

PART 5

Visualization Technologies and Practices





Eye Tracking as a Tool for Visual Research

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INTRODUCTION

All of us are doing it about 170,000 times each day, about three times per second, but we rarely think about it: moving our eyes. A closer look at our eye movement patterns reveals that our eyes tend to fixate only very briefly – typically fractions of a second – on objects or locations in space before they move on. The movements that we make with our eyes, the jumps from fixation point to fixation point, are called *saccades*. Saccades are important because moving our eyes allows us to represent samples of our visual environment on the fovea, the part of our retina, where visual acuity and color sensitivity are highest because here the density of photoreceptors is greatest (for example, Sparks, 2002; Duchowski, 2007). Saccades permit us to obtain samples of the visual world in high spatial resolution. Obviously, we are also able to perceive stimuli that fall outside the fovea. In fact, our peripheral vision provides us with much important information. For example, when we are looking at a page of text, we are aware of the

entire text, but reading it requires fixation on its parts, the words and letters. Thus, in order to represent the different parts of the text on the fovea we move our eyes. Figure 23.1 shows a typical scanpath of a person while reading. The person started at the top left-hand side and with each saccade moved further towards the right, the end of the line, before beginning with a new line. Apart from providing us with information regarding the normal reading process, data such as these are also very helpful in understanding why some individuals may have difficulties reading. For example, proficient readers are able to jump back and forth, anticipating features of sentence structures, whereas non-proficient readers are more glued to the sequence of words as they unfold (see Kutas et al., 2000).

Because we can only fixate a small area at a time and then move our eyes in only one direction at a time, our brain needs to decide where the eyes should be moved to and for how long they should dwell on a given area. Eye movement research is concerned with identifying the factors that influence and

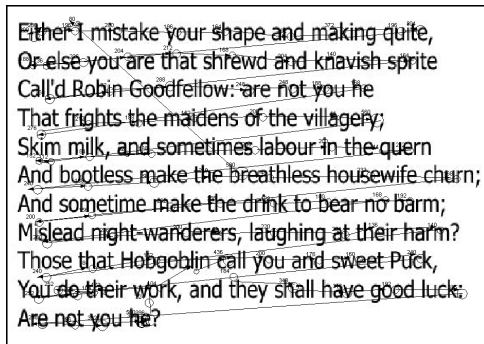


Figure 23.1 Example of a scanpath during reading. The arrows represent saccadic eye movements, the circles fixations, the numbers fixation duration in milliseconds. The option to show numbers referring to the order of saccades was deselected for this example. © 2010 Arvid Kappas and Bettina Olk

determine the outcome of this decision process. For instance, it is established knowledge that eye movements and attention are closely related (Hoffman and Subramaniam, 1995; Deubel and Schneider, 1996; Corbetta, 1998). Hence, eye movement patterns are informative about where attention is directed. Further, emotional content affects eye movements. People tend to look at emotional pictures first and for longer than at neutral pictures (Nummenmaa et al., 2006; Alpers, 2008; Kissler and Keil, 2008). In addition, eye movements are guided by the goals of observers (Yarbus, 1967). To provide a full review of the factors that have been identified and the models that have been created by researchers to describe and explain the processes involved in directing eye movements would be well beyond the scope of this chapter. Also, given the available space, an in-depth introduction into the more technical aspects is not possible. We thus refer the reader to review articles and books (for example, Duchowski, 2007; Land and Tatler, 2009). The purpose of the present chapter is to give an overview and thus we will provide examples of representative work. We will also point to possible applications of eye

movement research in different areas of visual research.

Measuring eye movements has become a tool for drawing inferences regarding underlying psychological processes, such as interest in certain contents, motivations, and the like (Duchowski, 2007). The problem is, of course, as in many other areas where behavioral or physiological measures are used to draw inferences regarding mental processes, that frequently, there are multiple determinants leading to a particular behavioral or physiological change (see Cacioppo and Tassinari, 1990). Without knowing more about the underlying processes one is bound to draw false conclusions as to the meaning of eye movements. Thus, even if the reader's interest is primarily in the applications of eye movement research, learning about the underlying processes is crucial for data interpretation (Coren et al., 1999; Hyönä et al., 2003; Duchowski, 2007; Goldstein, 2007).

WHICH FACTORS MODULATE EYE MOVEMENT PATTERNS?

In a typical experiment in the laboratory, the rapid sequences of saccades and fixations are recorded under different experimental conditions. Experiments have shown that where we look is influenced by several factors (see Henderson and Hollingworth, 1999 and Henderson, 2003 for reviews). Our attention and our eyes are attracted by suddenly appearing, visually salient and new stimuli and we may at times not be aware of this. Such behavior is for instance demonstrated in studies using the 'oculomotor capture paradigm' (for example, Theeuwes et al., 1998). In the experiment by Theeuwes et al. (1998) participants started each trial of the experiment by looking at six gray circles (dashed lines), each containing a small gray '8' (see Figure 23.2). These stimuli were equally spaced around an imaginary circle around a small asterisk in the center of

