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Master's thesis

Application of Different Sensory Methods in VR Sensory Analysis

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Summary

This research aimed to discover the different potentials of Virtual Reality (VR) technology usage in sensory science. The main goal is to look for the viability of the use of VR coupled with JAR and CATA tests not only as a tool but also as a platform for food product imagination and evaluation. Through comparative analysis it is demonstrated that VR is able to simulate the sensory analysis process as if the person was performing this activity in a physical setting. On the contrary, the outcome is also similar to the comparison of CATA analysis in virtue and VR-based CATA analysis. Hence, VR is valid for capturing refined sensory perception. The respondents' opinions pointed to immense strengths and areas of deficiencies in the application of the VR technology to sensory analysis. The participants enjoyed the experience all the same although it was a bit hard on their eyes as it was not clearly defined. Also, the simulator sickness was hard enough for some and the calibration process would need some tweaking. Such observations could lead to the development of systems to ensure maximization of VR technology use in sensory science applications. To sum up, the VR environment is very promising in the practice of sensory science; it not only provides the tool to assess products but also a new approach to our common knowledge. By tackling the problems described and adopting continuous design improvements, we believe VR is going to make a radical difference in sensory analysis with much less time, effort and money needed.

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Objective

The primary goal of this study is to explore the applications of Virtual Reality (VR) technology in sensory science, specifically through the use of Just About Right (JAR) and Check All That Apply (CATA) tests. The experiment aims to demonstrate that VR can serve as a versatile platform for creating and evaluating food products, offering significant potential to transcend traditional sensory analysis limits. Furthermore, the study seeks to identify areas of improvement within VR applications in sensory science, particularly focusing on participant feedback regarding simulator sickness.

Introduction

Sensory analysis has a rich history of evolution, closely mirroring the growth of the food industry and consumer preferences (Ruiz-Capillas *et al.*, 2021). Traditional sensory techniques have been in product development but they are often limited by their lack of contextual and environmental variables. The introduction of VR technology provides a new frontier, allowing for a simulated sensory experience that aligns more closely with real world conditions where consumers interact with food products.

The pursuit of ecological validity in sensory testing has led to the exploration of VR as a means to create realistic consumption environments. Studies by Kong et al. (2020) and Stelick et al. (2018) have demonstrated that the context provided by VR can influence the sensory perception of products such as chocolate and beverages. These studies suggest that VR can emulate and manipulate environmental factors, enhancing the ecological validity of sensory data and potentially reducing the discrepancy between tested acceptability and real-market product success.

Recent studies have further expanded the understanding of VR's impact on sensory and flavor perception. Ammann et al. (2020) found that product color in VR could affect flavor identification, suggesting a strong visual influence on taste. Similarly, Crofton et al. (2021) demonstrated that VR environments could significantly influence hedonic responses to food products, with meat and chocolate being perceived differently in various VR settings.

JAR and CATA methods are crucial in sensory analysis for capturing the nuanced perceptions of consumers. The immersive environments provided by VR have the potential to enhance these methods by presenting products in more realistic contexts. By employing VR technology, researchers can gather more accurate JAR and CATA data, which reflect not only the product attributes but also the consumer's emotional and psychological responses to them in different settings.

While VR presents numerous opportunities for sensory science, it also introduces challenges such as simulator sickness, which can affect participant feedback and the validity of sensory data. As VR applications in sensory science grow, understanding and mitigating adverse effects like simulator sickness becomes crucial. This study will focus on obtaining participant feedback related to this phenomenon to identify areas for improvement in VR sensory applications.

The body of research presents compelling evidence that VR can serve as a versatile platform for sensory science, offering innovative means to surpass the limitations of traditional methods. By leveraging VR technology in conjunction with JAR and CATA tests, this study aims to enhance the sensory evaluation process, providing a more comprehensive understanding of consumer experiences. Additionally, it seeks to recognize and address the limitations within VR applications, including the evaluation of simulator sickness, to refine and optimize the use of VR in sensory science.

1. Literature review

Traditional Sensory Analysis

Sensory analysis is a scientific discipline that uses the human senses to evaluate consumer products. It provides objective information about the consumer understanding of a product, the acceptance or rejection of stimuli, and the description of the emotions evoked (Marques *et al.*, 2022).

Sensory science has been successfully used in various industries for centuries. The first reports about sensory perception go back to the ancient Greeks, where Aristotle delineated five of the senses in 350 BC. Over the years, many techniques have been developed to meet different objectives and applications, each with their own advantages and disadvantages (Kemp *et al.*, 2018).

Descriptive sensory analyses are the most sophisticated tools in the sensory science. These techniques allow the sensory scientist to obtain complete sensory descriptions of products, to identify underlying ingredient and process variables, and to determine which sensory attributes are important to acceptance.(Lawless and Heymann, 1999)

There are several types of sensory tests, including discriminative tests, descriptive tests, time-intensity methods, instrumental sensory devices, and immersive techniques. Descriptive methods afford objective descriptions of the nature and intensity of sensory characteristics, as well as reliable statistical data (Marques *et al.*, 2022).

Sensory methods and Questionnaire

Just-About-Right analysis

Just-About-Right (JAR) analysis is a popular sensory evaluation method used in product development and optimization (Pivokonsky *et al.*, 2022). It's a type of quantitative descriptive analysis that measures consumer perception of the intensity of different attributes in a product.

JAR scales are designed to find out if people see any attribute in a product at a degree that is either too low or too high or "just about right". In order to measure sweetness of a soft drink, consumers could be offered sampling of a prototype and rating it on a scale that ranges from, for example, "too sweet" to "not sweet enough". On top of sweetness, some other characteristics of interest might be intensity of taste and carbonation, and JAR midpoint numbers could be added for the scale of assessment of these attributes. Consumers' responses will help in confirm whether there is any scope for further modification of the prototype and they will show where formulations might be changed. JAR scales, for instance, are widely used in research that is aimed at improving the levels of indulgence. Sensory properties are often associated with satiety, a principle that means whatever amount you consume is enough. In fact, one and the same attribute has intensity levels, at which consumers consider it "too low" and after, their desire increases and the level is "too big". JAR scale requires consumers to relate the intensity they experience in the product to the level they desire. (Varela, P., & Ares, G. ,2014)

The product attributes are chosen to identify the key attributes of the product that influence consumer perception. These could be taste, texture, color, smell, etc. Next scale development is set to develop a JAR scale for each attribute. The scale typically has a middle point indicating the 'just right' level, with points on either side indicating 'too low' and 'too high'. Then we have a panel of consumers to evaluate the product based on the JAR scales for each attribute. Finally we analyze the data to understand consumer perception of the product. The goal is to optimize the product so that the majority of ratings fall into the 'just right' category for all attributes.

The advantages of JAR analysis (Gere *et al.*, 2017):

- Consumer-Focused: It focuses on consumer perception, making it highly relevant for product development.
- Versatile: It can be applied to any sensory attribute of a product.
- It helps identify the optimal levels of different attributes to maximize consumer acceptance.

CATA analysis

A Check-all-that-apply (CATA) analysis is a sensory evaluation method that is often used in product development and optimization (Ares *et al.*, 2014). In a CATA analysis, the sensory panel of consumers is presented with a list of descriptors, and they are asked to select all the attributes that apply to a given product.

CATA is often used to obtain rapid product profiles from consumers. Consumers are presented with a list of attributes and asked to indicate which words or phrases appropriately describe their experience with the sample being evaluated. The terms might include sensory attributes, as well as hedonic responses, emotional responses, purchase intentions, potential applications, product positioning, or other terms that the consumer might associate with the sample (*Varela, P., & Ares, G.* 2014).

Ares *et al.*, (2014) had consumers evaluate food products; they collected consumers' sensory responses using CATA questions and hedonic responses using liking questions. Their presentation sparked considerable interest in using CATA questions to obtain a rapid profile.

In order to relate CATA results to consumer acceptance, CATA studies are often accompanied with liking questions and/or might include the evaluation of a (hypothetical) ideal product. CATA questions might be further combined with demographic and consumer psychographic questions, for example, to provide a so-called all-in-one test (Jaeger *et al.*, 2013).

Advantages of CATA Analysis (Schouteten *et al.*, 2024):

- Simplicity: CATA is simple for panelists to understand and quick to complete, which can lead to higher response rates.
- Rich Data: It provides rich data as consumers can select multiple descriptors that apply, giving a more complete picture of the product.
- Consumer Language: It uses language that consumers use, making the results more relevant and easier to interpret for product development.

SSQ

The Simulator Sickness Questionnaire (SSQ) is a tool used to measure symptoms of simulator sickness, a condition that can occur when using virtual reality (VR) or other simulation technologies. It was designed as a refinement of the Pensacola Motion Sickness Questionnaire (MSQ) for computer-based simulators (Balk, Bertola and Inman, 2017).

- Symptom Rating: The SSQ asks participants to provide subjective severity ratings of 16 symptoms on a scale from 0 (no perception) to 3 (severe perception) after exposure to the simulator.
- Score Calculation: Through some calculations, four representative scores can be found. These scores are based on three categories of symptoms: Nausea, Oculomotor Discomfort, and Disorientation.
- Interpretation: The scores are then used to quantify and compare simulator sickness in different virtual environments.

Table 1 Determinations of the Simulator Sickness Questionnaire (SSQ) symptoms belonging to categories (nausea, oculomotor, and disorientation).(Kennedy et al., 1993)

Simulator Sickness Questionnaire (SSQ) Symptoms	Categories		
	Nausea	Oculomotor	Disorientation
General discomfort	1	1	
Fatigue		1	
Headache		1	
Eyestrain		1	
Difficulty focusing		1	1
Increased salivation	1		
Sweating	1		
Nausea	1		1
Difficulty	1	1	
concentrating			1
Fullness of head		1	1
Blurred vision			1
Dizzy (eyes open)			1
Dizzy (eyes closed)			1
Vertigo	1		
Stomach awareness	1		
Burping			
Total	[1]	[2]	[3]

The SSQ score is considered negligible when it is lower than 5. A minimal score falls between 5 and 10, signifying a minor level of discomfort. A score of 10 to 15 is considered significant, indicating a notable level of discomfort. A score of 15 to 20 is regarded as concerning. Lastly, a score exceeding 20 is classified as severe.

However, there are some considerations to keep in mind when using the SSQ. For instance, the SSQ assumes that participants felt completely well before the exposure to the simulator (Bimberg, Weissker and Kulik, 2020). This assumption may not always hold true, as certain symptoms could also be provoked depending on the time of the day, the journey to the experimental venue, or the current mood of a participant. Therefore, it’s important to interpret the results of the SSQ with these considerations in mind.

1. Misleading Formula: The introductory paper of the SSQ omitted the notation of brackets in the total score computation. The correct computation involves summing up the category scores first before multiplying them with the scaling factor. The incorrect notation without brackets could lead to lower total scores and an imbalanced weighting of symptoms[1].

2. Non-Uniform Discretization: The scaling factors in the SSQ introduce an unequal discretization of potential outcome scores. Different symptoms contribute to the total score with varying step sizes, making comparability challenging across studies[1].

3. Military Reference Population: The SSQ's absolute interpretation thresholds were derived from a sample of military aviators, who might be less susceptible to simulator sickness than the general population. Average scores above the "bad simulator" threshold of 20 are frequently observed in related VR studies, suggesting that the initial calibration was not representative of the broader population[1].

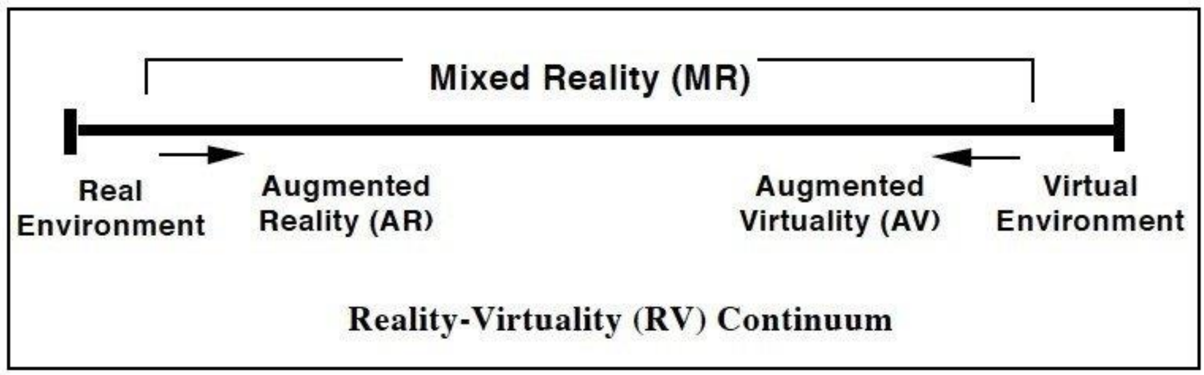
4. Missing Baseline Scores: The SSQ assumes that participants felt completely well before exposure to the simulator. However, assuming a rating of 0 (no perception) for each symptom can be challenging due to various factors like time of day, travel, or mood[1].

