IN FOCUS

EYE-TRACKING METHODS

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Application of eye-tracking methodology in food researches

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1. Summary

Eye-tracking is a widely applied tool to follow the human gaze direction. Due to the excessive technical development of eye-trackers, nowadays several fields of applications are available. A new field is food research where numerous questions can be answered by the analysis of gazing behaviour. The methodology might be applied not only in food marketing, but also in sensory analysis and consumer studies. In our article, we aim to introduce the principles of eye-tracking along with the major eye-movements and describe the meanings of the measured variables. Furthermore, several applications are introduced from food sciences.

2. What is eye-tracking?

Eye-tracking is a technique which enables the researchers to follow the eye-movements of participants. It defines the position where a person is looking at any given time and the sequence in which his or her eyes are shifting from one location to another **[1]**. In this way, eye-tracking provides a wide range of variables which facilitate the evaluation of the participants' gazing behaviour. Eye-tracking studies can be split into two major groups. Studies about human-computer interaction belong to the first group in which researchers develop and design technologies that let humans interact with computers in novel ways. Those studies belong to the second group, which aim to uncover what a person is looking at. This is the group where the food-related studies are found.

3. The History of Eye Tracking

Eye-tracking is not a novel technology since the first applications about reading research were performed more than 100 years ago **[2]**. Electro-oculographic techniques were applied for measuring differences in electric potential using electrodes placed on the facial skin around the eyes. These small differences described the eye-movements but this is relative to head position, hence further tools are needed to conduct point of regard measurements. Photo-OculoGraphy or Video-OculoGraphy are non-invasive methods of measuring different features of eye-movements e.g. horizontal, vertical and torsional position components of eye-movements, pupil shape, limbus position or corneal reflection. However, these methods are generally employed for medical purposes **[3]**.

Most commercial eye-tracking systems available today measure point-of-regard by the "corneal-reflection/pupil-centre" method. PCCR systems consist of a desktop computer running the eye-tracker software, a colour-calibrated recording screen (additional monitor). The PCCR eye-tracking device is attached to the recording screen and contains an infra-red light source which is directed to the user's eyes to generate strong reflection. Infrared light is used to avoid the disturbing effect of visible light. A large proportion of the emitted infrared light is reflected back making the pupil appear as a bright round spot. Furthermore, the corneal reflection appears also but as a smaller sharp glint **[4]**. From positions of the reflection of the pupil centre and the corneal reflection is used to compute a vector and, with further trigonometric calculations, point-of-regard can be found. In order to generate proper reflections, two major pupil illumination methods are used, the bright-pupil method and dark-pupil method. The aim of these methods is to generate the possible biggest contrast difference between the iris and the pupil which is significantly influenced by several external factors (*e.g.:* lighting, shades, reflections from objects, makeup on the participants, *etc*.).

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PCCR eye-trackers need to be calibrated before starting the recordings of the eye-movements. During the calibration, usually a point is displayed on the recording screen and participants are asked to focus on the point and follow its movements. The point moves around the screen and in the case of a five point-calibration, it stops in the corners and in the middle of the screen. The calibration is completed if all the points were captured **[4]**.

4. Eye Movements

There are six different types of eye movement: physiological nystagmus, smooth pursuit movements, vergence movements, vestibular movements, optokinetic movements and saccadic movements **[5]**. Physiological nystagmus are involuntary eye movements and not detectable under normal circumstances. Smooth pursuit movements are used to track moving objects and cannot be triggered voluntarily. During vergence movements, the eyes move different directions and it is used to select the distance of the object being observed. The eyes move in the opposite direction of the head during vestibular movements in order to retain the target object on the fovea when the head moves. It works together with optokinetic movements which occurs when a large portion of the visual field moves across the retina. Saccadic movements are responsible to bring new objects into the fovea hence they are very rapid and quick eye-movements. In eye-tracking, usually saccadic movements are measured. Within saccadic movements, there are two major eye movement types, fixations and saccades. Fixation is defined as the process of maintaining of the visual gaze on a single location. During fixations, information is acquired from the visual scene. The fixation lengths vary from about 100 to 600 milliseconds, during this stop the brain starts to process the visual information received from the eyes. A typical fixation frequency is less than 3 Hz (3 fixation/sec) saccades are extremely fast jumps from one fixation to the other and the average length of a saccade is about 20-40 milliseconds. The end point of saccade cannot be changed during the movement. Regressive saccades and the saccade pattern can reveal confusion and problems of understanding **[5]**.