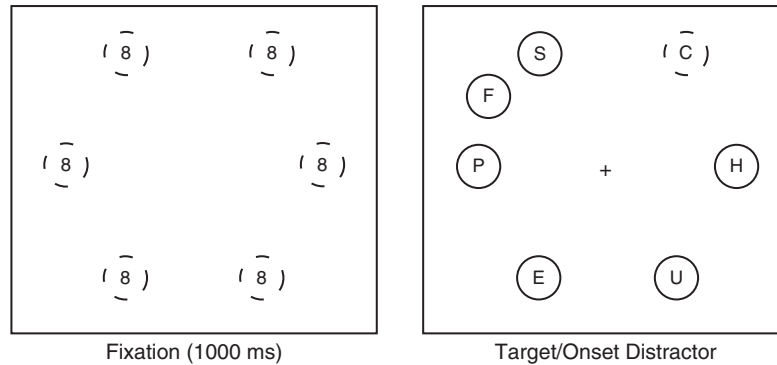


Figure 23.2 Graphic illustration of the displays and the temporal sequence of an experimental trial (from left to right). The target is defined simultaneously with the appearance of the onset distracter. The gray circles are indicated by the dashed lines. The red circles are indicated by the solid lines. Reproduced with kind permission from Jan Theeuwes from Theeuwes et al. (1998): © 1998 SAGE

the screen. At the beginning participants looked at the asterisk. After 1000 ms all but one circle changed their color to red (solid lines) and at the same time each small '8' changed to a different letter. The task of the participants was to look directly from the center towards the odd one out – the circle that remained gray – and to determine whether the letter inside it was a 'C' or a reverse 'C'. Importantly, participants did not know which one of the circles would be the odd one out in a given trial because its location changed randomly from trial to trial. In half of the trials an additional red circle was presented at one of four locations among the other red circles simultaneously with the color change. Although this additional stimulus was irrelevant for the task, participants tended to look at it first in about half of the trials, despite their instruction to look directly towards the gray circle. This finding demonstrates that participants' eyes were 'captured' by the additional stimulus. That they had understood the task was confirmed by the trials in which no additional red circle was shown. In those trials participants tended to look at the gray circle right away. And most interestingly, when asked after the experiment whether they were aware that the

appearance of the new circle affected their saccades, they denied an influence of the additional circle, even though their eye movement data proved that they had looked at it. This work demonstrates that where we look at is not always under our control and that suddenly appearing stimuli capture our attention and our eyes.

Studies in which participants were shown different pictures indicate that characteristics such as contrast, color, texture, luminance and shape of the visual information affect which areas are fixated. For example, areas of higher contrast, where contrast can be calculated as the local measure of the variability of image intensity, are fixated more (Reinagel and Zador, 1999; Parkhurst and Niebur, 2003).

Importantly, we are also able to direct our attention and eyes in a controlled, goal-directed manner to relevant information. Knowledge about types of scenes guides our eyes. For instance, when looking for your cat in the garden, you are more likely to find it sitting on the grass or in a tree than flying through the sky. Furthermore, the famous study by Yarbus (1967) illustrates the impact of goals. He recorded eye movements while observers looked at a print of the

painting 'They Did Not Expect Him' by Repin. The painting depicts a living room scene with a family and a person entering the room. Participants either engaged in free viewing or they were, for example, asked to estimate the social status of the persons, their age, to memorize the clothing of the persons or to estimate for how long the person entering the room had been away. The crucial finding was that the fixation patterns differed depending on the task that the participants had to complete. For instance, when they were asked about the economic standing of the persons, they looked predominantly at the clothes of the person in the foreground and on the furniture in the room and when asked to estimate for how long the person entering the room had been away, their gaze moved frequently back and forth between the faces of the persons. These results show that the distribution of fixations and saccades was influenced by the type of information required and illustrates that participants viewed scenes in an active manner, looking for pieces of information that were relevant for the task they had to complete. Recently, we replicated the findings by Yarbus with a different type of material: namely, press photographs (Olk et al., 2007). We presented participants with online press photographs that depicted a current event but were unknown to the participants. Photographs were a mixture of different camera angles, showed emotional situations that expressed a certain tension and anxiety and depicted motifs that were ambivalent in their interpretation outside their actual news context. In the experimental condition, participants viewed all photographs several times, each time with a different instruction. For instance, for the first viewing, participants were asked to simply look at each picture, and for the second viewing to describe what the people depicted felt. To analyze the eye movement patterns, 'areas of interest' were defined, and it was calculated how often and for how long those areas were fixated. This tested whether the fixation patterns changed with the

instructions, as would be expected according to Yarbus (1967). We found a clear effect of instructions on eye movements. When participants described what the people depicted felt, they clearly looked more at the persons in a photograph, which are the most informative components for this purpose, than at other parts of the images, such as objects. These data demonstrate that the observers' goals guided their attention and eyes.

THE NEUROPHYSIOLOGY OF EYE MOVEMENTS

Eye movement research also addresses the question of which brain areas of the are involved in the decision where eyes should be moved to, and what role these brain areas play in the decision process. Before we move our eyes, the information that is received on the retina has to undergo several stages of processing, which already begin on the retina itself. From the retina, the visual information is passed on via the visual pathways to those brain areas that deal further with the processing of location, shape, color, size, brightness and texture of the seen stimuli and eventually detect at which objects or people we are looking (see Duchowski, 2007). In order to determine and understand what we are looking at, the visual information has to be combined with our knowledge. For example, if we see something round with objects of different color, shape and texture on it, only the combination of the seen visuals with our knowledge will tell us that this is a plate of food in front of us. Visual perception is thus clearly more than the projection of the outside visual world onto the retina of the eye and the transfer of information to visual areas in the brain (see Bear et al., 2007). The features of the stimuli we see and their meaning both influence where we look.