In addition to the SSQ, researchers have developed other tools to assess cybersickness in VR, such as the Cybersickness in VR Questionnaire (CSQ-VR). The CSQ-VR demonstrates superior internal consistency and better psychometric properties compared to the SSQ and its variant, the Virtual Reality Sickness Questionnaire (VRSQ)[2]. Researchers continue to explore and refine assessment tools to better understand and mitigate cybersickness in VR environments.

Virtual reality

Virtual world is a filmed or simulated experience which displays environment around the user and tracks the movements of the user in the VR room. It must be pointed out that immersion into VR space is completely different from watching 2D screens. By making the space around the user interactive, VR provides the illusion of direct presence in a digital world. VR examples range from entertainment like video games, education for illustrating and creating trainings and simulations, to the vocational field which use virtual meetings (*Lacoma*, 2023)

Figure 1 A Taxonomy of Mixed Reality Visual Displays. (Milgram, Paul & Kishino, 1994)



VR usages in sensory analysis

The concept of VR is often discussed in relation to the Milgram & Kishino (1994) Reality-Virtuality continuum (Figure. 1), a framework that positions different realities with varying degrees of virtual content. This continuum helps in understanding the spectrum between Augmented Reality (AR) and Virtual Reality (VR) (Simeone et al., 2020). While AR is closer to the real world end of the continuum, VR represents the extreme virtual end. VR technology enables users to immerse themselves in computer-generated virtual environments, providing a unique and interactive experience (Kim et al., 2018).

Virtual Reality (VR) is increasingly being used in sensory analysis due to its ability to create immersive, interactive, and multi-sensory environments. This technology represents a paradigm shift in sensory evaluation, opening up new avenues for studying sensory immersion and its impact on perception and engagement (Zulkarnain *et al.*, 2024).

The investigation into the impact of contextual factors on sensory perception and consumer behavior within the realm of virtual reality (VR) has garnered significant attention in recent literature (Oliver and Hollis, 2021) highlight VR's capability to simulate various eating environments, such as restaurants or home settings, allowing researchers to explore how contextual factors shape sensory experiences and consumer responses. Furthermore, the integration of virtual and augmented reality technologies in sensory marketing efforts within the food industry has opened up new avenues for enhancing consumer engagement and perception. (Crofton *et al.*, 2019) emphasize VR's potential to deliver immersive and interactive user experiences, thereby influencing consumer sensory experiences and behaviors. Moreover, the incorporation of multi-sensory cues within VR contexts has been shown to enhance presence and engagement, ultimately impacting the perception of food stimuli (Song, Pérez-Cueto and Bredie, 2022). Collectively, these studies underscore the burgeoning interest in leveraging VR technology to elucidate the intricate interplay between context, sensory perception, and consumer behavior, thus paving the way for innovative approaches in sensory marketing and research within the food industry.

The investigation into cross-modal correspondence within virtual reality (VR) environments has unveiled intriguing insights into the interplay between sensory modalities and their influence on perception. (Cornelio *et al.*, 2022) delve into how ambient color within VR settings can shape taste perception, highlighting the potential of VR as a tool for exploring such relationships. (Torrico *et al.*, 2020) extend this exploration by assessing the impact of VR settings on consumers' wine tasting experiences, revealing its potential to influence product acceptability and consumer emotions. Similarly, (Crofton, Murray and Botinestean, 2021) delve into the sensory perception of beef steaks and chocolate within VR environments, showcasing the burgeoning interest in replicating consumption contexts for enhancing ecological validity in sensory evaluations. Their findings underscore VR's potential to shape product acceptability through immersive sensory experiences. Moreover, (Picket and Dando, 2019) emphasize how the level of environmental immersion in VR settings affects hedonic responses, perceived appropriateness, and willingness to pay in alcoholic beverages, highlighting VR's capacity to engage participants in real-world scenarios while maintaining experimental control. Collectively, these studies underscore the transformative potential of VR in shaping both sensory perception and consumer responses, offering novel avenues for enhancing product acceptability and consumer experiences across various domains.

The utilization of virtual reality (VR) extends beyond conventional sensory evaluations, offering promising avenues for enhancing sensory training, investigating sensory disorders, and exploring novel food experiences. (Colombo *et al.*, 2021) emphasize VR's potential for enhancing emotion regulation through the manipulation of sensory stimuli and exposure to diverse contexts, suggesting its applicability in sensory training programs. Furthermore, VR serves as a valuable tool for studying sensory disorders, as demonstrated by Lestari et al. (2022), who utilized VR to assess sensory and motor functions in children with developmental disorders, thereby shedding light on the impact of sensory abnormalities on food perception. Additionally, VR facilitates the creation of immersive experiences for exploring novel food sensations and flavors, as evidenced by Kong et al. (2020), who simulated unique culinary experiences such as tasting virtual chocolates or exotic cuisines. Moreover, (van der Laan *et al.*, 2022) presents a novel VR food choice task, showcasing VR's potential to create immersive sensory experiences and assess fundamental valuation processes in food selection. Collectively, these studies highlight the versatility of VR technology in enhancing sensory training, investigating sensory disorders, and providing unique avenues for exploring and experiencing novel food sensations, thereby contributing to advancements in sensory science and consumer behavior research.

Understanding consumer preferences in the context of food choices and shopping behaviors has become a focal point of research, with virtual reality (VR) emerging as a potent tool for investigation. (Mishra *et al.*, 2021) delves into the impact of technology interface and product type on consumer responses, underscoring the preference for immersive and visually rich sensory environments that stimulate cognitive and affective responses. This underscores the importance of creating captivating experiences to influence consumer preferences effectively. (Lombart *et al.*, 2019) explore consumer perceptions and purchase behavior toward imperfect fruits and vegetables within an immersive VR grocery store, revealing VR's potential to shape consumer behavior and preferences in virtual environments. Furthermore, (Plechatá *et al.*, 2022) investigate the effectiveness of VR in promoting pro-environmental dietary changes, highlighting VR's capacity to influence consumer preferences and behaviors regarding food choices and consumption patterns. Collectively, these studies underscore the transformative potential of VR in understanding and shaping consumer preferences, thereby offering novel insights into consumer behavior research within the food industry.

The exploration of consumer emotions within virtual reality (VR) sensory evaluations has revealed intriguing insights into the impact of VR on participants' emotional states (Zulkarnain, Kókai and Gere, 2024a) demonstrates the significant influence of VR sensory evaluation on participants' assessments, noting an increase in overall positive effects and a reduction in negative ones. This underscores the transformative potential of VR in shaping consumer emotions and perceptions. Furthermore, Zulkarnain et al. (2023) highlights the utility of VR sensory laboratories as valuable resources for both sensory scientists and consumers interested in exploring emerging opportunities in VR technology. Their findings underscore the potential applications of virtual laboratories in the food industry, particularly within the realm of sensory science, showcasing VR's capacity to revolutionize sensory evaluation processes and consumer experiences. Collectively, these studies underscore the pivotal role of VR in understanding and enhancing consumer emotions and experiences within the sensory science domain (Schouteten *et al.*, 2024).

The advantages of using VR in sensory analysis include the creation of realistic and immersive sensory experiences, the ability to study the influence of various factors on perception and engagement, and the potential for improved consumer engagement and ecological validity (Zulkarnain, Kókai and Gere, 2024b).

However, like any technology, VR also has its limitations. These include the need for specialized equipment and software, potential issues with user comfort and motion sickness, and the challenge of ensuring that virtual experiences accurately replicate real-world sensory experiences.

2. Methods and Materials

2.1. Participants

Participants for both the biscuit trial (n = 43, 33 females and 10 males, ranging in age from 20 to 40 years) and the orange juice trial (n = 43, 33 females 76.7% and 10 males 23.3%, ranging in age from 20 to 40 years) were recruited via internal email from a pool of staff and students based at Hungarian University of Agriculture and Life Sciences (MATE) Food Sensory laboratory, Budapest, Hungary. Participants had to meet the following inclusion criteria: had no known history of food allergies related to the study products; and did not suffer from severe motion sickness; will be able to attend the second measurement. Selected participants were asked to refrain from eating, drinking, or smoking for at least one hour prior to the start of the trial. Informed consent was obtained from each participant (Figure. 2)and they were free to withdraw from the study at any time. Half of the participants have some experience with VR and frequency is mostly rare to none. (Figure. 3) The sessions were conducted throughout the days of available participant dates and took place at the Sensory Laboratory at Buda campus, MATE, which has been designed in accordance with ISO 8589:2007.

Figure 2 Users former experience in VR (Tuvshintugs, 2024)

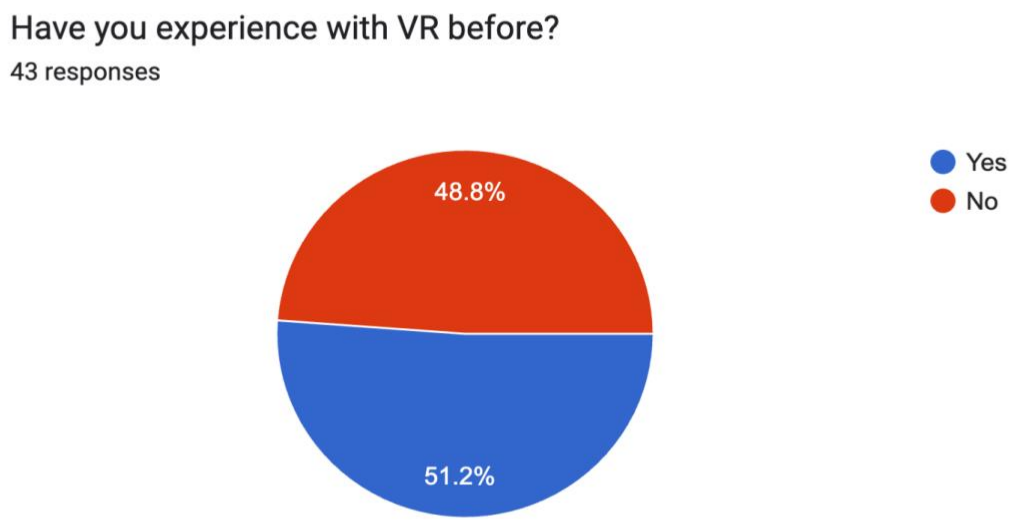
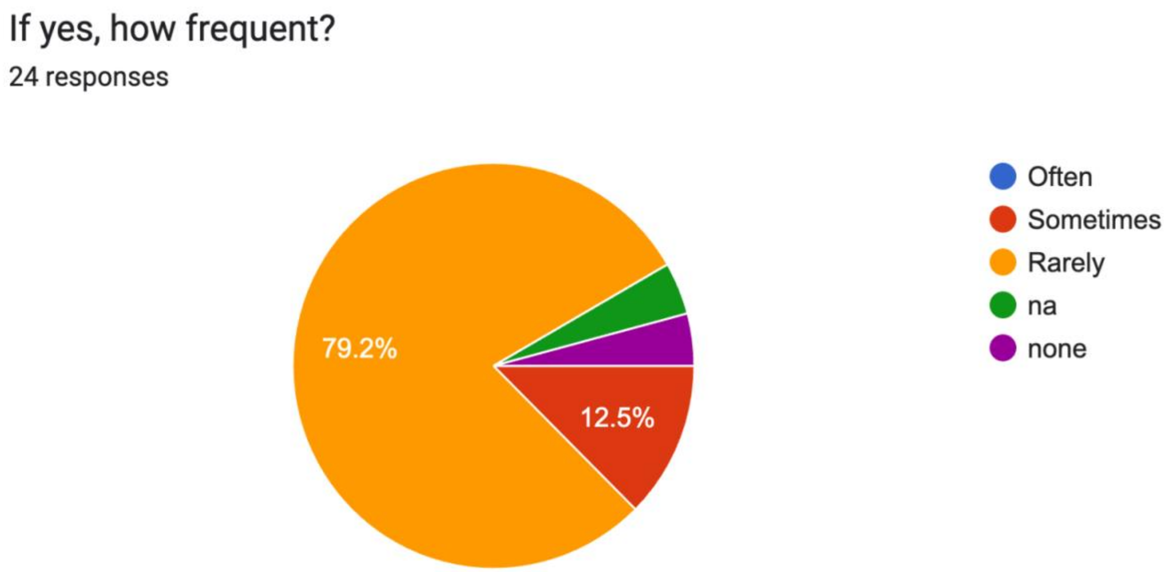


Figure 3 Participants frequency in usage of VR (Tuvshintugs, 2024)



2.2 Place and measurement setup

VR Sensory Booth: A virtual reality setup created in Unity version 2022.3.10f1 (Unity Technologies, Unity Software Inc., San Francisco, California, US) specifically for sensory evaluation (Figure. 4), employing the Meta Quest 2 (Reality Labs, Meta Platforms Inc., Menlo Park, California, US) VR headset (Fig. 5) to immerse participants in a simulated sensory booth environment. Meta Quest 2 VR headset was selected due to its lightness and extra sensors.

