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Virtual reality applications in food science. Current knowledge and prospects

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ABSTRACT

Virtual reality (VR) offers a new instrument for food scientists to evaluate different aspects of food products. The possible applications range from product design testing, evaluation of the labels, effects of different placements or the evaluation of store layouts. These analyses help us to get a deeper understanding of consumers' minds. Additionally, VR can be coupled by several different tools (e.g. eye-trackers or skin conductance sensors or even electroencephalographs). However, as there have been only a limited number of applications published, there are several open questions which need to be answered. In the presented paper the authors aim i) to introduce the current knowledge on VR applications in food science by introducing several fields of applications and ii) to point out the most important questions regarding the applications of VR in food science.

KEYWORDS

sensory analysis, consumer, augmented reality, design of experiments

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INTRODUCTION

After many years of using paper-based questionnaires, the wide and fast spreading of computers and mobile devices enabled companies to develop sensory software which support the application of scales and methods used in traditional sensory testing of foods. These solutions saved a significant amount of time and resources by introducing special features which cannot be used when working with paper and pencil. Such features include the option of mandatory questions; therefore, participants cannot finish their evaluation without answering all the questions on the sensory ballot. Additionally, these software support sample coding, randomized sample presentation, which helps the researchers to follow the good sensory practices. One of the major advantages is the built-in data analyses methods. By using these options, the researcher gets the results of the sensory test immediately, which might be used in the training of panellists or in reporting as well (Stone and Sidel, 2004).

However, these advancements were not able to solve a critical issue of questionnaires. When dealing with sensory evaluation, we expect the respondents to provide an answer on a scale to a given stimulus. This process is straightforward and direct when the stimulus is basic, such as heat or pain. These stimuli are processed automatically, and humans have a limited ability to change their reaction. In sensory evaluation, we expect the panellists to react to more complex stimuli and we instruct them to give a conscious answer. This means that after tasting or smelling the sample, panellists must take some time to process the information (e.g. the perceived taste/smell) and to convert their sensations into a number or a category on the presented scale. This information processing, however, can influence the final answer of the participant. If the participants do not focus entirely on the survey, their answers can be heavily biased. Acquiescence bias occurs when the participants show too much engagement to the product they test, e.g. they give higher (or better) ratings to the samples even if they are not satisfied with it. This bias is usually expressed in tests incorporating liking or agreement questions and can be triggered by not proper formulation of questions (I like the taste of the newly developed product [agree–disagree] vs. How much do you like the presented product [extremely–not at all]) (Lawless and Heymann, 2010).

When participants try to figure out the purpose of the study, they might create pre-set expectations, which might affect their answers. This could take place if a participant knows the company whose products are tested. The demand characteristic bias can be eliminated by creating an interactive questionnaire, so participants forget the main aim of the research (Brew et al., 2021).

Extreme responding bias occurs when participants use mainly the two endpoints of the scale and forget about the middle option. Its counterpart is when participants give merely neutral answers, scoring mainly in the middle of the scale (Weijters et al., 2021).

Desirability bias occurs when participants want to provide socially appropriate answers. In food testing this might be expressed by higher liking scores of products which are believed to be healthier compared to the others in the test (Forde et al., 2016).

In the past few years, several new tools have been available for sensory testing of food products which not only provide partial or complete solutions to the above-mentioned biases but are able to measure several other variables during the evaluations. These techniques involve Virtual reality (VR), eye-tracking, skin conductance measurement, face reading, heart rate monitoring and electroencephalography (EEG), and are widely used in neuromarketing, which is an emerging field focussing on the "measurement of physiological and neural signals to gain insight into customers' motivations, preferences, and decisions, which can help inform creative advertising, product development, pricing, and other marketing areas" (Harrell, 2019).

In the present paper the authors focus on VR and its combination with eye-tracking as several technological advancements have been introduced in this field during the past few years.

VIRTUAL REALITY

The application of VR gives an efficient solution to these problems, as virtually presented stimuli is easy to produce. In order to get a deeper understanding of VR technology, we first need to make a distinction between two, similar terms, namely VR and augmented reality (AR).