Neurophysiological and neuropsychological studies have contributed much knowledge

about the network of brain areas involved in the generation of eye movements and how these brain areas work. The network of brain areas consists of structures lying under the cortex (subcortical) such as the basal ganglia, the brainstem and the superior colliculi. In the superior colliculi, for instance, cells have been identified that are active when we fixate and cells that are active when we move our eyes. These types of cells are rarely active at the same time and are involved in mutual inhibition (for example, Coren et al., 1999: 68). The size and direction of each saccade is determined by where the superior colliculi are stimulated. For example, stimulation of the front part results in small saccades while stimulation more towards the back produces large eye movements (Schiller, 1984). Signals from the superior colliculi are passed on to the brainstem, where omnipause neurons fire tonically when we fixate and stop when we make a saccade. Burst neurons are active before and during saccades. This information is further sent to the six extraocular muscles that move each eye (Schiller, 1984; Sparks, 2002). Cortical areas that are involved in eye movement generation and control are for example the frontal eye field, the supplementary eye field, and the dorsolateral prefrontal cortex in the front of the brain, as well as the parietal eye field, which is located more towards the back of the brain (Schiller, 1984; Guitton et al., 1985; Henik et al., 1994; Schlag-Rey et al., 1997; Everling and Fischer, 1998; Gaymard et al., 1998; Connolly et al., 2000; Rafal et al., 2000; Olk et al., 2006). Frontal cortical areas have, among other functions, been associated with the control of eye movements, such as the inhibition of unwanted saccades towards irrelevant stimuli. Understanding the exact role of such areas as part of the network and their connections, as well as which rules and mechanisms underlie their processing and communication between each other, is one of the major fascinating challenges of eye movement research.

TECHNOLOGY FOR THE RECORDING OF EYE MOVEMENTS

Modern technology allows us to track eye movements in and outside the laboratory. Eye trackers allow the non-invasive registration of eye movements with a great spatial and temporal accuracy. Some eye trackers are able to record the fixation location of the eyes up to twice every millisecond. There are different types of eye tracking devices on the market, produced and sold by different companies. Some eye trackers consist of headsets with small cameras attached to them that are placed on the head of the participants (see Figure 23.3a). The headsets can be adjusted to the dimensions of a person's head in order to be comfortable. However, when designing an eye movement study, researchers should take into consideration that participants may find such headsets heavy after a while, although this may vary from person to person. We have found that, typically, experiments of a length of half an hour to an hour are very feasible. The tolerance of the headset can be greatly enhanced by including short breaks. Remote eye trackers are positioned on the table about 40–70 cm away from the eyes of the participant, while participants view visual stimuli on a computer monitor (see Figure 23.3b). These eye trackers are especially useful if the participants to be tested might feel uncomfortable wearing a headset, or if the participant's head needs to remain free of a headset so that further measurements are possible. For example, the activation of facial muscles can be measured with small electrodes applied to the participant's face (see below). Apart from eye trackers that are used in the laboratory, mobile systems allow the participant to move around, usually wearing an eye camera and a camera that records the environment on their head, and carrying further necessary equipment in a small bag (see Figure 23.3c). Mobile eye trackers can be used to study eye movement patterns while participants engage in everyday life tasks, such as making tea and

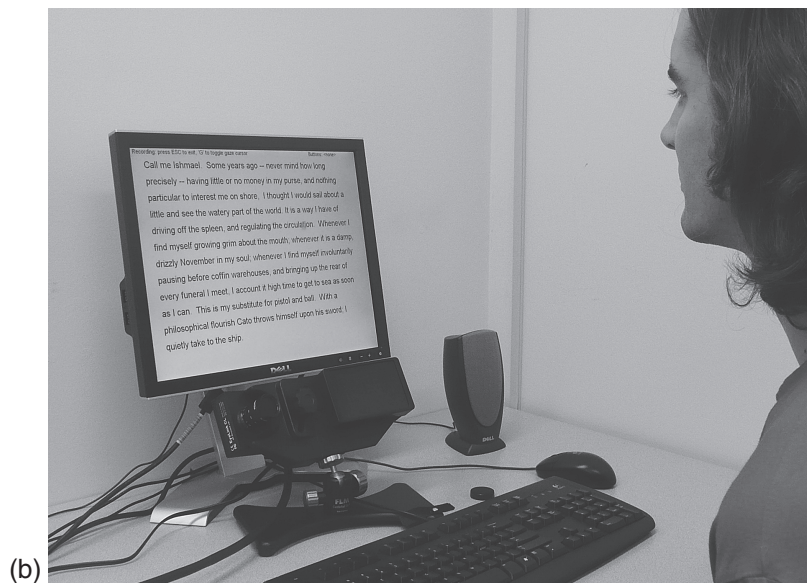
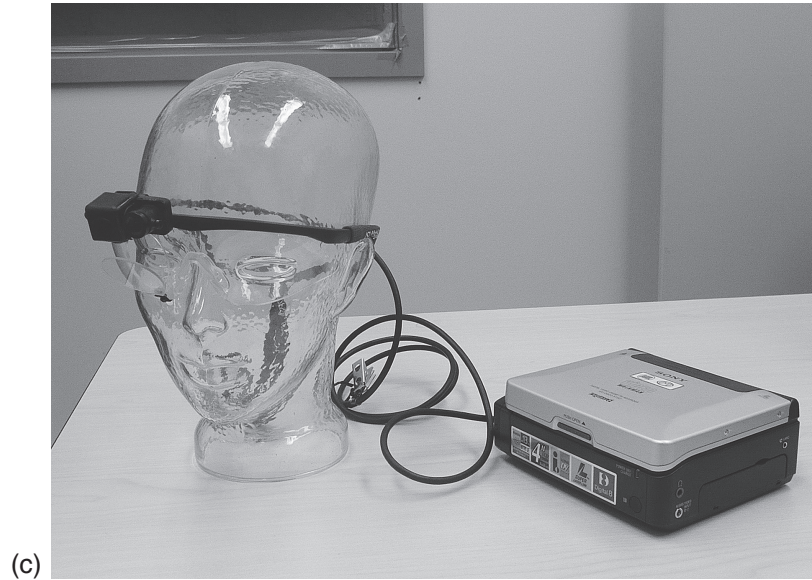


Figure 23.3 The figure shows three different eye trackers (EyeLink® and Applied Science Laboratories). It should be noted explicitly that this is only a selection and many other excellent systems are on the market. (a) The 'EyeLink II' eye tracker (www.sr-research.com) consists of two eye cameras for binocular tracking. A head-tracking camera is integrated into the headband and allows accurate tracking of the participant's point of gaze while allowing head motion and speech. (b) The EyeLink 1000 Desktop System is a remote eye tracker. (c) The 'Mobile Eye' eye tracker (www.asleyetracking.com/Site/) is an example of a mobile eye tracker. © 2010 Bettina Olk



(c)

Figure 23.3 Cont'd

driving (Land and Lee, 1994; Land et al., 1999). Further eye tracking devices are described by Duchowski (2007).