The VR sensory booth (Fig. 6a) used in this research is a duplication of a real sensory booth (Fig 6b) at the MATE. The study was conducted in the Sensory Laboratory at Buda campus, MATE university

Figure 4 Unity platform (Tuvshintugs, 2024)

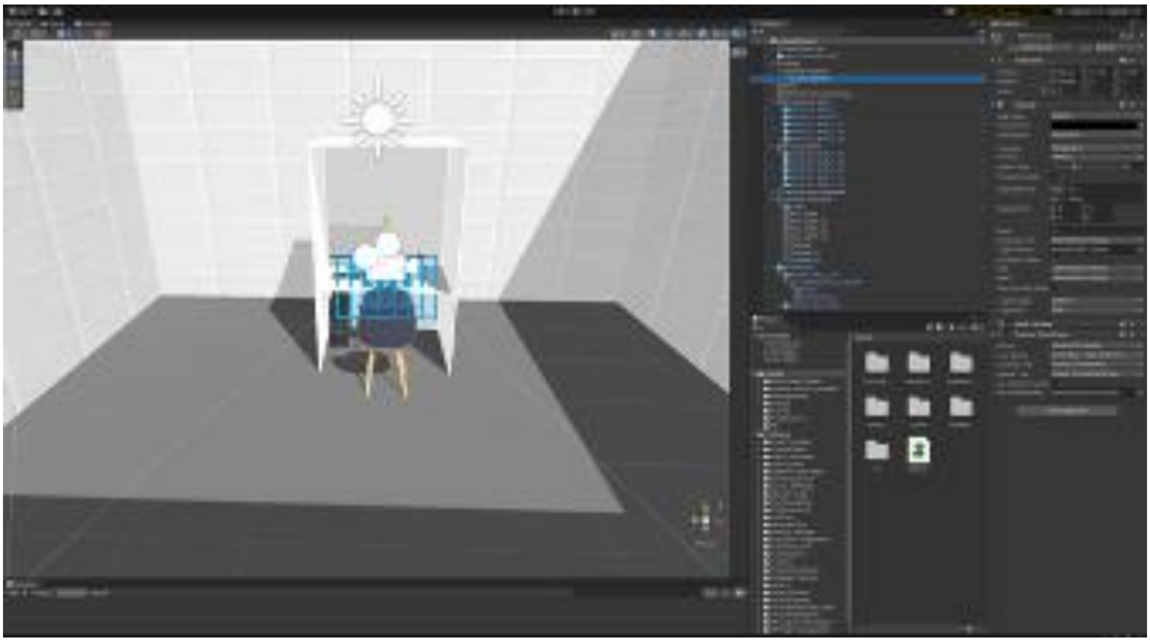
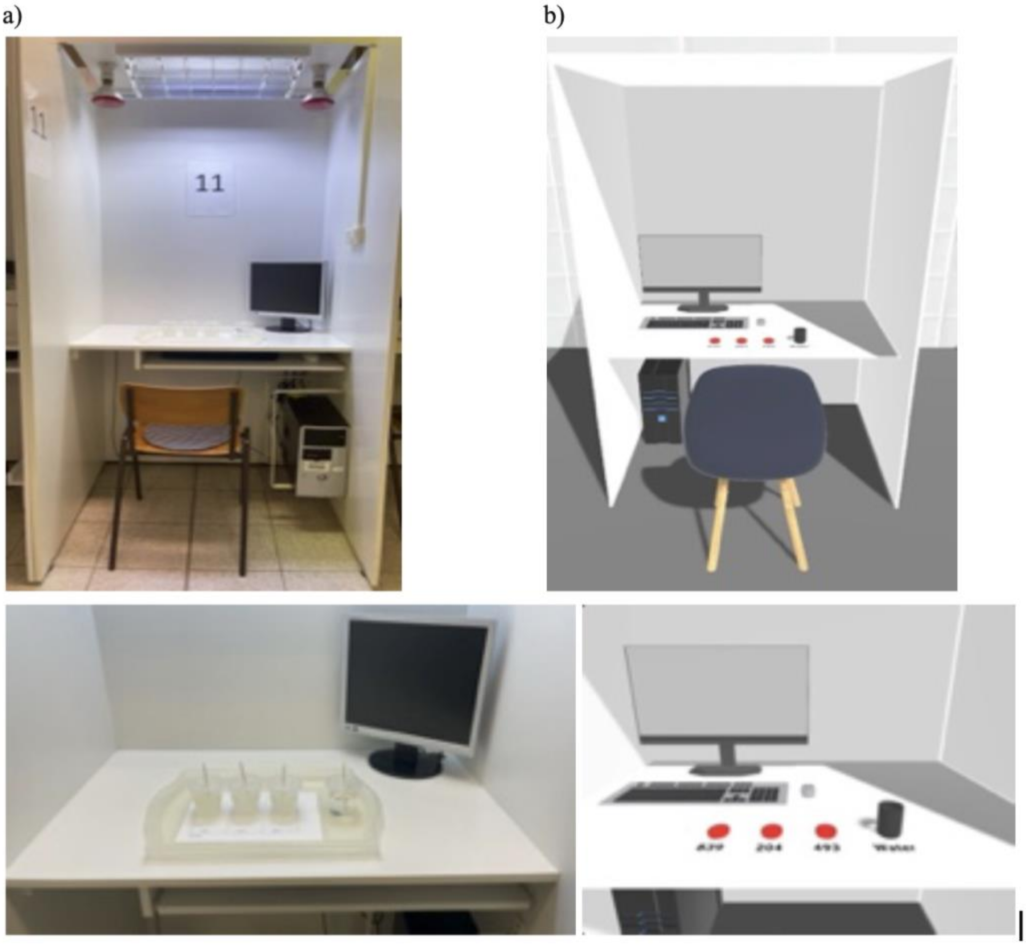


Figure 5 Meta quest 2 VR headset (Gamedeveloper.com)

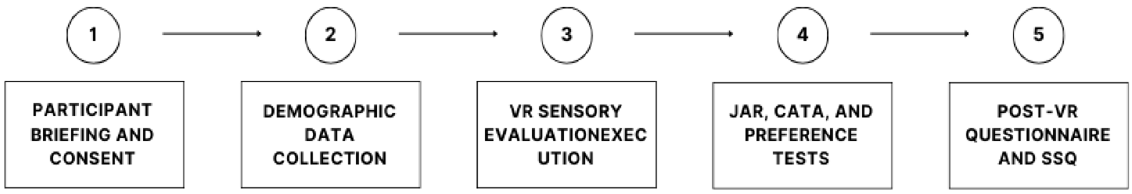
Figure 6 a) Traditional sensory booth; b) virtual sensory booth



2.3 Procedure

The experiment was designed to ensure the effective use of VR in sensory analysis (Fig. 7).

Figure 7 Experiment methodology



1. Before the experiment, participants were briefed about the study's objectives, the procedures involved, and the use of VR technology. We asked for consent and obtained it from each participant, ensuring ethical standards throughout the study.
2. We asked the participants to fill out a demographic questionnaire on a tablet. This step was for collecting basic information that could help to context the study's findings and understand the diversity of sensory experiences among participants.
3. Participants equipped the VR headset to immerse themselves in a virtual environment designed for sensory evaluation. In this controlled virtual setting, participants were given samples of biscuits and orange juice for evaluation.
4. While in the VR environment, participants were asked to conduct Just About Right (JAR) and Check All That Apply (CATA) tests on the biscuit and juice samples. These analyses allowed participants to evaluate the sensory attributes of the biscuits and orange juice. Participants would provide detailed feedback on their preferences and the appropriateness of each product's sensory characteristics.
5. After completing the sensory evaluation in VR, participants were asked to remove the VR headset and complete a post-VR questionnaire on the tablet. The Simulator Sickness Questionnaire (SSQ) was filled to assess any symptoms of discomfort or disorientation experienced during the VR experiment. We wanted to identify potential areas of improvement in using VR for sensory analysis. This is to ensure participants' well-being and the practicality of VR applications in sensory science.

2.3.1 Task 1 - JAR test on biscuits

Just About Right (JAR): This method is used to evaluate the optimal level of an attribute in a product. In this method, participants are presented with a list of attributes, and they are asked to rate the product on a scale of 1 to 5 based on how close it is to their optimal level. The scale ranges from "too little" to "too much," with "just about right" being the optimal level. This method is useful for identifying the optimal level of an attribute in a product.

A consumer sensory panel rates a set of products using multiple JAR variables and express their overall liking on a categorical scale. JAR categories are merged into three main levels. Independently of the number of categories used, the midpoint is kept as JAR level, categories lower than the midpoint go to the "too little" level, while the right side of the scale becomes the "too much" level. In the case of a 9-category scale, categories 1, 2,3, and 4 are merged to the "too little" level, category 5 becomes the JAR level, while categories 6, 7, 8, and 9 are merged to the "too much" level. In the next step, the mean overall liking scores are calculated for all three groups, e.g., the mean overall liking of consumers belonging to the too weak, JAR, and too much levels are calculated. The so-called mean drop values are calculated as the mean overall liking of the two endpoints is subtracted from the mean overall liking of the JAR group. Using a t-test, the overall liking scores of the non-JAR levels are compared to the overall liking scores of the JAR level, therefore a significant difference can be determined. To assess the effect of the JAR variable on overall liking, the overall liking scores of the two non-JAR levels are merged and compared to the overall liking scores of the JAR level, creating the Penalty of a given JAR variable. The mean drop values are then plotted with the percentage of consumers who rated the non-JAR endpoints in a mean drop plot. (Gere, 2022)

Biscuits Trial

We used the Győri Édes brand. Three types of similar flavors of biscuits were chosen with the flavors of cacao - sample 973 (Fig. 8a), cacao and whole grain - sample 231 (Fig. 8b), and chocolate chips - sample 231 (Fig. 8c). For JAR analysis hardness, sweetness, chocolate intensity, and grittiness were selected as main attributes and 5-level was selected.

Figure 8 Biscuits a) cacao - Sample 973, b) cacao and whole grain - Sample 231, c) chocolate chips - Sample 528 (Spar.hu)

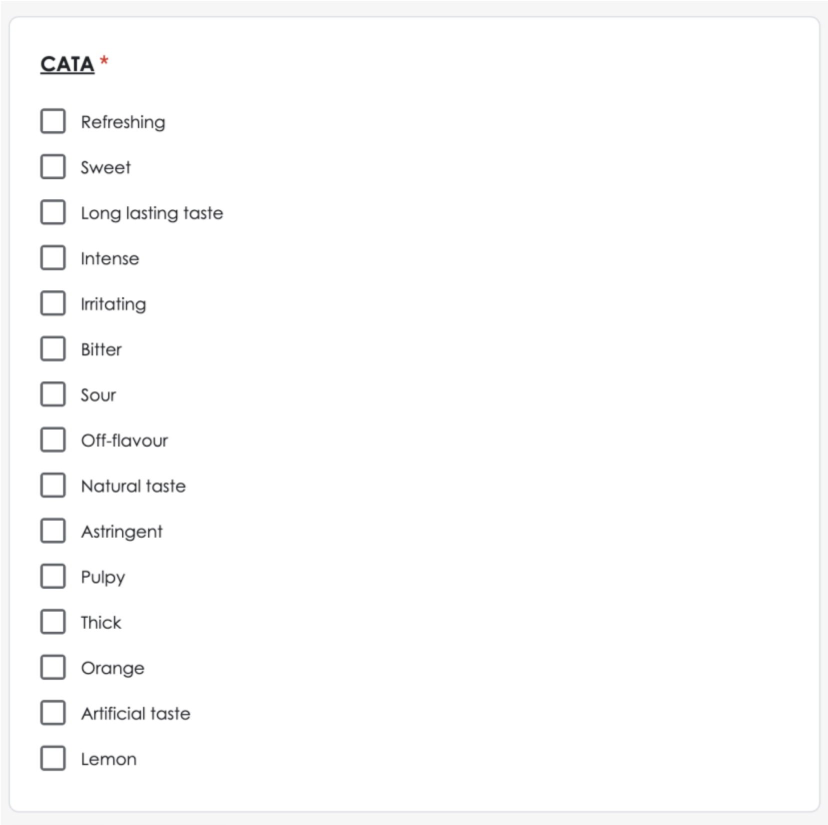
2.3.2 Task 2 - CATA test on orange juices

Check All That Apply (CATA): This method is used to evaluate the sensory characteristics of a product. In this method, a list of attributes is presented to the participants, and they are asked to select all the attributes that apply to the product. The attributes can be positive or negative, and the participants can select as many attributes as they want. This method is useful for identifying the most important sensory attributes of a product.