VR is defined as a computer-generated stimulation on the whole picture of the environment, either real-life environment or a situation. Its main purpose is to involve the user to experiencing the stimulated environment in reality and at the same time the user will use one or more senses to feel like in a real world. Most current VR environments are dominated by visual stimuli which are displayed on a screen through special or stereo displays. The visual information is supplemented with auditory cues such as sound through speakers or headphones, and also tactile experiences, for example haptic touch or controller.

AR is a special field of computer research which deals with the combination of real-world (RW) and computer-generated data. AR is a technology that allows for virtual objects to be placed in the real world in real time, thus enhancing our information about the world around us. The main difference between VR and AR is that VR creates the perception of real world based on virtual information while AR improves the perception and uses the actual surrounding with added computer-generated information (Wedel et al., 2020). AR is different from VR since AR basically overlays the digital information in the real world on the time and environment, whereas VR totally transforms the whole environment into a virtual world (Crofton et al., 2019).

In the following, we focus on the possible applications of VR in food science. Recently, a special issue in *Food Research International* was published, which introduced seven papers dealing with the application of VR in food studies and especially in food sensory science (Ares, 2019). The special issue highlighted that there are only a limited number of publications dealing with VR in food science. However, one of the most promising fields of application is (consumer) sensory testing as VR provides a great tool to create immersive environments for testing consumer experiences with food products or even to study consumer behaviours in virtual supermarkets (Ares, 2019).

One of the first questions that come into the mind of researchers is the validity of VR environments compared to real life. The quality of VR environments heavily depends on the time and effort, however, it requires enormous resources to create a real-life environment in VR, if it can be done at all. Therefore, validation of VR is needed in order to form general conclusions based on the results of VR tests. A validation study compared consumers' behaviour in VR and real life by asking consumers to rank cereal products based on their perceived healthiness (Xu et al., 2021). During the real-life study, participants entered in a room, where 20 cereal products were randomly placed on a table. Their task was to rank the products based on their perceived healthiness on a second table, next to each other, from healthy to unhealthy. The VR task was similar, however, in this study participants wore a VR headset. In the virtual environment, the 3D models of the 20 cereals were presented, similarly to the real-life study, on a table. Using the VR headset and controllers, participants could pick up, turn, read and replace the products, just as in the real-life experiment. VR participants completed the same ranking task and placed the products next to each other on a virtual table. Results of the two studies were compared based on the rankings and decision times (time needed to rank the products). There was a strong positive correlation found between the VR and real-life ranks of the products ($r = 0.91$, $P < 0.001$, $N = 20$), however, participants needed longer time to complete the same task in VR environment compared to the real-life study. By comparing the number of fixations on nutrition and ingredients information, information seeking was measured. The authors did not find any significant differences between the two environments. These findings demonstrate that results obtained during the VR study are highly comparable to those obtained during the real-life study, even though the VR environment was completely different (Xu et al., 2021).

Similarly, promising results were obtained during a virtual buffet setting, where participants were asked to sit down at a table and scoop food from three bowls (chicken, pasta, and carrots) into the plate in front of the participants. The energy contents of the self-made plates showed strong positive correlation for single meal components as well as for the total meal (Ung et al., 2018).

Validation of VR measurements has been done for food selection behaviours when VR environment was compared to a real-life supermarket. In one condition, participants stood in front of a real shelf and were asked to choose one from the presented products. The other condition involved VR, but the task was the same. The VR group needed significantly longer time to complete the task, while there were no significant differences regarding the shelf from which the cereals were chosen (Siegrist et al., 2019).

For a detailed description of the validation studies regarding food and non-food application of VR technology, we refer to the book chapter of Hartmann and Siegrist (2019).

VR IN FOOD TESTING

VR is a rising and uptrend method to stimulate the different environment surroundings. Torrico and colleagues had aimed to analyse the acceptability of sensory and emotion response of no- and full-sugar chocolate on VR environments. The study aimed for the understanding of the effects of contextual information in the shaping of the hedonic responses under different VR testing conditions, as well as the effects of VR on the emotional responses towards the chocolate products. In this study, a total number of 50 untrained participants' emotions and acceptability of full-sugar (FS) and no-sugar (NS) chocolate had been evaluated under three environments, which are: traditional sensory booth; positive-VR, for which the study had used open-field forest environment, and negative-VR in a closed-space old room environment. The usage of VR in this research is to create virtual surroundings and stimulating the actual environment which can influence customer choices in sensory testing. Participants had rated the acceptability of sweetness, bitterness, texture, mouth-coating, aftertaste, and overall liking (9-point scale). Results of the study showed that chocolate type and VR did not affect the liking of participants but different conditions of VR environments had affected the sweetness and emotional response of the consumer on the chocolate (Torrico et al., 2020).