SETTING UP AND CONDUCTING AN EYE TRACKING EXPERIMENT

Before an experiment in the laboratory can begin, a computer program needs to be written for displaying the visual stimuli and specifying the parameters of the experiment, such as for how long and at which position a stimulus or a sequence of stimuli should be shown. The program can further specify which variables are recorded. Such programs are frequently written in programming languages such as C, C++ or MATLAB® and require specialized programming training, but depending on the eye tracking device other languages may also be used and some companies sell special software for the development of experiments (see also Duchowski, 2007).

Before the actual data collection can start, a calibration procedure needs to be

completed to determine the correspondence between pupil position in the eye-camera image and the gaze position on the display shown to participants. Experience has shown that this procedure is not too cumbersome and even particular participant populations, such as children or clinical populations, can easily be calibrated. During calibration, fixations on target stimuli are recorded. A typical calibration procedure may require the participant to look at a simple dot that appears randomly at different locations on the screen, while the system records where on the screen the person is looking, and normally only takes a few minutes. At times it may take longer to calibrate participants who wear glasses as the surface may produce reflections, which interfere with the detection of the pupil by the system. The calibration procedure should be repeated for validation. If the calibration and validation are satisfactory, the experiment can begin. The visuals are presented on screen and the participant completes an assigned task. A wealth of information is recorded, including spatial data such as each fixation location and start and end position of each saccade. Each location on

the screen can be described in x and y coordinates. For example, if the screen resolution is 800×600 pixels, then a data point with the x value 400 and the y value 300 would indicate a gaze position in the center of the screen. Further, temporal data is recorded, such as the beginning and end time of fixations and saccades. This is possible through time-stamping of each recording in milliseconds. The recorded objective measurements can then be used to reconstruct the exact scanpath (see Figures 23.1 and 23.4a). It can be inferred where, when and for how long a participant looked at a certain location, where the exploration started and how it continued.

Data analysis depends on the research question at hand. If, for example, the research question is similar to Yarbus (1967), whether participants look at a picture differently, depending on which question they need to answer about it, one may choose to define 'areas of interest', using special software. Based on those defined areas, the researcher can obtain data reports that inform about how much time a participant spent looking at a given area of interest, how many fixations were made and in which area of interest a saccade started and ended. Figure 23.4a shows the scanpath of a participant who was asked how the depicted people felt.

The analysis reveals that the participant fixated the faces of the man and the woman 30 times, for 6628 ms, which amounts to 77 percent of the total fixation time. In comparison, the body and the arms of the man were fixated for 1088 ms with seven fixations, which constitutes 12 percent of the total fixation time. Only 1 percent of the time was spent on the rowing machine. The percentages are shown as the light bars in Figure 23.4b. The dark bars in the same figure indicate the outcome of the analysis when the same person was asked what was happening in the picture. Only 23 percent of the total fixation time was then spent looking at the faces, but 32 percent on the body and arms of the man and 27 percent on the rowing machine. Clearly, modern eye

tracking technology allows and supports statistical analyses that were not possible in the late 1960s when Yarbus conducted his seminal study.

The reconstruction of a scanpath and defining areas of interest is one way of analyzing the data. Other research questions may need to determine the time between the onset of a stimulus to when the eyes start to move. This time is termed saccadic latency or saccadic reaction time and is one of the main dependent variables used in experiments such as the oculomotor capture study mentioned above (Theeuwes et al., 1998) or the antisaccade paradigm described below (for example, Hallett, 1978; Olk and Kingstone, 2003; Godijn and Kramer, 2006). Other research may require the use of pupil size or the duration, amplitude and velocity of saccades as dependent variables (see also Duchowski, 2007).

THE COMBINATION OF EYE TRACKING TECHNOLOGY WITH OTHER ONGOING MEASUREMENTS

Depending on the research question at hand, the recording of eye movements is motivated by the wish to draw specific inferences as to the cause of the eye movements. In other words, the eye movements are seen as a privileged pathway to obtain knowledge about a mental process that is typically hidden, or about which participants cannot or do not want to provide explicit reports: for instance, which details are of particular interest to participants or are emotionally arousing and hence receive attention. Instead of just relying on the information provided by where people look and for how long, there is also the possibility to combine the analysis of eye movements with other dependent variables that are relevant for a diagnosis of underlying processes, such as emotional responses. For example, if somebody is looking repeatedly and for long periods of time at a particular feature of a car – is this because this feature is interesting and positive, or is it