Orange Juice Trial

Different brands of 3 different orange juices were selected and assigned random sample numbers according to guidelines in the laboratory. We have selected Sio - sample 932 (Fig. 10a), Tesco - sample 134 (Fig. 10b), and Happy day - sample 359 (Fig. 10c) brands of orange juices. After a brief study and experiment we decided 15 attributes for CATA analysis on the orange juices. The attributes are: Refreshing, Sweet, long-lasting taste, Intense, Irritating, Bitter, Sour, Off-flavor, Natural taste, Astringent, Pulpy, Thick, Orange, Artificial taste, Lemon. (Figure. 9)

Figure 9 CATA attributes for the experiment


CATA *

- [ ] Refreshing
- [ ] Sweet
- [ ] Long lasting taste
- [ ] Intense
- [ ] Irritating
- [ ] Bitter
- [ ] Sour
- [ ] Off-flavour
- [ ] Natural taste
- [ ] Astringent
- [ ] Pulpy
- [ ] Thick
- [ ] Orange
- [ ] Artificial taste
- [ ] Lemon

Figure 10 a) Sio - sample 932, b) Tesco - sample 134, c) Happy day - sample 359 (Spar.hu)

2.4 Assessment tools

The Simulator Sickness Questionnaire (SSQ) was determined using the formula developed by Kennedy et al. (1993), wherein each category (nausea, oculomotor, and disorientation) has its specific SSQ symptoms that contribute to the severity score as shown in Table 1.

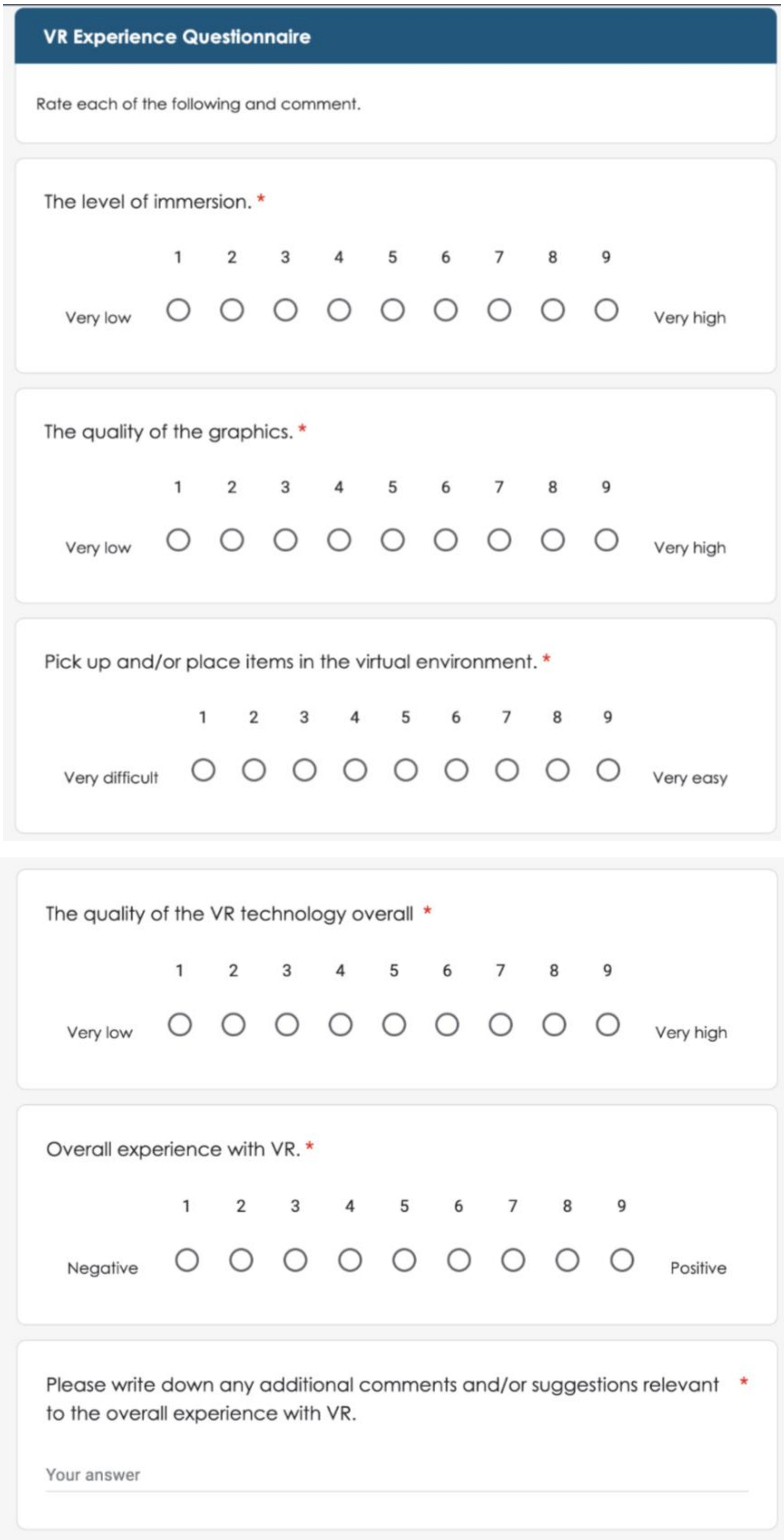
Score Calculation:
Nausea = [1] x 9.54
Oculomotor = [2] x 7.58
Disorientation = [3] x 13.92
Total Score = ([1] + [2] + [3]) x 3.74

The SSQ score is considered negligible when it is lower than 5. A minimal score falls between 5 and 10, signifying a minor level of discomfort. A score of 10–15 is considered significant, indicating a notable level of discomfort. A score of 15–20 is regarded as concerning. Lastly, a score exceeding 20 is classified as severe.

Post VR questionnaire

Post questionnaire (Fig. 10) was prepared to evaluate the overall usefulness of VR for the participants. The questions include the level of immersion, the quality of graphics, coordination in picking up items in the virtual environment, overall quality of VR technology, overall liking of VR experiment and comments. The post-VR questionnaire serves the purpose of measuring the immersive level and the acceptability of the VR SB. Some parts of the post-VR questionnaires were adapted from Virtual Reality Neuroscience Questionnaire (VRNQ) (Kourtesis *et al.*, 2019)

Figure 11 Post VR questionnaire (Zulkarnain, 2024)



VR Experience Questionnaire

Rate each of the following and comment.

The level of immersion. *

	1	2	3	4	5	6	7	8	9	
Very low	○	○	○	○	○	○	○	○	○	Very high

The quality of the graphics. *

	1	2	3	4	5	6	7	8	9	
Very low	○	○	○	○	○	○	○	○	○	Very high

Pick up and/or place items in the virtual environment. *

	1	2	3	4	5	6	7	8	9	
Very difficult	○	○	○	○	○	○	○	○	○	Very easy

The quality of the VR technology overall *

	1	2	3	4	5	6	7	8	9	
Very low	○	○	○	○	○	○	○	○	○	Very high

Overall experience with VR. *

	1	2	3	4	5	6	7	8	9	
Negative	○	○	○	○	○	○	○	○	○	Positive

Please write down any additional comments and/or suggestions relevant to the overall experience with VR. *

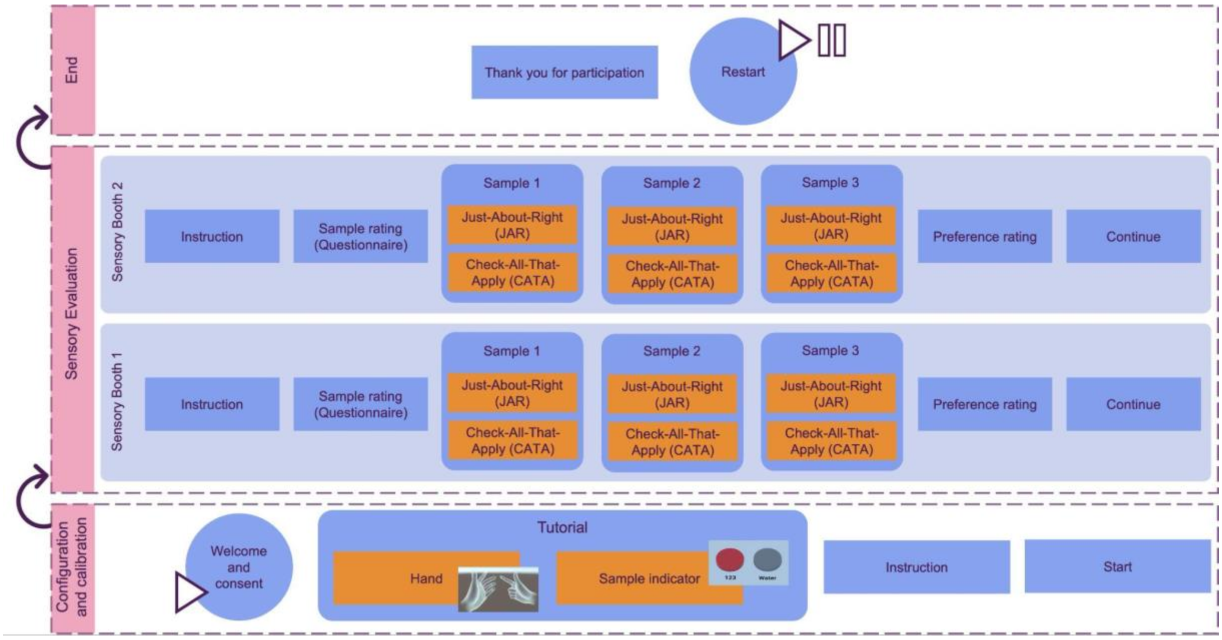
Your answer

3. Results and discussion

3.1 Software development

Two different experimental conditions were set-up in an immersive VR sensory booth.(Figure. 12) The VR sensory booth was used which was created in Unity 3D VR creation software. The sensory booth imitates the sensory booth at the MATE university sensory laboratory as close as possible to real-life conditions. The objects would appear as shapes in front and participants were given the sensory scales in front allowing the participants to use their hand to pinch the answers. The video was presented to participants through a head mounted display (HMD) (META Quest 2). First trial the biscuits were given with randomized 3-digit numbers. Second part was the orange juice trial followed with the same setting.

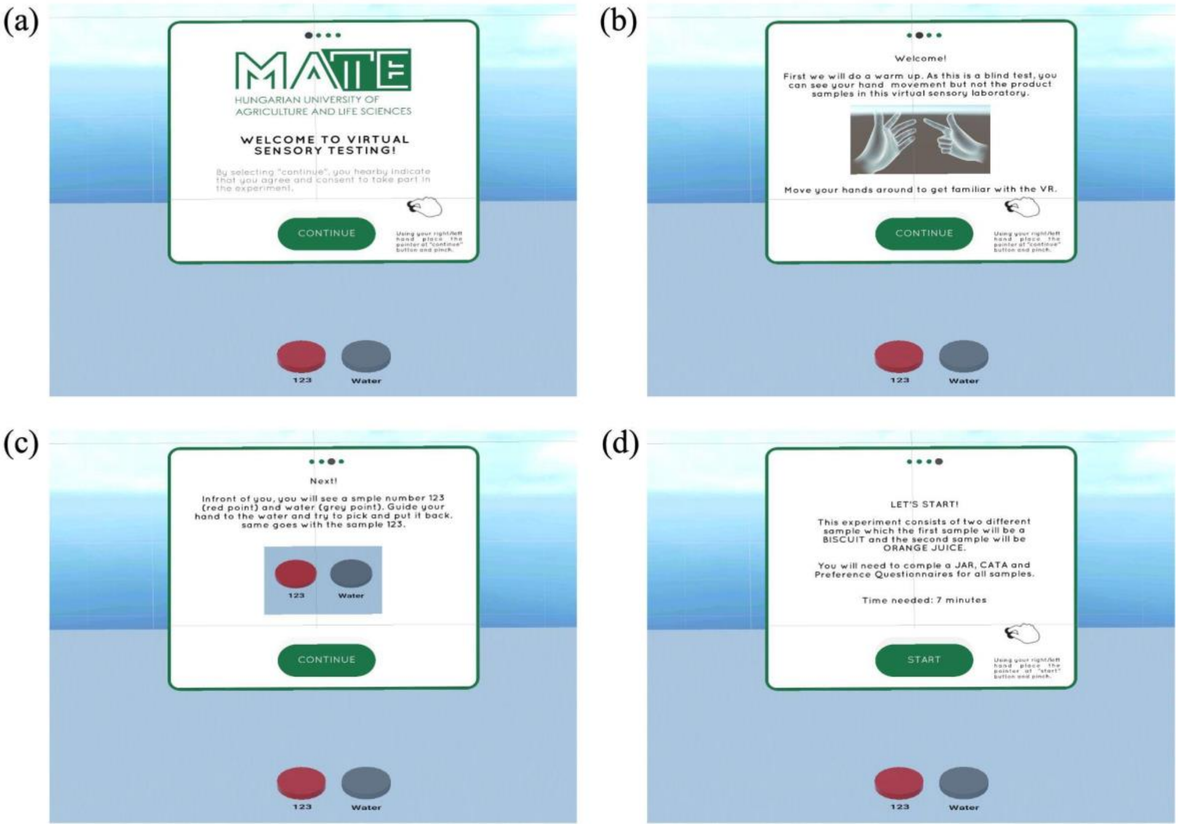
Figure 12 Process of experiment (Tuvshintugs, 2024)



The experimental procedure within the Virtual Reality (VR) setting unfolded with a structured sequence of interactive pages and tasks designed to facilitate sensory evaluation (Fig. 12). Upon commencing the VR experience, participants were greeted with a welcome page (Fig. 13a) providing instructions on how to interact within the environment, specifically guiding them to use a pinching gesture with their fingers to make selections.