5. Eye-movement metrics

Eye-movement metrics have been extensively considered as good indicators of information acquisition **[6]**. In order to compute the eye-movement metrics from a recording, it is necessary do decide, which parts of the visual stimuli is in question. These parts are the so-called areas of interests (AOIs) which can be defined using the data processing software of the eye-tracker. Definition of AOIs help to analyse the fixations and saccades on each AOI and/or outside the AOIs. This way, a comprehensive data set is created which can be analysed by different statistical methods to uncover the information of gazing behaviour.

Fixations are task-dependent; hence their evaluation should be done carefully. In a free viewing task, higher fixation count (the total number of times that a participant fixates his/her gaze on an AOI) can be indicative of greater interest, or it can be a sign that the AOI is complex and more difficult to encode **[7], [8]**. However, in a search task, higher number of fixation count is often an index of greater uncertainty **[7]**. The percentage of consumers who fixated their gaze on an AOI is a measure of the attentional capture of an AOI. It is related to the proportion of participants who extracted information from an AOI to complete the task. Fixation duration is also used to describe how difficult was to process the information. It is widely accepted that external representations associated with long fixations are not as meaningful to the user as those associated with short fixations **[9].**

Time to first fixation is a measure of the time from the start of the stimulus display until the participant fixates his/her gaze on the AOI for the first time and is indicative of the attentional capture of the AOI and the order in which participants process them for completing the task [6]. First fixation duration is defined as the time a user gazes at his/her first fixation point and can be indicative of the attentional capture of the AOI **[10]**.

Dwell durations are defined as time elapsed between the user's first fixation on a product and the next fixation outside the product, hence longer dwell duration means higher attentional capture **[6]**. Dwell counts are the number of "visits" to an AOI **[10]**. The metrics are summarized in ***Table 1.***

6. Eye-tracking in food research

As the package is the first impression of the consumer towards the product; it is a key factor for consumer attraction. Rebollar and co-workers aimed to identify patterns of viewing chocolate snack packages and at exploring how the layout of packaging design elements affects the prospective buyer's visual behaviour in impulse buying. Two main viewing patterns were identified in the study. The first consists in viewing first the most important elements from a visual perspective and then moving onto the ones of lesser importance. The second relates to the Western reading system, since people tend to look first at the top-left part of the packaging. The results obtained are of interest for graphic designers of packages **[11]**.

Another application of eye-tracking is to understand consumers' perceptions about the healthiness of food product. A study investigated the perceptions of the healthiness of fifteen different combinations of fish products and side vegetables. The obtained data was plotted in so-called heat-maps where the most fixation-dense parts of the stimulus images are coloured as red. Heat-maps revealed that fish burger products attracted more the consumers, they had more intense red areas in their heat-maps compared to the other products (fillet or nuggets). The highest healthiness scores were recorded for the fillet but the lowest scores were given to fish burger and nuggets presented with fried side vegetable dishes (French fries or tempura). The study introduced that both fish products and side vegetables had significant effect on the perception of healthiness but their interaction did not show significant effect **[12]**.

Another further interesting field of application for eye-tracking in food research is the analysis of nutritional labels and their use. Food labels play an important role in consumers' perception and purchases. For better understanding of consumer's visual processing of food labels, Ares and his co-workers discussed the information acquisition process from unknown food labels. Results revealed that consumers mainly fixated their gaze on the brand, ingredients, nutritional information and the image on the label. It was introduced that consumers tend to look for specific information on the labels. The authors concluded that label design could have significant effect on attention **[13]**.

Bialkova and van Trijp explored whether and how attention to nutrition information mediates consumers' choice. In their study, consumers were asked to select the healthiest or their most preferred product from a range of possibilities. Different labels were presented on the products (product logo, monochrome Guideline Daily Amount (GDA) label, or color-coded GDA label) which all communicated the nutritional profile of the given product. Their results revealed that, consumers can differ both, in motivation for healthy eating and in information processing style. A more motivated consumer would spend more time to extract information from the label than a less motivated consumer. The highest choice frequency was observed in the case of products with color-coded and monochrome GDAs and this effect was related to the attention-getting property of the label, as the authors reported. Furthermore, two interesting results were found. One of them is that attention mediates the effect of nutrition labels on choice which opens new research directions. They concluded also that the product fixated the most, had also the highest likelihood of being chosen **[14]**.