Another application of VR in food testing is to determine the food choices in VR buffet environment. This research was performed to examine the relationship between nutritional content on the choices of the consumer in the VR and RW food buffet selection. The authors carried out the experiment to compare participants' food selections made in the VR buffet and a RW food buffet cafeteria one week apart and assessing participants' rated perceptions of their VR experience (0–100 scale). There were a total number of 35 participants of young adults who were ethnically diverse. In this study the use of VR was to mimic as close as possible the RW environment, in which the applied VR can control the environment factors. These factors include food colour and texture, and also presence of audience. The result of VR and RW food buffets were not significantly different and positively correlated in calories, grams, carbohydrates, and protein. Based on the findings, it is an introductory proof of using VR environment to imitate the real world of the food environment and that using VR can be an up-and-coming tool in examining the psychological and behavioural factors especially in food choices (Cheah et al., 2020).

Meanwhile, Andersen and colleagues had performed research by enhancing atmosphere using VR and photo-enhance imaginative (PIC) environment, in order to understand how these techniques influence the choices and liking of beverages and skin care products. A total number of 60 participants were using VR, which facilitated the imitation of any environment and atmosphere for the experiment. The alternative choices offered to the participants is either a cold or a hot beverage on a VR sunny beach environment. This resulted in a more frequent choice towards the cold beverage, since in a real situation the participant would also choose a cold beverage. Based on the experiment, it is concluded that VR can be an effective tool to determine the influencing factors of consumer food choices (Andersen et al., 2019).

The earlier mentioned study by Siegrist and colleagues not only validated VR measurements but provided further insights into consumer food selection behaviour using three-dimensional (3D) VR as the authors compared the similarities of consumer behaviour both in a virtual and a real supermarket. During the previously mentioned first study, there were two groups of participants: the first group choose from 33 commercially available cereals from the real shelf, while the second group made its choice in a VR environment. Results did not show a large extent of difference during the choice of cereals. In the second study, participants had to choose between a healthy cereal ('healthy' condition) and a tasty cereal ('hedonic' condition) in a virtual world supermarket. Results showed that only in the 'healthy' condition study were participants looking at the nutritional content of the cereal and not in the 'hedonic' condition. Both study outcomes suggest that the VR environment is suitable to the investigation of food choices (Siegrist et al., 2019).

Researchers also applied VR to manipulate eating behaviour, focussing on the elderly population having mobility impairment, or who lived alone. The use of VR mainly focused on the surrounding and eating environment. The authors carried out this research to answer a question "*What virtual environment do mobility-restricted older Danish adults perceive as engaging and suitable for pleasurable, mixed-reality solitary meals?*". There were 7 elderly participating in the experiment which used a prototype of suitable virtual eating environment for each of the participants. This is important for the elderly population, because with age the physiological changes and environmental factors might cause undernourishment. An interview had been conducted after the experiment being carried out, showing that the participants prefer "cosiness", which suggest to them comfort and safety. This study had its limitation as the environment in the VR had made the participant more curious in using the technology, but had a positive feedback that VR will be accepted in the future of virtual eating environment (Korsgaard et al., 2019).

Another research carried out by Sinesio and colleagues was focussing on the vegetable freshness in VR environment combined with real-life tasting of food. The main aim of the experiment was to better understand the effect of VR technique on the consumer perception compared to the traditional sensory analysis (in booth environment). Consumer preference is influenced by its intrinsic (e.g. colour, taste and smell) and extrinsic factors (e.g. packaging, nutritional label and ingredient list). This experiment was conducted by involving two different environments (countryside patio and traditional sensory laboratory setting) while eating the food (salad tomato and wild rocket, *Diplotaxis tenuifolia*) among the participating 48 adult volunteers. The results showed that the VR countryside environment had boosted up the liking of food samples in terms of its freshness compared to the traditional sensory laboratory. There is a large potential of VR in the development of immersive sensory analysis to be used in investigations of consumer perception and behaviour (Sinesio et al., 2019).