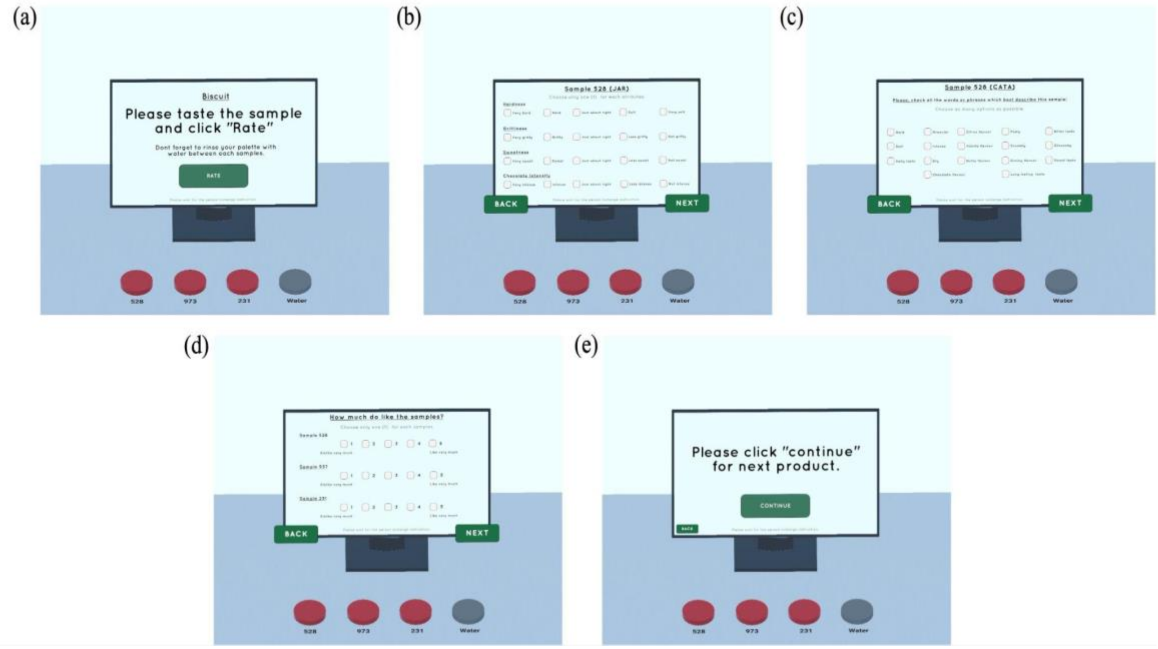
Calibration (Fig. 13b) was the first essential task, requiring participants to physically engage with a real cube positioned before them, maintaining contact for a specified duration to ensure the accuracy (Fig. 13c) of virtual interactions. Additionally, participants had access to a real plastic cup of water, equipped with a straw, to hydrate themselves both prior to and during the sensory tests (Fig. 16), as well as to cleanse their palate between samples. A page was added for signaling the start of the experiment (Fig. 13d).

Figure 13 Start and calibration process (Tuvshintugs, 2024)



After successful calibration, three objects were virtually presented to the participants (Fig 14a). Upon tasting the samples provided, the Just About Right (JAR) (Fig 14b) analysis page was displayed. Participants executed the pinching motion to select their responses, recording their sensory evaluations of the biscuit samples in bowls. In the subsequent phase of the experiment, participants consumed orange juice, followed by the appearance of the Check All That Apply (CATA) analysis screen (Fig 14c), which allowed them to select attributes that matched their sensory perception of the juice.

Figure 14 JAR and CATA analysis (Tuvshintugs, 2024)



The final evaluative component (Fig. 14d) was the Overall Liking page after each test, which captured the participants' general impressions of the samples tested. Upon completion of all assessments, participants were directed to a closing page that expressed gratitude for their participation, signaling the end of the VR experiment (Fig. 14e). The experiment length depended on prior experience of VR with the participants and lasted 10-25 minutes.

Figure 15 End scene with a restart button. (Tuvshintugs, 2024)

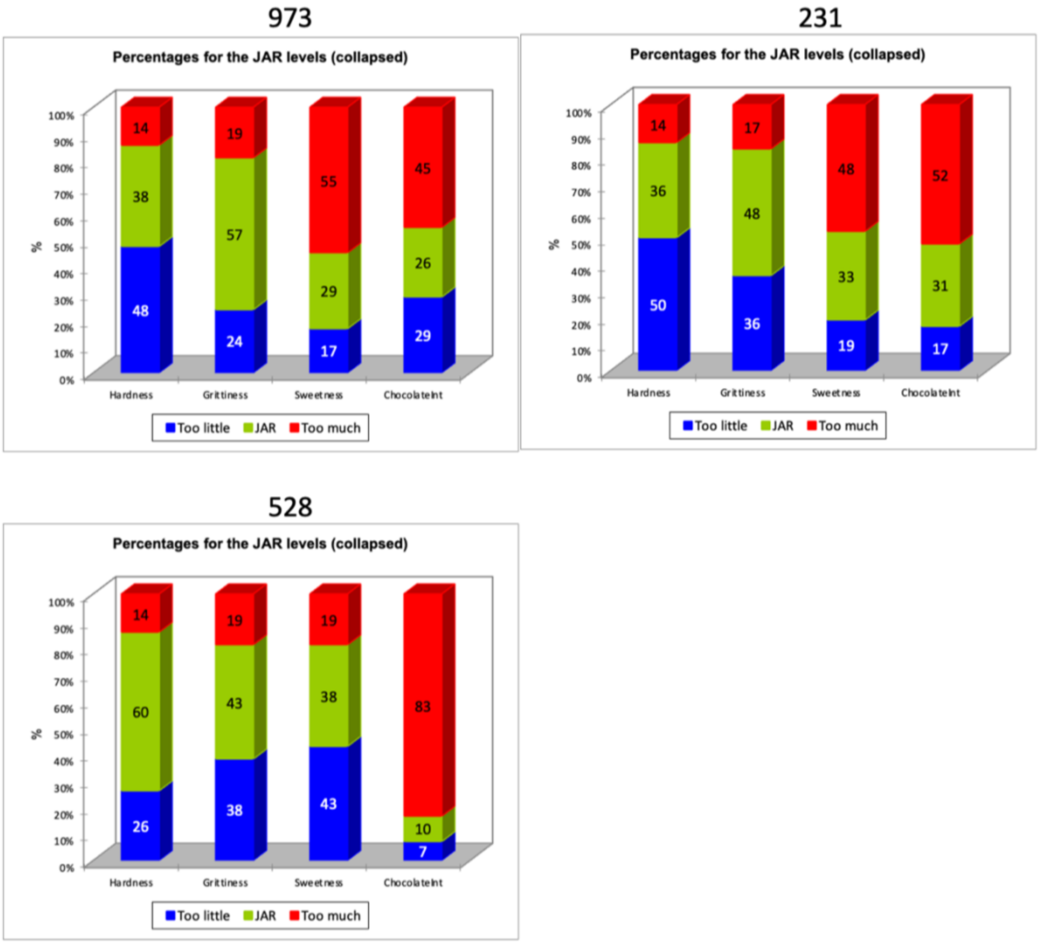
In the end scene, participants are thanked for participating in the test (Fig. 15). The restart button can be clicked by the laboratory assistant to repeat the process for the next participant. Instructions and images can be changed within the Unity software.

Figure 16 Participants evaluating the products in VR (Tuvshintugs, 2024)

3.2 JAR analysis

JAR analysis was successfully done using VR and processed with XLSTAT (Addinsoft, New York, USA) software without missing values. We could conduct an analysis and extract clear results of 43 international participants on 3 biscuit samples (Fig.8). From the 3 level collapsed graph (Fig. 17), it's easy to see if the attributes are just about right, too less, or too much. However to make more sophisticated analysis mean drops are used to portray which attributes are more important to consider.

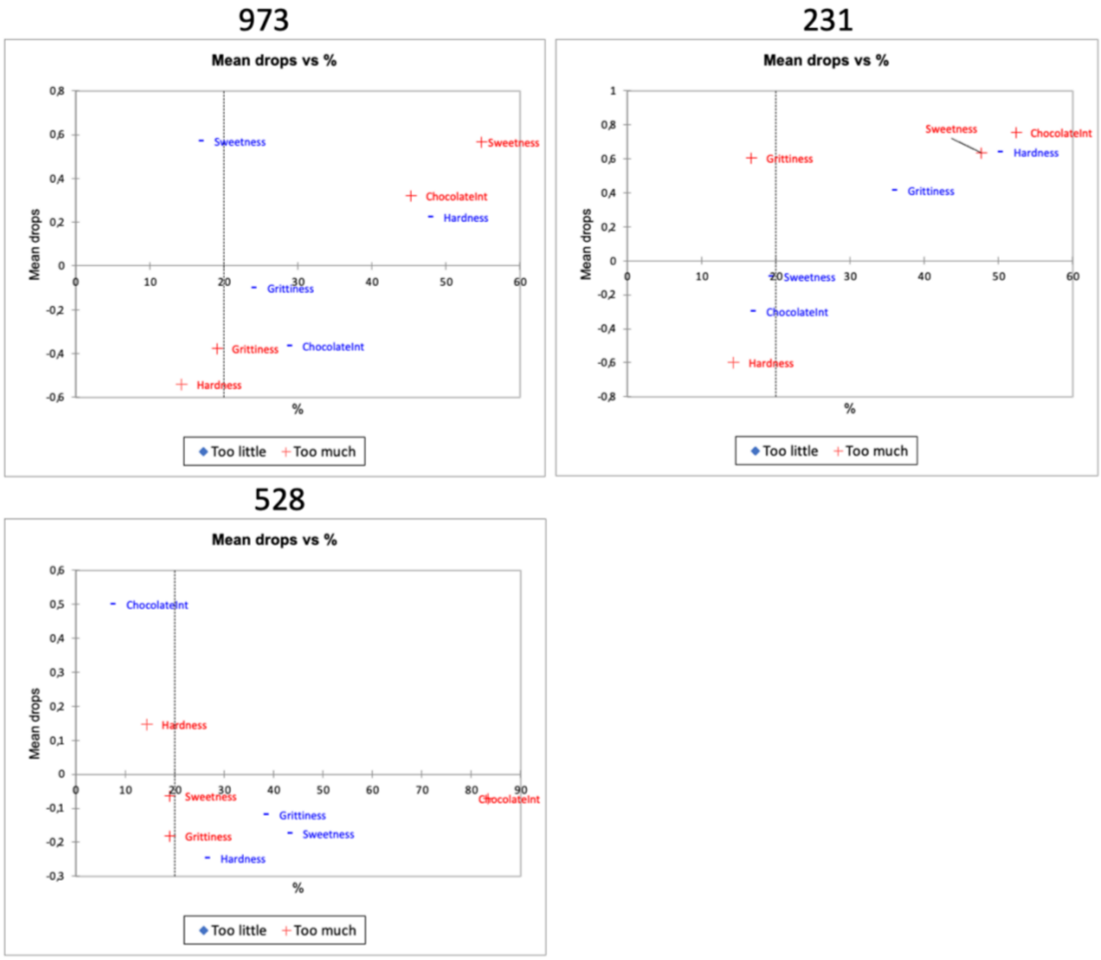
Figure 17 JAR collapsed levels (Tuvshintugs, 2024)



Each plot presents only the non-JAR attributes and uses blue and minus signs for the too weak level, while red font color and plus signs are used for the too intense levels. All mean drop plots can be divided into four distinct quadrants based on the horizontal axis representing the percentage of consumers who rated the non-JAR attributes and the vertical dashed line representing the 20% threshold discussed above. Attribute levels placed into the upper right corner have high mean drop values and were rated by a high number of consumers, therefore these are the ones that should be addressed during product development. (Gere, 2022)

For product 973 (Fig. 18), the sweet taste is the only one located here, meaning that reduction of sweet taste (e.g. using less sugar) might increase product liking. Too weak hardness and too much sweetness and too much chocolate intensity are located here in the case of product 231, indicating that this product had too weak attributes for consumers. Product 528 has no attributes in this area even though chocolate intensity was showing too much meaning this attribute is less significant for overall liking of the biscuits and this product is favored by the consumers.