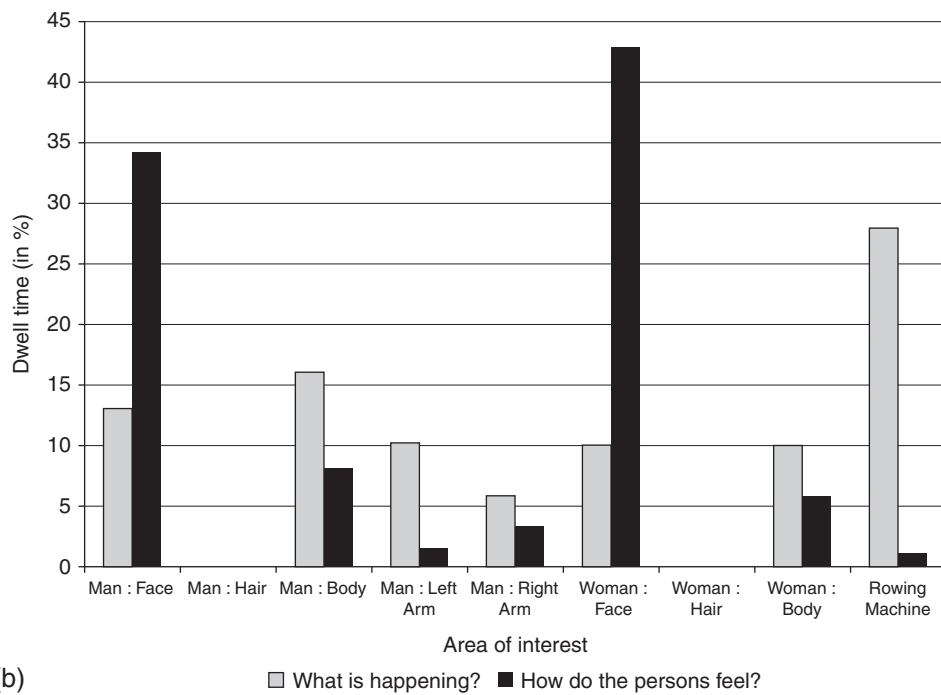
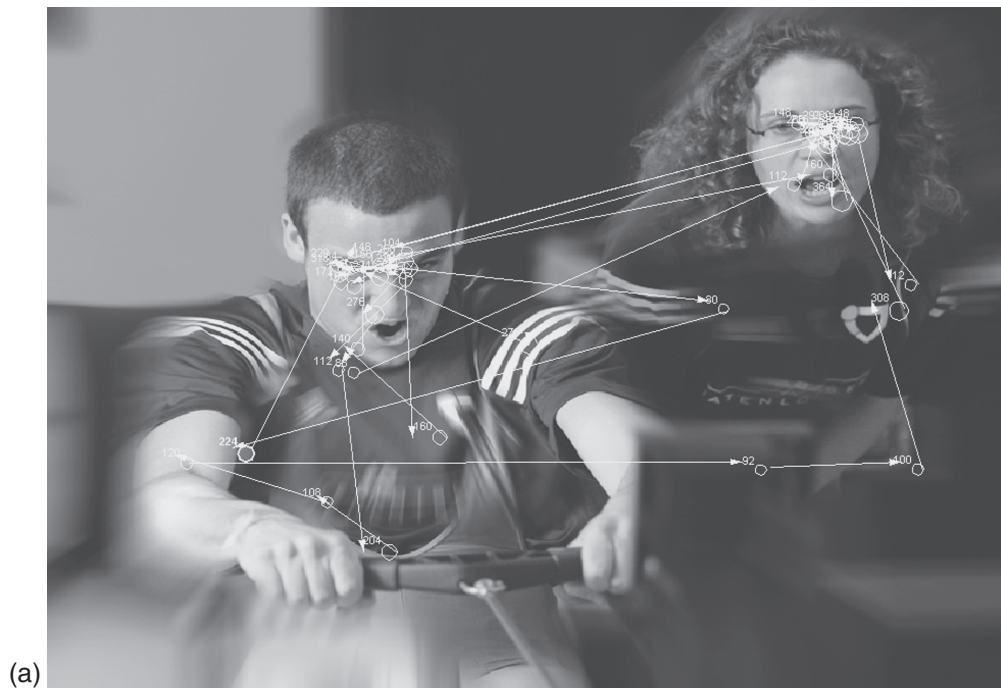


Figure 23.4 (a) Example of a scanpath while looking at a photograph. © 2008 Jacobs University. (b) Behavioral data for a single participant looking at the photograph in two different conditions – describing what happened and describing what the two people feel. The bars indicate dwell times on regions of the image that were previously defined as areas of interest. © 2010 Arvid Kappas and Bettina Olk

because it is perceived as being ugly and disappointing? If we know that a particular spot is relevant – because it is being repeatedly regarded – and it is associated with indications/reports of pleasure or liking, then we have learned more about the underlying mental process when exploring the visual stimulus at hand.

When discussing multi-method approaches one has to distinguish sequential from concurrent paradigms. In a sequential paradigm the same material is tested more than once, allowing the assessment of eye movements at one point, and self-report, behavioral or physiological measures at another point in time. The problem is, of course, that the second time around an object or an image is processed in a different way. The alternative, thus, is a concurrent approach where other measures are taken simultaneously, while the participant explores a target stimulus.

The easiest concurrent measurement is self-report, more specifically the think-aloud procedure. Participants are asked to comment on what they are seeing, or what they like, while their eye movements are recorded. Later, the content can be coded and related to fixations or dwell times on particular aspects (for example, in the case of a preference task between several products). However, it is clear that the think-aloud task, despite being used in different areas of psychology, interferes with ongoing processing. It shapes and biases interaction with the visual material and it is, depending on the material under study, subject to pressures associated with the social context. In other words, having to comment aloud might shift a spontaneous exploration into an analytical exercise. In the case of dynamic stimuli, such as a movie or a television spot, speaking also interferes with the participant's understanding of the sound track. Clearly, a participant commenting aloud while their eye movements are being assessed is frequently not what the researcher or practitioner wants. Furthermore, we have already stated that on average there are three fixations per second; it is thus very difficult to link specific verbal

content to a subset of an image currently being observed.