A recent and interesting research carried out by Ammann, Stucki and Siegrist investigated the advantages and challenges of VR sensory science in terms of how colour influences the flavour identification. Using VR, the visual features of product properties can be modified without changing the product composition. The authors had made two AR studies and compared them with the real-life (RL) setting. The aim of the study was to investigate the differences and similarities of real-life sensory science with VR setting. The first study was a normal typical sensory analysis in a VR environment. With 100 participants, they tested two samples of fruit juices and a piece of cake. The products had been shown either in the original or in the modified colour. Since in the VR environment it is easy to change product attributes (especially the colour of the product samples), and participants had been asked to identify the most dominant flavour, this resulted in a deviation of flavour identification in the case of the modified colour product. This is mostly due to the phenomenon that participants always correlated a certain colour with a specific taste. During the second study the same experimental setup was repeated with an added RL condition. There were no significant differences among the test results of the VR and RL conditions according to the chi-square test. As a conclusion the authors state that the VR technique might be used in sensory studies as the results were showing a similar pattern to the RL condition (Ammann et al., 2020).

COMBINED APPLICATIONS OF VIRTUAL REALITY AND EYE-TRACKING

Eye-tracking is a simple but effective tool, which enables the researchers to follow the gaze movement of the participants. Eye-trackers have two main components. A light source beams infrared (IR) light on the face of the participants. Our face absorbs most of this IR light; however, the pupils reflect them. The reflected light is captured by a camera equipped on the eye-tracker. By combining the information about the position of the two components and the distance of the eyes, the eye-tracker software calculates the exact position of the gaze.

There are two types of eye-trackers available on the market. Screen-based eye-trackers are used to analyse stimuli presented on a screen, therefore are the perfect choice to analyse digital stimuli, such as images, videos, or webpages, just to name a few. Mobile eye-trackers are wearable, glass-shaped eye-trackers, which are used to record the eye-movements of the participants completing tasks in real situations. Mobile eye-trackers are widely used in food science to assess package attributes (Varela et al., 2014), nutritional label use (Machín et al., 2019), preferences for organic labels (Meyerding and Merz, 2018), the influence of eating behaviour on visual attention (Hummel et al., 2018), the influence of the arrangement of different food images on participants' attention (Hummel et al., 2017), product displays (Radon et al., 2021), just to name some key aspects. A more detailed introduction to the application of eye-tracking in consumer perception of food was published by the authors earlier (Kovács et al., 2016).

As it can be seen from the above list of studies, mobile eye-trackers provide an effective tool to analyse real world stimuli. Participants can walk through the aisles, grab products to look at their labels and/or packages while their gaze is captured. This feature enhances the ecological validity of mobile eye-tracking measurements and provides some extra freedom for the researchers when designing their experiments. However, this extra freedom needs extra resources when it comes to studies where different settings/products are compared. For example, testing different store layouts, different labels on the same product, or different packages of the same product needs extra resources. Rearranging a real store multiple times is sometimes difficult to carry out. Packing products into different packages or placing different labels on the products might be challenging.

As VR tools require a head-mounted device, the integration of an eye-tracker into the VR tool is technologically a viable option. This combined application enables the researchers to record the gaze pattern of participants in a virtual environment. This equipment can be completed by other sensors to create immersive environments. It has been shown that immersive VR (iVR) technology enhances the virtual experience. iVR equipment includes not only the head-mounted display but body-tracking sensors and motion-tracked controllers, therefore, all movements of the participants can be recorded and later analysed (Schnack et al., 2019).

This combined application enables the researchers to manipulate the presented virtual stimuli, record the gaze movements and record all body movements (hands, legs, body, etc). Combined testing requires the same laboratory equipment as a general VR study without eye-tracking. If the participants are allowed to move around (e.g. in a supermarket), then proper space should be provided. For studies, in which participants do not need to move, a relatively small area is enough. Due to the virtual environment, there are no limitations regarding the size of the virtual stimuli in terms of space. For example, complete cities (with more than 150 houses and other objects) can be generated and all (eye) movements of the participants can be recorded (Clay et al., 2019). Additionally, gaze interaction provides an excellent way for human–computer communication in virtual environments (Ma et al., 2018). These advantages are used extensively by psychologists (Lutz et al., 2017; Porras-Garcia et al., 2019) and in other fields such as designing indoor guidance systems (Porras-Garcia et al., 2019).