Figure 18 Penalty analysis mean drops (Tuvshintugs, 2024)



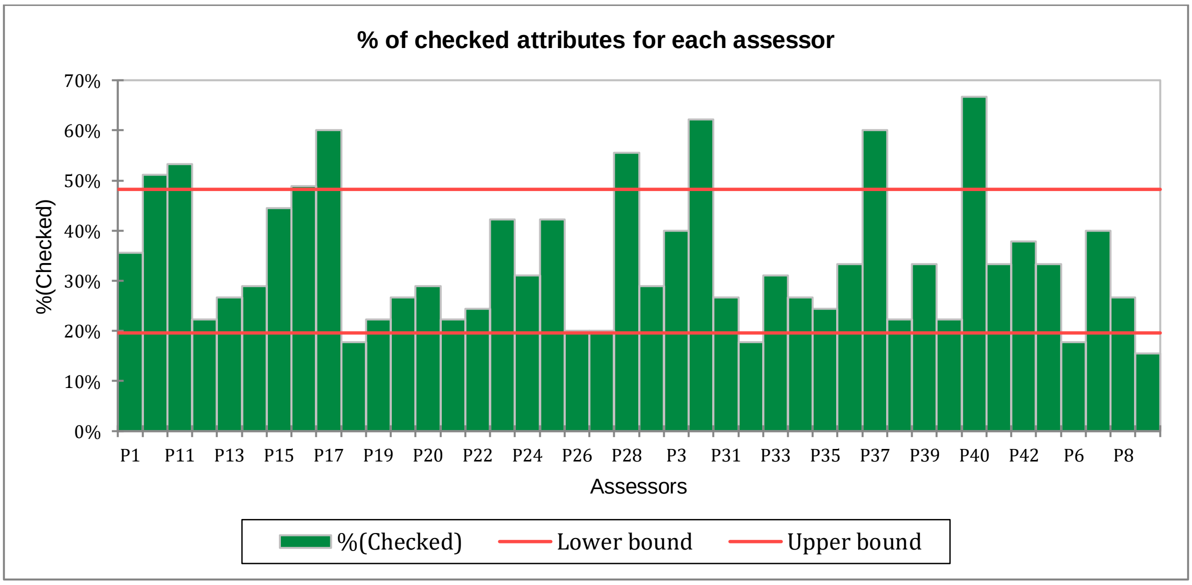
A comparison of overall liking scores indicates that products 528 was the most liked one, while penalty analysis tells us that the sweetness was too intense for product 973 and 231. As sugar and sweeteners are responsible for sweetness reducing the amount could improve the overall liking of the product. A drawback of penalty analysis is that no exact amounts are defined. For example, it is impossible to define the perfect amounts of sugar and sweetener. However, a possible composition could be determined and experimented.

Just-about-right scales and penalty analysis are easy-to-use tools able to help product formulations quickly and cheaply. Naturally, the complexity of the analyses grows with the complexity of the products being tested. Although rarely done but a repeated consumer test with the same consumer panel can validate the results of changes (Gere et al., 2017).

3.3 CATA analysis

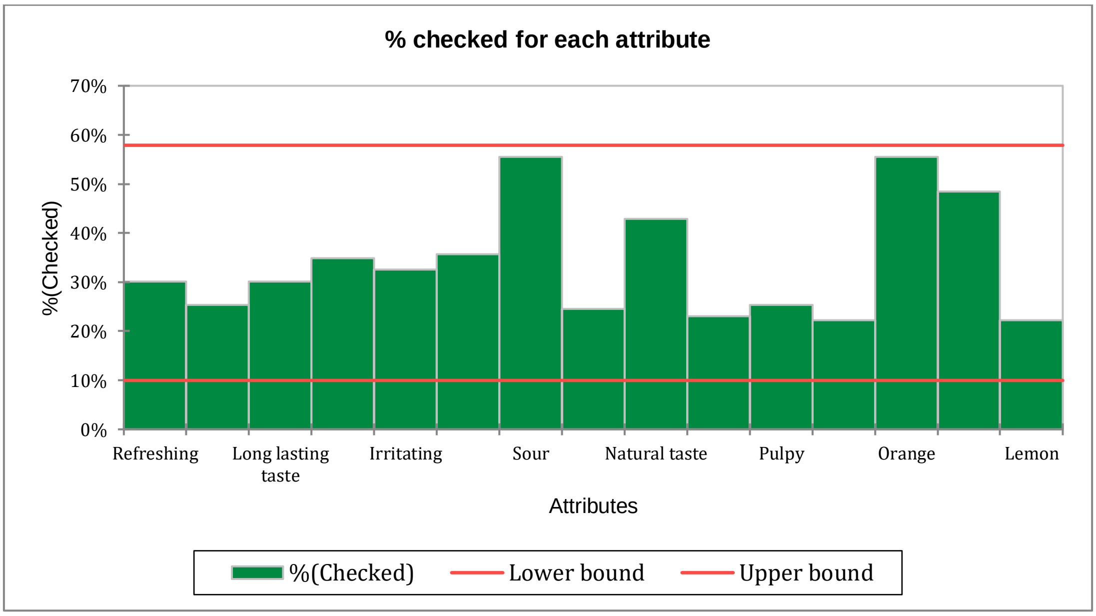
The graph (Fig. 19) relates to the **validation of CATA data.** First of all, a detection of the assessors who checked much more or less than the others are performed. In our case, most of the judges checked between 20% and 50% of the time, some of them have a particular behavior. For example, assessor 17 checked only 18% of the time! Although there werer some participants that checked more than 50% of the attributes, after careful evaluation I deciced not to remove these participants from the analys. A similar attribute analysis was performed to detect over- or under-used attributes.

Figure 19 CATA attributes, lower and upper bound (Tuvshintugs, 2024)



The graph (Fig. 20) shows percentage of each attribute selected by participants. Judges chose between 10% to 60%. There are no over or under used attributes, meaning these attributes are all important for further analysis.

Figure 20 CATA each attribute chosen by participants (Tuvshintugs, 2024)

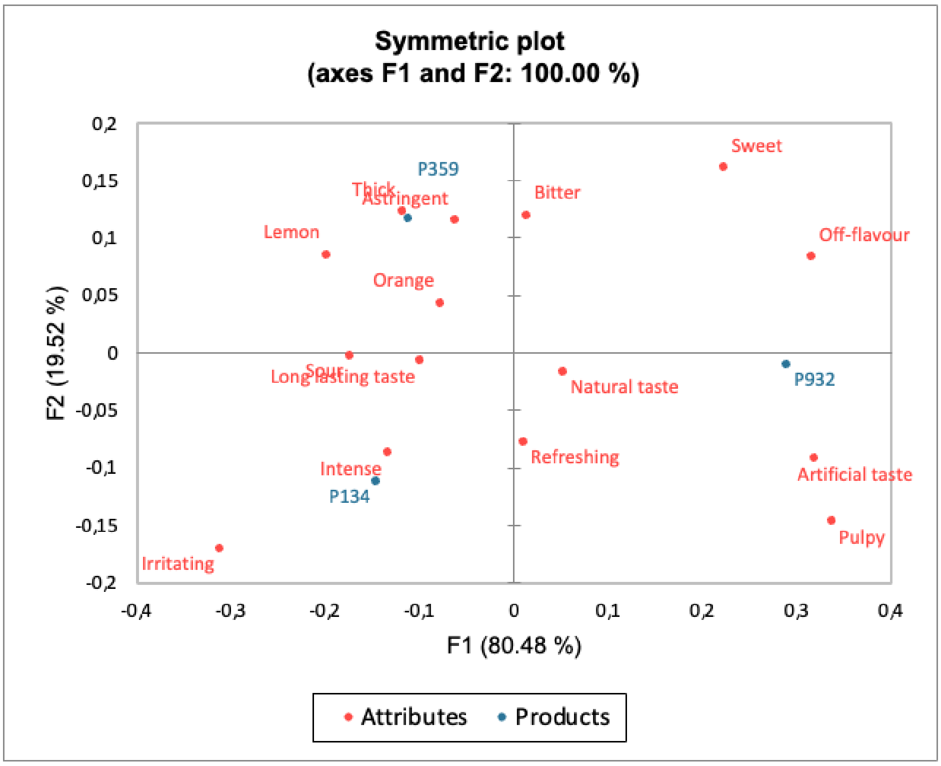


The table of the eigenvalues and the corresponding plot allow to verify the quality of the analysis. The quality of the analysis is good (100% of explained total inertia on the first two dimensions). (Fig. 21)

According to the map of the analysis, Product 359 is closely realted to the attributes of thick astringent, orange, and lemon flavor and does not iclude attributes of pulpy, artificial taste. The product 134 is related to intense, irritating, sour and long lasting taste. Product 134 and 359 share the sourness and long lasting taste. The product 932 is more representing artificial taste, ulpy and off flavor.

This symmetric plot is very useful for similar products that have closer attributes and gives the researchers how to categorise the products for further business applications.

Figure 21 Symmetric plot for CATA attributes (Tuvshintugs, 2024)



The **mean impact** chart (Fig. 23) shows the attributes with a significant mean impact. Mean increases are displayed in blue and are identified as "must have", mean decreases are displayed in red. The mean drops vs % chart also allows to clearly identify the "must have" attributes. (Ares *et al.*, 2014) The Y-axis corresponds to the differences in product appreciation when consumers check both a product and the ideal product (cell [1,1] of the "attribute analysis" table) and when they check only the ideal product (cell [0,1]). The X-axis represents the percentage of entries including a check for the ideal product without the actual product being checked. This corresponds to a situation where the attribute describes the ideal product well but is relatively little felt in the actual products.

Therefore, attributes that are associated to high coordinates on both the X and Y axes appear here to be “must have”. The **mean impact** chart shows the attributes with a significant mean impact. Mean increases are displayed in blue (refreshing, intense, natural taste, sweet, long-lasting taste, orange, pulpy) and are identified as “nice to have”, mean decreases are displayed in red and are identified as **must not have**. Here, the attributes bitter and off flavor could be analyzed. The mean drops vs % (Fig. 22)chart also allows to clearly identify “must not have” and “nice to have” attributes.

The Y-axis corresponds to the differences in product appreciation when consumers did not check either the ideal product or the product (cell [0.0] in the "Attribute Analysis" table) and when they checked the product (cell [1.0]). The X-axis represents the percentage of inputs including a check for the real product without the ideal product being checked, which corresponds to a situation where the attribute describes the real products well but is relatively unchecked for the ideal product.

Therefore, attributes that are associated to low coordinate on the Y axis (off flavor, bitter, artificial taste, sour, irritating) appear here again to be “must not have”. Attributes associated to high coordinates on the Y axis are “nice to have”.