The alternative is using behavioral or physiological measures that can be taken at the same time and with a temporal resolution that is comparable to the recording of the eye movement. There are many reasons why such an approach is desirable – for example, using multiple dependent measures, the ambiguity as to the origin of a particular behavioral or physiological response can be reduced (see Cacioppo and Tassinary, 1990). The problem is, of course, that some measures relate to processes that take a certain time between the perception of a stimulus, or stimulus feature, and the presence of the bodily correlate. For example, in principle it is highly desirable to combine the analysis of eye movements with an analysis of electrodermal activity, a classical measure in psychophysiology associated with a sweat reaction linked to the activation of the sympathetic branch of the autonomous nervous system and frequently used as an indicator of psychological arousal. The salt in the sweat makes skin thus more electrically conductive. Psychologically, skin conductance changes as a function of several factors, particularly personal relevance of a stimulus (see Dawson et al., 2000; Pecchinenda, 2001). However, the problem is that there is a latency of about 2000 ms between the perception of a relevant stimulus and the response in electrical conductivity. This means that linking specific physiological reactions to observing specific contents on a computer screen still might require complex procedures to account for the time shift. Nevertheless, there have been published attempts for example to link changes in skin conductance and heart rate with an analysis of eye movements (for example, Wieser et al., 2009).

Ever since Charles Darwin's publication of *The Expression of the Emotions in Man and Animals* (1872), there has been a considerable number of empirical studies investigating the relationship between how someone feels and the muscular activity on their face.

While facial behavior is in no way a simple readout of emotion (Kappas, 2003), there is, under certain circumstances, a link between feeling and muscular activation in the face, moderated by the social situation (see also Kappas and Descôteaux, 2003). While the results of empirical studies concerning facial activity during specific emotional states, such as anger, fear, or disgust, do not recommend using muscular activity as a diagnostic of underlying emotional state (see Russell and Fernández-Dols, 1997; also Russell et al., 2003), the situation is more straightforward when it comes to the more general notion of valence: i.e. to what degree something is evaluated positively or negatively (see also Cacioppo et al., 1986; Larsen et al., 2003). Thus, if a person frowns while looking at something, chances are that the object in visual focus is associated with a blocking of important goals (see Smith, 1989; Smith and Scott, 1997), or more generally, negative affect. Hence, measuring the contraction of the brows, associated with the activation of the corrugator supercilii muscle, is a frequently used measure in emotion research. Inversely, activity at the two muscle sites involved in smiling, zygomaticus major (pulls the corners of the mouth back and up) and orbicularis oculi (muscle around the eyes, produces the 'crow's feet wrinkles'; see also Niedenthal et al., 2009) is frequently measured for positive emotions. However, while these measurements are quite reliable at a moderate level of affect, the contraction of the brows is a better measure than activity related to smiling when very negative material is being investigated. As Larsen et al. (2003) reported, there is smiling-related muscle activity when looking at very negative images – likely, a grimace rather than a typical smile (also Kappas and Pecchinenda, 1998). However, without a qualitative assessment of the facial actions using methods such as Ekman and Friesen's Facial Action Coding System (FACS; 1978) these expressions cannot be differentiated. Yet, a FACS analysis is costly in terms of time and money.

The advantage of using facial activity as a correlate of affective processes is the short latency between the perception of an emotional stimulus and the response. Unlike electrodermal activity, mentioned above, changes in facial activity occur in the range of several hundred milliseconds after stimulus onset. We are currently evaluating the concurrent use of electromyography (EMG) (Fridlund and Cacioppo, 1986; Tassinari and Cacioppo, 2000) and eye tracking in our laboratories to assess affective responses to complex press photography of conflict (also Olk et al., 2007).

While emotional responses are obviously associated with changes in bodily activation, many researchers are increasingly interested in measuring these directly in the brain. However, functional magnetic resonance imaging (fMRI), currently the most popular means of assessing in-vivo brain activity, relies on a change in blood oxygenation level that has a latency of seconds (Cacioppo and Berntson, 2005). Thus, fMRI is clearly slower than the measures discussed above, particularly facial EMG. This means that 'peripheral' bodily reactions such as facial responses will remain relevant in the foreseeable future as dependent variables for understanding visual perception. Nevertheless, there is some promising progress being made linking simultaneous measurement of brain activity while eye movements are recorded (see Van Reekum et al., 2007).

EYE MOVEMENTS – EXPERIMENTAL PROCEDURES AND INFERENCE

It should be kept in mind that interpreting eye tracking data requires more than employing a particular technical apparatus. Depending on the particular research question or applied purpose, specific control material must be found and included in the experimental session. For example, to scale the affective reactions to press photography material that we are currently studying

(for example, Olk et al., 2007) all participants are also reacting to positive, negative, and neutral samples of the International Affective Picture System (IAPS; Lang et al., 2005). These images have been used in psychological research in many different countries and have well-known properties as regards their valence and the arousal they elicit (Bradley and Lang, 2007). They show, for example, babies, cuddly animals and food, exciting sports, household objects, bodily injuries, or threatening images, such as guns pointed at the camera. Using this standardized material allows us to scale the affective responses to the new material we investigate.