Jantathai and co-workers investigated the effect of food colour on gazing behaviour and the correlations between gazing behaviour and choice. The results revealed that the gazing behaviour of consumers was significantly influenced by the applied three colours (pink, green, yellow) and the three products. Although, no significant effect of sample position was found. Since there were significant positive correlations between two eye tracking parameters (fixation count and visit duration) and the choice rate, the parameters fixation count and visit duration could further be investigated and discussed as predictors of consumers' choice **[15]**.

The correlation between eye-movements and choice was analysed later by Danner and co-workers. Eight different food product groups were evaluated by 54 students who were asked to choose the most appealing product alternative from the presented four. Different product groups were defined in order to obtain general results: salads, apples, breads, soft drinks, instant soups, sausages, chocolates and beers. By examining the gazing behaviour during multi alternative choice tasks, very strong correlations between choice and gazing behaviour, in forms of more fixation counts, longer total dwell duration and more dwell counts, on the chosen alternative, were found. It has been showed, that there is a weak correlation between the first fixated and the chosen product but their findings supported the ones of Bialkova and van Trijp when they concluded that there is a strong correlation between the last fixated and the chosen product **[10]**.

Since there is a significant correlation between eye-movements and choice, Gere and his co-workers investigated which prediction models could be utilized to predict consumers' choice. Thirteen statistical models were tested and their ten performance indicators were computed. The models were trained to predict the choice of the participants based on their eye-movement data (*e.g.:* fixation duration and count, dwell duration and count, *etc.*). The models were ranked regarding their prediction performance to identify superior ones. Close relationship between gazing behaviour and food choice was observed; furthermore, the food choice was accurately predicted by gazing parameters using decision tree algorithms, preferably with ID3 models. The workflow, proposed in their study, is well-suitable to similar practical eye-tracking problems **[16]**.

Among the analysis of food labels and choice, several studies aimed to describe the influencing factors that can affect consumers' eye-movements. This was studied by Vu and co-workers who studied different factors influencing consumers' gazing behaviour in an eye-tracking task. The work was aimed to study how test design influences gazing behaviour and decision time. The following factors were investigated: number of images in one testing picture (two, three, four, five, and six images/picture); content of question (tastiness, healthiness, price, convenience, and familiarity); and type of evaluation (maximum choice, minimum choice, ranking, rating, and grouping). Two of the three factors proved to be significant (type of evaluation and the number of images). Ranking or grouping required more visual attention and time compared to the other tasks while higher number of images required more visual attention. No joint effect of influencing factors (number of images and type of evaluation) was found **[17]**.

A recent study investigated the effect of fruit disorders on the rejection of the given fruit using eye-tracking. The authors evaluated, which of the following apple defects has the highest attentional capture: Bruising, internal browning or internal browning and cavities. One hundred twenty-three participants were asked to look at images about apples with different defects, and then they had to indicate their future purchase intention about seven apples with different defects. In case of non-damaged fruits, participants fixated on the core of the apples but as soon as any disorder appeared, consumers shifted their gaze to the disorder. The authors introduced that if 4.8±0.7% of the total area is defected, 50% of the consumers rejected the further purchase of the product **[18]**.

7. Conclusions

Eye-tracking is a useful tool to analyse subconscious behaviour of participants. The advantages of the method are that it is non-invasive, fast and it provides immediate results in forms of heat-maps and gaze maps. Furthermore, if the researcher needs more detailed information, the recorded huge amount of data is also accessible which can be easily analysed using different statistical methods.

In food researches, eye-tracking can be used to assess all those attributes which can be processed through vision.

A further advantage is that eye-trackers can be used jointly with other tools *e.g*. face readers (which analyse the facial expressions of the participants and identify basic emotions such as happiness, anger, *etc.*) or electroencephalograph (which records the electrical activity of the brain). These tools applied together can give answers, which cannot be reached using the traditional questionnaire-based methods because the measured variables cannot be changed intentionally by the participants.

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