Figure 22 CATA orange juice mean drops vs % (Tuvshintugs, 2024)

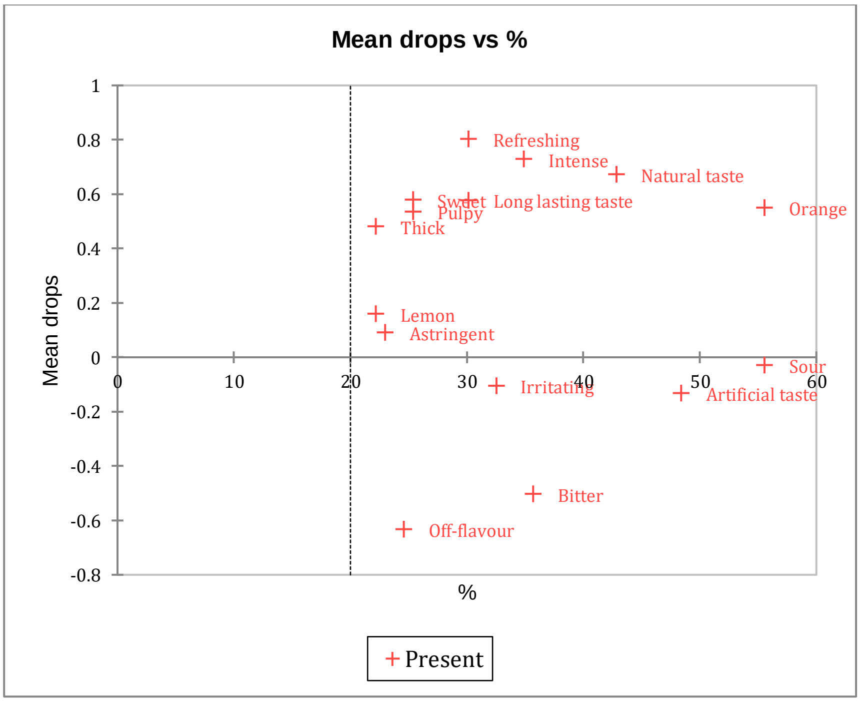
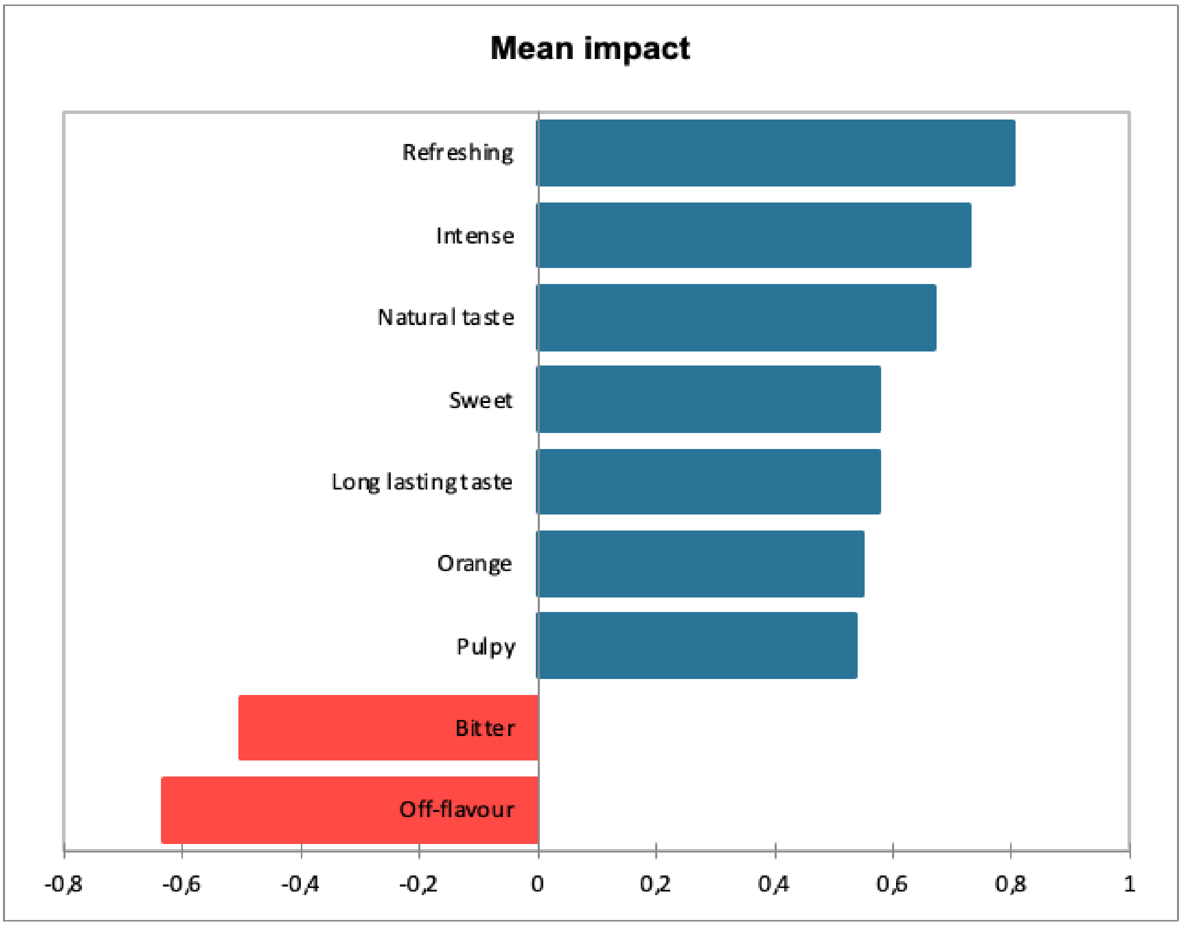


Figure 23 CATA orange juice mean impact (Tuvshintugs, 2024)



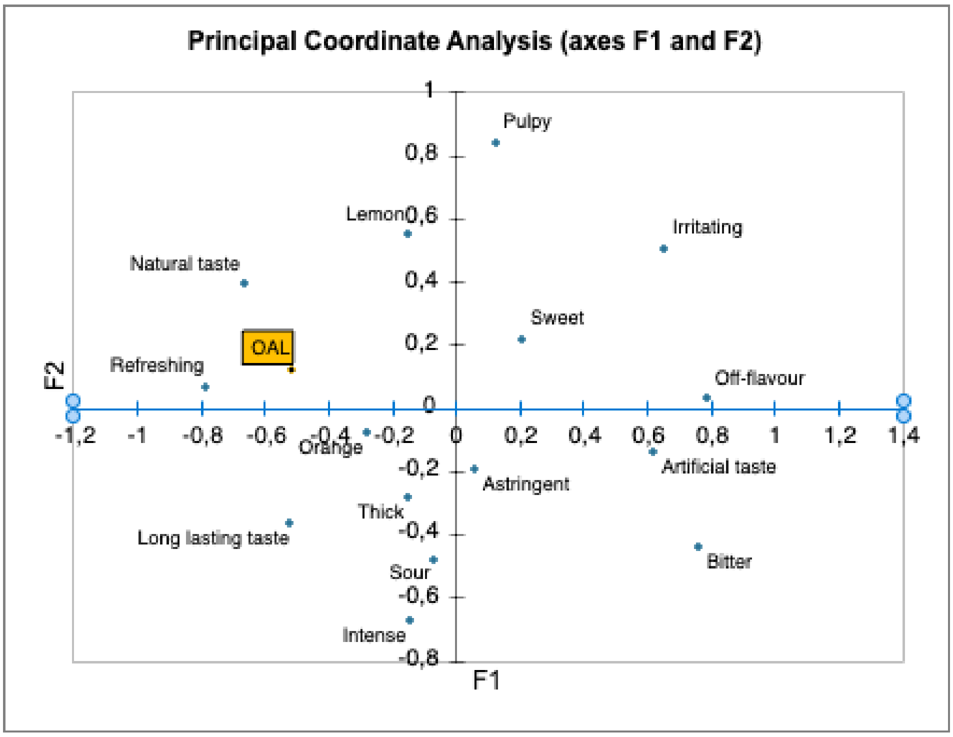
A comparison of CATA test with traditional test between VR CATA test

Principal Coordinates Analysis (PCoA) (Fig. 24) is applied to the correlation coefficients and results are visualized in a two-dimensional map. The scree plot indicates that the two first dimensions are sufficient to interpret relationships between attributes. Here again, we see that liking is associated to the attributes long-lasting taste, refreshing, natural taste and orange flavor.

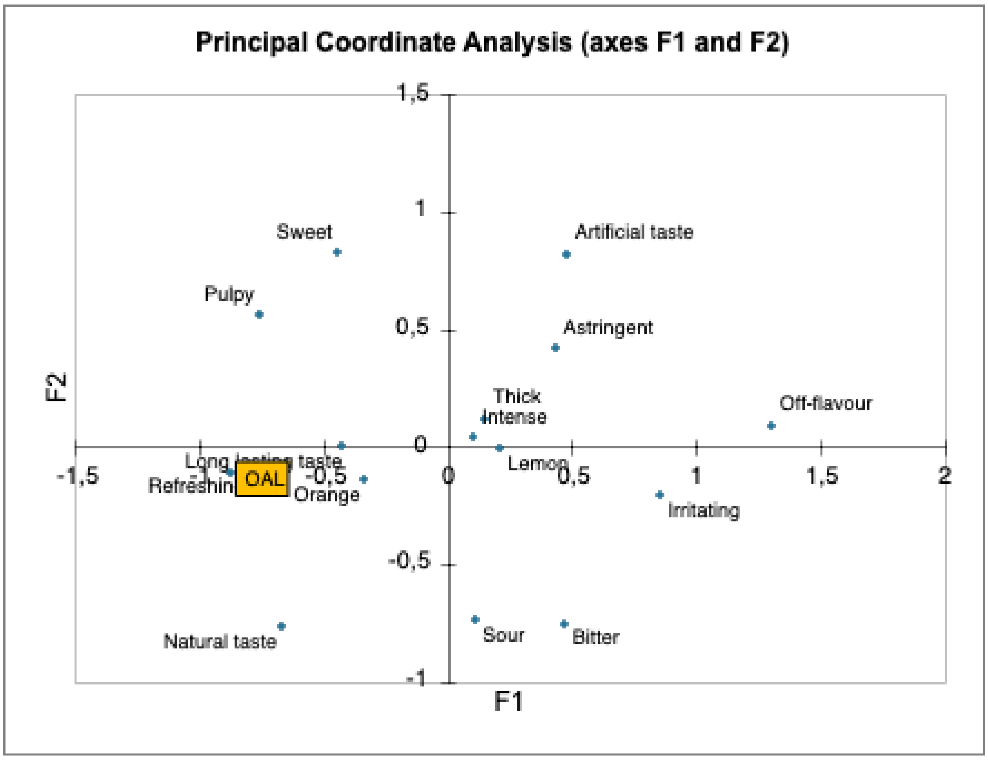
During the experiment we compared the traditional CATA analysis and VR CATA analysis with random same 25 participants with a gap of a month to validate if the results are comparable. The Overall liking is around the same area and there are no significant difference is observed from the result.

Figure 24 Comparison of VR and Traditional CATA analysis with same 25 participants (Tuvshintugs, 2024)

a) Principal coordinate analysis in VR sensory booth



b) Principal coordinate analysis in Traditional CATA

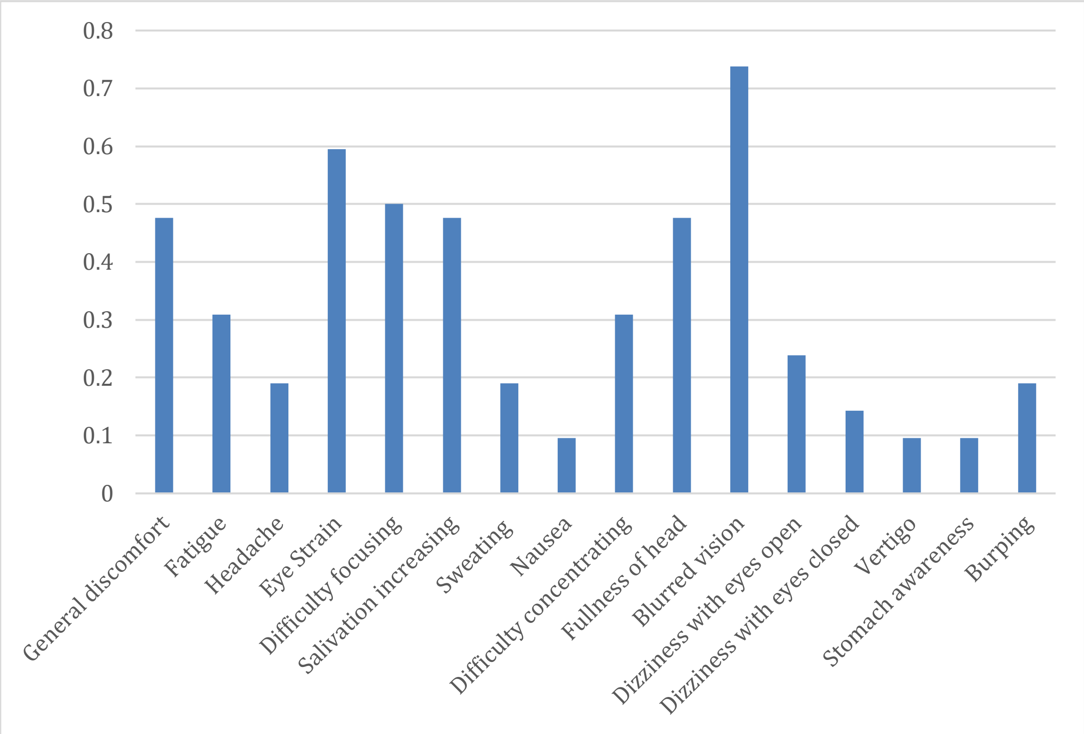


3.4 Simulator sickness questionnaire

Table 2 Simulator sickness questionnaire results

Simulator Sickness Questionnaire (SSQ) Symptoms	Score ±Standard Deviation (SD)
Nausea	**18.63 ±9.38**
Oculomotor	**21.48 ±23.25**
Disorientation	**31.82 ±36.89**
Total Score	**26.44 ±25.06**