A study that illustrates the importance of proper control stimuli from a different research context was conducted by Turati (2004). It is apparent that faces are very important stimuli in everyday life. Many researchers assume that faces are biologically potent stimuli and, thus, already relevant for babies from birth (see Kappas, 2003). To test the assumption that faces are 'special', several classical studies showed pictures of faces to infants or, as control stimuli, outlines of faces where features such as the eyes, nose, and mouth were shuffled around, so that the resulting image held little resemblance to a face, but contained all of its elements. In this case, babies looked longer at the real faces – a pattern of behavior interpreted as their preferring the real faces. But can it really be concluded that infants always prefer realistic stimuli – only based on the comparison of real and scrambled faces? In fact, Turati (2004) presented face-like stimuli (see Figure 23.5) and other controls. She showed that the critical factor appears to be that babies are attracted to a particular distribution of features in a bounded shape – more high-contrast elements in the upper part. In the natural environment, real human faces do correspond to such a distribution. However, Turati demonstrated (see also Turati, 2004) that infants even preferred stimuli which looked less like faces but contained more features in the upper part of the oval shape,

than the more face-like stimuli (see Figure 23.5). Thus, the conclusion that it was specifically face-likeness that attracted infants was incorrect. Earlier conclusions were based on an analysis of eye movements using the 'wrong' control stimuli. Examples such as these highlight the importance of procedural details that are often disguised by the high-tech aspect of eye movement recording. Measuring and interpreting eye movements is only in part a technological challenge. Engineering problems can and will be solved – it is the experimental tasks that are used and the conditions under which the data are recorded that are the biggest challenges to drawing firm and accurate conclusions.

There is no doubt that in the next few years complex multi-modal measurement of eye movements and other variables targeted at information processing and affective responses will become more and more established. While some of these methods require multi-million dollar equipment (such as magnetic resonance imaging), others will be more affordable and hence trickle down from piloting and basic research to concrete applications in a variety of fields.

THE APPLICATION OF EYE TRACKING

Eye tracking technology can be applied in a vast number of research fields, ranging from studies that investigate the fundamental mechanisms underlying eye movements, such as the programming of saccades, and that aim at devising and improving models to explain eye movement patterns, to studies in advertising and marketing that seek to characterize consumer preferences or human factors, for example to optimize the interfaces between humans and machines (see Duchowski, 2007 for an overview). In the following sections we will provide examples of the application of eye tracking in the fields of research dealing with eye movement control and clinical applications.

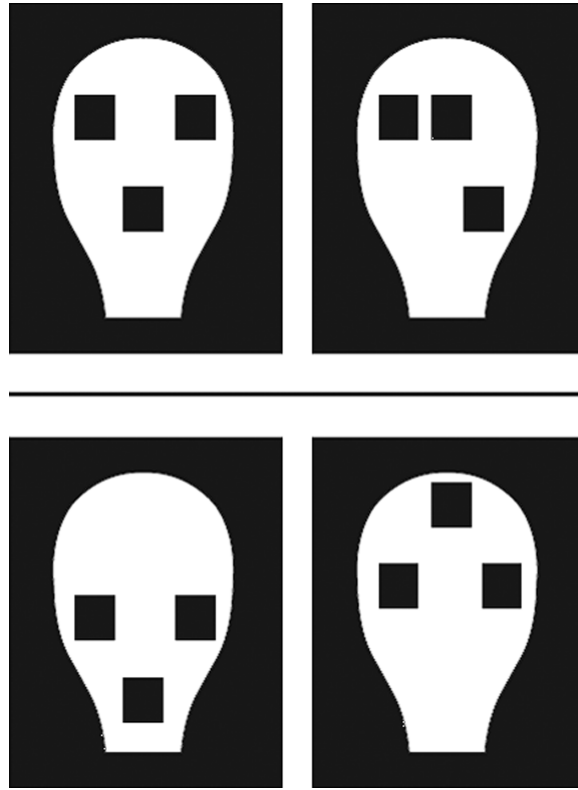


Figure 23.5 Both panels on the top are equally long fixated, despite one resembling a face more than the other. At the bottom panel it is the right stimulus that is more regarded, despite the fact that the left panel is more face-like. In particular, this example is consistent with the hypothesis of Turati that faces are interesting because they have a particular preference for non-specific image features. Reproduced with kind permission from Chiara Turati; from Turati (2004): © 2004 SAGE

Eye movement control

How well are we able to ignore distractions and to attend and look towards information in accordance with the goals that we wish to achieve? An effective interaction with our complex visual world necessitates that we are able to direct our eyes to relevant pieces of information and to suppress gaze towards distractions. In some situations involuntary shifts of our gaze may be rather disrupting and in conflict with our goals: for example, if a colorful, salient advertisement at the side of the road distracts us and we look there, instead of looking at the road ahead.

This situation requires controlled, voluntary guidance of our eye movements in line with our goals. Studying oculomotor control is important because it contributes significantly to our knowledge about the mechanisms underlying eye movement behavior and also because it allows us to discover and characterize differences in performance under different conditions of a task – for instance, differences in difficulty of tasks or differences in performance between persons. For example, research in this area has shown that the ability to control our eye movements may decline as we age. This has been demonstrated using different experimental

paradigms, one being the 'pro- and antisaccade task'. In this task, participants are typically presented with a stimulus, such as a simple dot, in the center of the screen, and are asked to fixate on it. After about 1 second, a further simple dot appears on the left or on the right side of the screen. On 'prosaccade' trials participants are instructed to look at the peripheral dot as quickly and accurately as possible. These trials do not require much oculomotor control as participants can simply allow their eyes to be guided by the suddenly appearing stimulus. On 'antisaccade' trials, however, they are requested to look *away* from the peripheral dot in the opposite direction, without first looking at it. Antisaccade trials require control because it is essential to suppress the tendency to look at the visual stimulus and to select the saccadic response in the direction opposite to the stimulus (Reuter et al., 2006; Olk and Kingstone, 2009). This task may seem easy, but in fact participants look erroneously towards the stimulus in a certain percentage of antisaccade trials, and they are also slower to make an antisaccade than a prosaccade (Olk and Kingstone, 2003; Godijn and Kramer, 2006). When comparing younger and older participants, it is typically found that elderly participants have longer saccadic reaction times and a higher rate of erroneous saccades to the dot when saccades away from it are required than younger participants (Olincy et al., 1997; Klein et al., 2000; Sweeney et al., 2001; Bojko et al., 2004; Eenshuistra et al., 2004; Abel and Douglas, 2007). Furthermore, the difference between age groups becomes especially apparent when the demands for control increase (Olk and Kingstone, 2009). Such a decline in oculomotor control is commonly attributed to a decline in the ability to inhibit the prepotent saccade to the visual stimulus (for example, Hasher et al., 1999; Butler and Zacks, 2006) or to the failure to select the less potent antisaccade response away from the stimulus in a situation when two opposing saccade programs compete (Olk and Kingstone, 2009). One implication of such

findings is that in certain conditions aging may be related to being more easily distracted, and such knowledge can be used to devise tailored training programs.