However, these advantages can be used in food science by creating virtual supermarkets, products shelves, etc. In such environments, researchers will get the right data to evaluate consumers' brand-related in-store decision processes by analysing the visual salience of different packaging elements or assessing the effect of brand positioning. Other possibilities are the optimisation of retail environment and/or store design by determining the best guiding systems by testing different virtual store layouts. Naturally, the system gives data to help consumers achieve their purchase goals by evaluating the proper placement of information such as product categories or allergens (Meißner et al., 2019).

A recent study investigated consumers' food selection behaviours in a three-dimensional VR environment using a head-mount VR device coupled with eye-tracking. A VR shop was created which offered cereal products. The packaging of the products was presented as 3D, therefore participants could grab and look at the packages one-by-one. The authors used two motivation conditions and assigned the participants into them randomly. The first condition contained directions about choosing a healthy product, while the participants in the second condition were asked to choose a tasty product. The task was to choose a product based on the given condition, place it into the shopping cart and check out of the store. The study design enabled the researchers to include any products without limitations as well as any modifications on the packaging could be done. The application of eye-tracking enabled them to evaluate the fixations of the participants, which indicated that those in the healthy condition paid more attention to the nutrition information and looked longer at them than those in the hedonic condition (Siegrist et al., 2019).

INFLUENCING FACTORS OF VR

We live in a multisensory world and our perception is continuously influenced by a variety of factors. In order to increase the ecological validity of virtual environments, different sensory stimulations can be used, such as touch, taste and smell (Flavián et al., 2021). Analysis of Chinese tea samples revealed that when participants tasted Chinese red or green tea samples after seeing the VR-based simulation of the actual tea colour, virtual colour did not influence significantly the ratings of the tea taste. Seeing the colour that the participants associated with the tea taste in VR influenced the saltiness ratings of the tea in reality (Huang et al., 2019).

In another study, the congruency of visual, auditory and olfactory cues using VR technologies were manipulated and the authors assessed the impact on context recall, evaluation time, and preference for cold brewed coffee samples. Coffeehouse environment was used as control during which the sights, sounds and smells commonly experienced in coffeehouses was mimicked. A laboratory setting, construction noise, and laundry detergent represented the individual incongruent visual, auditory, and aroma streams, respectively. Results indicated that olfactory cues were less recalled than other stimuli. Participants spent more time evaluating the coffees when all the sensory cues were congruent (Liu et al., 2019). These findings were supported later when perceived sweetness of the beverage was reported as higher when a sweet-congruent VR environment was displayed (Chen et al., 2020).

During a VR sensory test, participants saw the product either in its original colour (orange coloured orange juice) or in product-atypical colour (green coloured orange juice). After the product tasting, participants were asked to identify the most dominant flavour. It has been reported that participants had more difficulties identifying the flavour when the product colour was atypical than when it was shown in its original colour (Ammann et al., 2020).

CONCLUSIONS AND FUTURE PROSPECTS

The applications of VR show an increasing tendency. Although there are limited publications available within food science, this is expected to change in the following years. The advantages provided by VR tools will be further evaluated and it is expected that other biometric tools such as skin conductance analyser or EEG, etc. will be combined with VR. However, there are some limitations which should be mentioned. The use of VR headsets might cause motion sickness, disturbance of balance or even drowsiness for some participants.

On the technological side, the render quality of the visual stimuli might influence the results negatively. Bad quality stimuli might obstruct participants in their tasks. Additionally, as the representation of virtual environments develops, participants might expect higher quality virtual environments during the tests (Meißner et al., 2019). Additionally, when participants are asked to grab products, the virtually presented products have different weights and textures than real life ones (Siegrist et al., 2019). However, these drawbacks do not decrease the importance of VR in future food testing especially due to the rapid technological development of VR headsets (e.g. the used of cordless headsets) and to the development of software supporting the creation of VR environments.

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