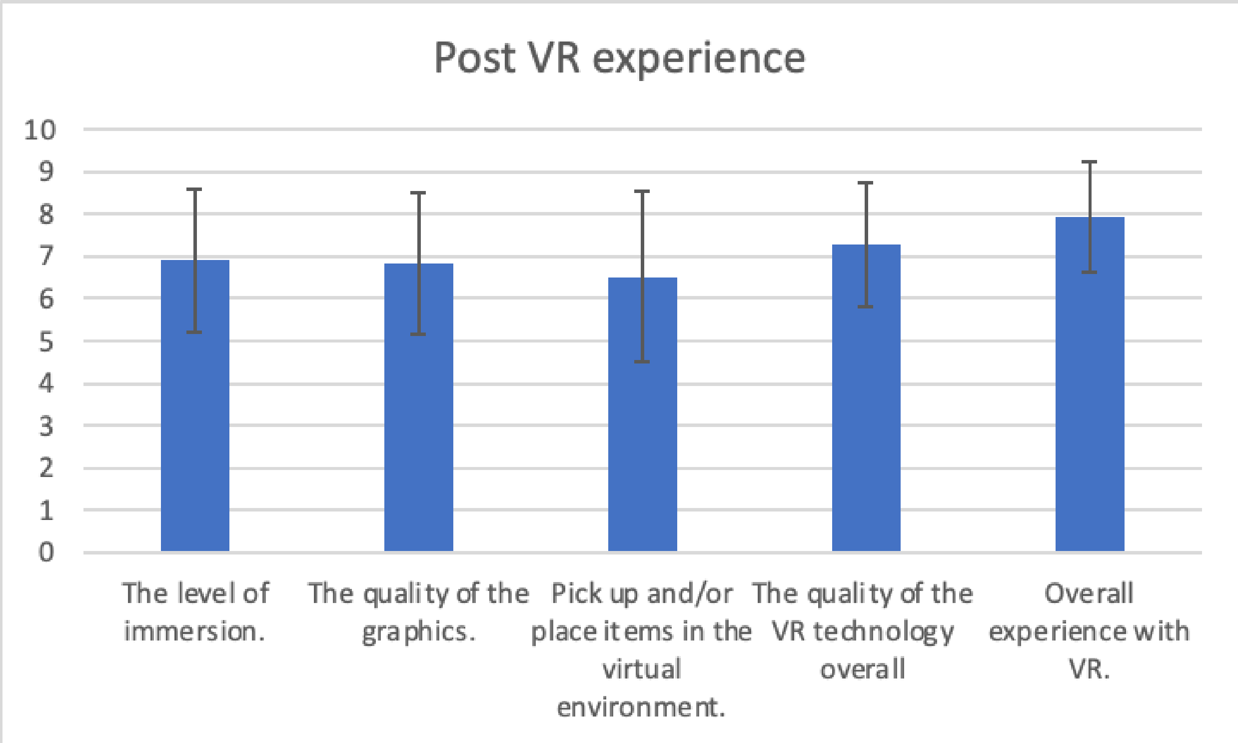
Figure 25 Individual Simulator sickness values (Tuvshintugs, 2024)



The findings of this study indicate a notable level of simulator sickness experienced by participants, with an average SSQ score of 26.44 and a standard deviation of 25.06 (table 2). The scores for oculomotor symptoms and disorientation were particularly high (Figure. 25), aligning with common trends observed in similar studies. Interestingly, despite the elevated discomfort levels, none of the participants reported experiencing nausea. These results suggest that while simulator sickness remains a prevalent issue in virtual reality experiences, the specific manifestations of symptoms may vary among users. Further research is warranted to explore effective strategies for mitigating discomfort and enhancing user comfort in virtual environments.

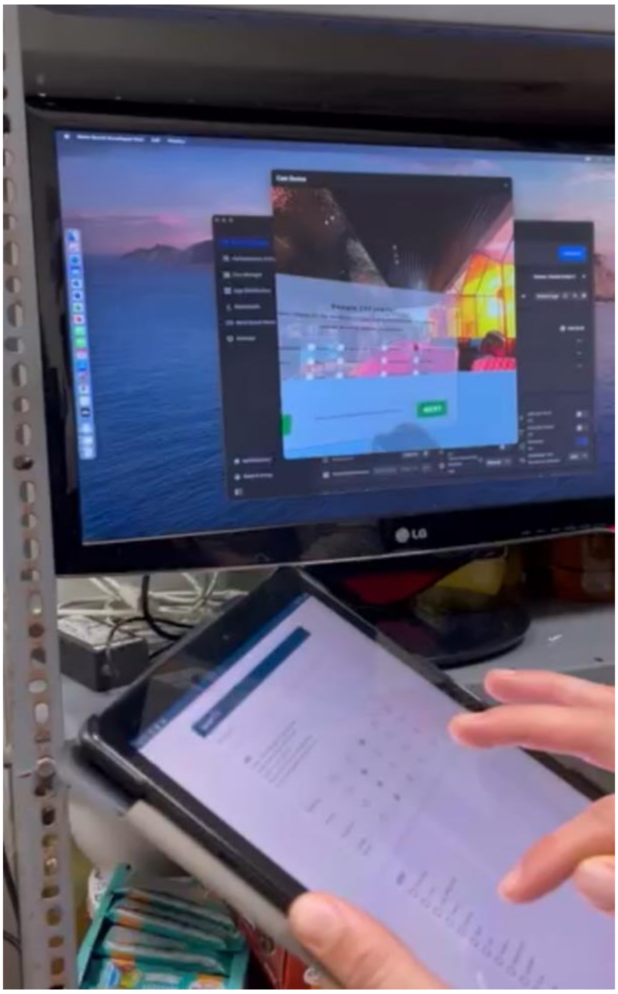
3.5 Comments and participants experience

Figure 26 VR rating of participants (Tuvshintugs, 2024)



The participants' responses to the VR sensory analysis experience were overwhelmingly positive (Fig. 26), indicating an appreciation for the innovative approach and its potential applications in food science. Many found the VR experience enjoyable and interesting, likening it to playing a game, which suggests a high level of engagement. Positive remarks also highlighted the practicality and effectiveness of the method for blind tests and its relevance in educational settings. (Table. 3)

Figure 27 Participant filling simulator sickness quesntionaire after the VR experiment (Tuvshintugs, 2024)



However, there was constructive feedback (Table. 3) that pointed to specific areas for improvement. Participants noted occasional difficulties with visual clarity, suggesting a need for better visual quality, particularly for those with glasses. Additionally, the physical coordination between real and virtual objects, as well as the ergonomic setup of the virtual environment, were highlighted as aspects that could be refined. Feedback also mentioned the responsiveness of the interface, with some users reporting that buttons did not always work on the first press. Calibration and additional instructions were suggested to enhance the user experience.

These insights are invaluable for refining VR sensory analysis methods and environments. By addressing the ergonomic and technical feedback (fig. 27), future iterations of VR applications in sensory science can become even more effective and user-friendly, fostering a more comfortable and accurate sensory evaluation experience.

Table 3 Comments of participants

Positive comments	Constructive comments
- It's cool - I enjoyed the experience - I really liked the immersion - It was a very interesting yet comfortable test, I enjoyed it! - A really good first experience with VR - Thank you - Very practical - Very good - A positive use for the food industry - I like it, it has potential in food science. - Very good job, better than the last experiment - I liked it. - It is a really good experience - This application should be practiced more often in various practicals for its relevance to be realized, embraced, and appreciated - I like it - Great experience - Nice experience - Good job, looking forward to the future and next evolution of VR - It was a nice experience; I was nervous since it's my first time but it was fun. I would like to try it again - Easy to understand, good method. - Everything was fine, it was good that I could participate - Overall, I really like the experience that I had - It was like playing a game. It was very interesting - Everything was great, great job! :)	- Fix the positions of objects - Sometimes a bit blurry - We were a little bit too close to the end of the table. - The coordination between physical objects and virtual graphics is a little bit difficult - It was not easy to pinch but it was great overall. - It was difficult to recognize dimensions but nice to try - Better visual quality - Adjustment should be used in good quality and fully fixed, especially for eyeglasses people. - Add more graphism - Calibration can be improved as well as a little extra explanation. However, very fast and effective method to measure blind tests - Can imitate the object/shape of the container of the sample for easy for the participant to pick up the sample. - We need a more comfortable environment - A possibility to change the environment of the VR and it can be interesting to experiment. - Sometimes buttons did not work from the first press. - I had difficulties seeing without glasses, maybe that is what made my experience less perfect and hard to concentrate

Constructive criticism from participants largely centered around graphics quality and blurriness, highlighting areas for improvement in future VR studies. The decision to utilize the META Quest 2 was driven by its wireless functionality and comfort, factors that were well-received by participants. Unlike wired head-mounted gears, which can detract from immersion and necessitate additional hardware such as graphic cards and special ports, the META Quest 2 offered a seamless and convenient setup. However, the downside of the META Quest 2 was its 720 resolution, which impacted the visual experience. To address this limitation and further enhance VR studies, transitioning to more powerful and modern versions of head mount gears.

3.6 Discussion

Expanding on the conclusions drawn from this study, the potential for further exploration in Virtual Reality (VR) technology within sensory science becomes evident. Future investigations may focus on conducting comparative analyses between various VR environments to assess factors such as visual resolution, interactivity, and overall user experience. Additionally, the integration of Augmented Reality (AR) alongside VR could be examined to understand how mixed reality environments influence sensory evaluations.(Kourtesis *et al.*, 2019)

Another avenue for research lies in exploring the effectiveness of VR and AR in facilitating collaborative sensory evaluations. This could involve studying user interactions and communication within immersive environments, as well as evaluating the accuracy and reliability of sensory assessments conducted in such settings.

Moreover, it would be valuable to refine VR technology to address the challenges identified in this study, such as simulator sickness and calibration issues. Experimentation with alternative VR hardware, software optimizations, and user interface designs could help mitigate these concerns and enhance the usability and acceptance of VR technology in sensory analysis.(Bimberg, Weissker and Kulik, 2020)

By undertaking these avenues of research, we can further advance the application of immersive technologies in sensory science, ultimately contributing to more efficient and innovative sensory evaluation processes.

4. Conclusion

This study ventured into the novel terrain of utilizing Virtual Reality (VR) technology within the field of sensory science. By employing Just About Right (JAR) and Check All That Apply (CATA) tests in a VR environment, we endeavored to showcase VR's capabilities as a dynamic and versatile platform for product creation and evaluation. The experiment was designed not only to align VR-based sensory analysis with traditional methods but also to push the boundaries of what is conventionally possible in sensory evaluation.

Our findings indicate that VR can indeed replicate the sensory analysis typically performed in physical settings, as evidenced by the comparable results obtained from traditional and VR CATA analyses conducted with the same group of 25 participants. The innovative application of VR in sensory science was appreciated by the participants and they recognized the potential of VR in enhancing sensory evaluation processes. Their experiences within the VR environment were mostly positive, underscoring the engaging and immersive nature of VR as a tool in sensory analysis.

Our study also illuminated areas requiring further refinement. The Simulator Sickness Questionnaire (SSQ) scores were slightly higher than average, signifying a need to address the elements contributing to simulator sickness. Common feedback from participants pointed to the visual resolution within the VR environment and the time required for individual calibration as aspects needing improvement. These insights are critical, as they guide future developments in VR technology tailored to sensory science applications.

In conclusion, the results of this study affirm that VR holds significant promise as a practical instrument in sensory science, with the potential to revolutionize how sensory evaluations are conducted. However, to realize its full potential the identified challenges such as enhancing visual resolution and streamlining calibration processes must be addressed. With continued technological advancements and a commitment to iterative design improvement, VR is able to become an practical asset in sensory analysis, offering a more efficient, immersive, and cost-effective alternative to traditional methods.

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DECLARATION

the public access and authenticity of the thesis/dissertation/portfolio[1]

Student's name: TUVSHINTUGS DEMCHIGSUREN
Student's Neptun code: JE4J3H
Title of thesis: Application of Different Sensory Methods in VR Sensory Analysis
Year of publication: 2024
Name of the consultant's institute: Institute of Food Science and Technology
Name of consultant's deparment: Department of Postharvest, Supply Chain, Commerce and Sensory Science

I declare that the final thesis/thesis/dissertation/portfolio submitted by me is an individual, original work of my own intellectual creation. I have clearly indicated the parts of my thesis or dissertation which I have taken from other authors' work and have included them in the bibliography.

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Student's signature

MATE Organizational and Operational Regulations
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DECLARATION

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