Clinical applications

Eye movement studies with clinical populations such as patients with brain injuries can help to characterize the impact of brain injuries and thereby guide the way to efficient rehabilitation. They also contribute to our understanding of which brain areas mediate visual exploration. Brain injuries can, for example, lead to a syndrome referred to as visuospatial neglect. Patients with this syndrome do not respond or orient to stimuli presented to the side opposite a brain lesion or can be very slow to respond to such stimuli, thus exploring the visual world differently than healthy persons (Heilman et al., 1987; Mark et al., 1988; Làdavas et al., 1993; Rusconi et al., 2002; Olk and Harvey, 2006). Patients with an injury to the right brain hemisphere may thus not orient towards stimuli presented on their left side. Eye tracking studies have shown that patients exhibit a strong deviation of exploratory gaze towards one side of space – for example, the right side of space after an injury to the right brain hemisphere – although in principle being able to move their eyes towards the other, left side (Karnath and Fetter, 1995; Karnath et al., 1998; Olk et al., 2002). The registration of eye movements has also proven to be a very sensitive method to demonstrate where patients allocate attention, to reveal deficits that may not be apparent on standard neuropsychological tests and to illustrate differences in performance between patients (Harvey et al., 2002).

A good example of how measuring eye movements can considerably affect understanding the neural bases of mental processes is the discussion concerning the role of the amygdala in the processing of fear-relevant data. It is widely assumed that the amygdala,

a particular brain structure, part of the so-called limbic system, is critical for processing emotions, specifically fear and anxiety. LeDoux (for example, 1996) asserted in studies on rats the importance of the amygdala for emotional processes. However, while it is possible to experiment on rats – for example, destroying a particular brain region – as LeDoux has done, such research is not possible on humans. This means that it is not always clear to what degree animal research can be translated to understanding human psychological processes. It was thus with particular interest that the scientific community learned in an article in the well-esteemed journal *Nature*, that the research group of Antonio Damasio in Iowa had tested a patient, S.M., regarding her capacity to recognize emotions in photos of faces. S.M. suffers from an exceedingly rare condition in which the amygdalae on both sides of the brain have been destroyed (Adolphs et al., 1994). Using standardized pictures, developed by Ekman and Friesen (1976), Adolphs and his colleagues described a specific deficit of S.M. to identify fearful expressions. Independent of the question of how specific the deficits were for fearful faces (there had been the notion that the pattern of data could also support a more general pattern of recognition deficits – S.M. might have difficulties recognizing negative expressions in general, but more pronouncedly so for fear), a recent study by the authors of the original study (Adolphs et al., 2005) changed the interpretation of the original data completely and dramatically. In the context of investigating a different question, the authors had recorded eye movements and noticed that S.M. would not look at the upper part of faces spontaneously. However, in particular, the eye region provides important cues to the identification of fear expressions. Thus, it is not that the damage to a brain region caused a failure to interpret a particular facial configuration in a particular way, but instead the damage influenced the visual exploration – a consequence then was a deficit in identifying fear expression. Causing the patient to look at the

upper part of the picture either by explicitly telling her or by pulling the image of the faces down to the lower part of her visual field led to a normal performance in the identification of fear. Thus, measuring eye movements can have a dramatic impact on interpretation of certain behaviors.

CONCLUDING REMARKS

Modern eye tracking technology provides user- and participant-friendly as well as affordable eye trackers and it allows us to investigate a wealth of research questions inside and outside the laboratory – basic or applied – with great spatial and temporal accuracy. There are thus many reasons why eye tracking could be of interest to researchers from different disciplines. The questions that are investigated stem from many different areas such as understanding eye movement control, reading, scene perception, neuropsychology, brain mechanisms, advertising, or human factors. Eye movement patterns provide information on where persons are attending. So taking research on advertising as an example, information about dwell times on an ad or areas of an ad will provide information about how much attention it attracts. Surely, this information is useful for design purposes and the evaluation of advertising campaigns. To what degree visual attention to details of an ad translates into consumer behavior is an open question. Here one of the problems is that much of the applied research done by commercial enterprises is not available for scientific scrutiny, but remains proprietary.

The set-up of specific studies does require programming and technical expertise, knowledge with respect to the planning of research studies and the analysis of the obtained data sets. However, a number of vendors sell very powerful systems, some of which are completely integrated into large monitors and include user-friendly software for the design and analysis of experiments. Clearly, these

methods are getting more and more accessible. Detailed information on the different devices is available from manufacturers of eye trackers (see also Duchowski, 2007), helping those interested in adding the study of eye movements to their methodological toolbox. A potential drawback could be that only one person can be tested at a time and some types of analysis might be time-consuming. However, this is also true for other types of measures and does not constitute a unique issue for eye tracking. The combination of eye tracking technology with other current methodologies such as electromyography opens new, exciting ways of studying the processes that underlie our exploration of the visual world.

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