in Machu Picchu one day and in Rome the other day” (P2). The last two participants expressed conditional acceptance of the concept. The amount of technical gear required for the setup was an issue, as the time to set it up would exceed the duration of a simple meal. Another issue was the connection between the eating and the experience and why this had any value: “Let’s say that I had to do thanksgiving and my sister was in Australia and I didn’t have money to travel to her. Having the opportunity to take on my VR glasses and enjoy my thanksgiving dinner with her… that would work…” (P5).

## 4 Discussion and future improvements

All participants spoke positively about the park experience and all were able to eat their meals (only one participant was observed spilling a small amount). In addition, the VE was both timewise and perception-wise the dominant reality among all of the participants, enabling at least one participant to spontaneously evaluate her sensation of the food with respect to the presented VE (Q2/P3).

However, a number of challenges were found, which are relevant to both engineers, developers, and researchers: (1) a limited field of view; (2) a lower resolution and refresh rate compared to viewing food with the naked eye; (3) the possibility of collision with the HMD; (4) the properties of the food; (5) the properties of the cutlery; (6) a mismatch between proprioceptive and visual senses; (7) the transition to the room reminded participants that they were sitting in a room and not at the park.

Some food types are just harder to handle while wearing an HMD. Avoiding food that is not eaten with the hands or is likely to detach from cutlery is worth considering when performing experiments with a similar test setup. The careful design of the eating utensils could also improve the experience (e.g., giving the fork more weight and altering the shape of the glass to avoid collision with the HMD).

Other problems were caused by the limitations of the video see-through technology [12]. The transition from the VE to the see-through mode appeared to induce breaks in presence, and all of the participants expressed discomfort and performed poorly during the hand-eye coordination test while wearing the HMD. The latter has been seen in previous research [13] investigating the visual-proprioceptive effects of the eye-camera parallax caused by the distance between the cameras and the eyes. The effects may have been perceived as even stronger because the virtual cameras used for rendering the VE were correctly placed, thus forcing the participants to continuously switch between a natural and an unnatural viewing experience. Future studies could explore whether such discomfort would be reduced by setting up the virtual cameras to mimic the placement of the real cameras. Ultimately, the discomfort may be removed by using mirror mounts [14] or by producing a high-fidelity graphical representation of the food in the VE.

All of the findings indicate relevant research directions for future work leading toward the perception of natural eating while wearing an HMD.


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