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USING EYE TRACKING TO REFRESH RESEARCH METHODOLOGIES

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ABSTRACT. Recent literature points to the emergence of a promising methodology that can be used in a wide range of research domains, eye tracking. This paper summarizes the most frequently used indices used in eye tracking and what they relate to in terms of mental processes. Since there is a scarcity of studies that outline and focus on the advantages and disadvantages of employing eye tracking, this overview comprises the main benefits and costs of implementation of this new methodology. Also, there is a slight focus on a comparison to Dot probe task when discussing the advantages and disadvantages. In addition, the paper mentions several applications which stand to highlight the possibilities in using eye tracking. Lastly, there is a summary regarding procedural aspects concerning the type of stimuli, exposure time and input frequency acquirement.

Keywords: eye-tracking, eye movements, fixation, saccades, pupil dilation, attentional processes, attentional bias, emotion processing

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ZUSAMMENFASSUNG. Die Fachliteratur aus den letzten Jahren zeigt die Entwicklung einer neuen und vielversprechenden Methode, die in verschiedenen Forschungsbereichen eingesetzt werden kann, nämlich das Eye-Tracking (Augenverfolgung). Dieser Artikel beschreibt kurz die Hinweise, die in der Eye-Tracking-Methode verwendet sind und wie sie sich auf die kognitiven Prozesse beziehen. Da es relativ wenige Studien, die sich auf die Vor-und Nachteile der Anwendung dieser Methode konzentrieren, gibt, fasst diese Synthese die wichtigsten Vorteile und die anfallenden Umsetzungskosten dieser neuen Methode um. Wir möchten auch Vergleichen mit der Dotprobe-Aufgabe, wenn es sich um die Vor- und Nachteile handelt. Außerdem erwähnt dieser Aufsatz einige theoretische Anwendungen, die die angeblichen Verwendungsmöglichkeiten dieser neuen Methode hervorheben. Am Ende befindet sich eine Zusammenfassung der Aspekte des Verfahrens, d.h. die Art der Reize, der Dauer der Exposition und die Häufigkeit der Sammlung der Informationen, die in den beschriebenen Hinweisen verarbeitet werden.

Schlüsselwörter: Eye-Tracking, Augenbewegungen, Fixationen, Blicksakkaden, Pupillenerweiterung, Aufmerksamkeitsverfahren, Aufmerksamkeitsverfahren, Aufmerksamkeitsverzerrung, emotionale Verarbeitung

Introduction

An overview of studies using eye tracking reflects the evolution of this technique since its debut, in all fields of research that use it. It has become one of the best non-invasive procedures used to this day, not only in psychology but in a variety of domains that require knowledge about the gaze of an individual. Preeminently, it has been used in studies looking at human-computer interaction (Jacob & Karn, 2003), marketing and advertising (Wedel & Pieters, 2008), neuroscience (Duchowski, 2002), animal behavior (Mitchell, Sundberg, & Reynolds, 2007), developmental, cognitive and clinical psychology (Duque & Vazquez, 2015; Matsuda, Okanoya, & Myowa-Yamakoshi, 2013; Spering & Carrasco, 2015) and even geography (Kiefer, Giannopoulos, Raubal, & Duchowski, 2017). Eye movements captured by the eye tracker are used to get a better understanding of how the participant visually processes a certain stimulus, that is, where he looks and the duration of the gaze (Granka, Joachims, & Gay, 2004). In addition, ocular movements enable one to determine a pattern in stimuli processing, providing a dynamic track of the directionality of attention in a visual display and of the amount of processing applied to a particular target (Poole & Ball, 2006).

The aim of this paper is to examine some of the aspects that make eye tracking suitable for answering certain research questions, especially in the field of psychology, with an emphasis on emotional processing, attention and other cognitive processes. Its purpose is to briefly describe the metrics involved in research for a better understanding of their use, while outlying some of the advantages of incorporating new methodology such as this. This overview also intends to draw attention to a part of the applications of eye tracking, as to highlight the possibility of adding knowledge to previously studied topics and the ability to gain insights on new subjects.

Specific eye tracking measurements / indices

In psychological research, eye tracking can be achieved through different hardware options. There are several ways researchers can measure eye movements: contact lens-based, electrooculogram-based and video based (Lupu & Ungureanu, 2013). Most commonly, because of its ease and comfortability, studies have used the video-based eye trackers, capturing the gaze as the participant looks at a stimulus that is presented on a screen in front of them.

The principle of origin behind using eye tracking in research is the eye-mind hypothesis (Just & Carpenter, 1976, p. 471), which states that "the locus of the eye fixations reflects what is being internally processed". To be able to infer certain findings, one must know the key measures/ indices specific to this type of procedure. These provide additional information about the processed stimulus and are all related to the movement of the eye, namely, fixations, saccades, pupil dilation, scan paths, gaze and blink rate (Granka et al., 2004).

A more detailed account of these measures involves splitting them into categories. As such, there are three scales: *temporal, spatial and count*. The *temporal* scale includes measures such as: total fixation duration, gaze duration, average fixation duration, time of first fixation, revisited fixation duration, proportion of fixation duration. Measures included in the *spatial* scale are fixation position and fixation sequence, while the ones included in the *count* scale are fixation count, average fixation count and revisited fixation count. Typically, measures are aggregated in what researchers call *areas of interest* (AOIs) and are further used in comparisons and more complex analyses (Nguyen, Richards, El-Nasr, & Isaacowitz, 2015). Some authors say that these measures are rather problematic to interpret, because there is difficulty in establishing the level of processing involved. Thus, without knowing the (superficial vs. deeper) level of information processing, it is hard to determine the nature of this processing (Xue, Quan, Li, Yue, & Zhang, 2017). Still, most commonly research has shown particular interest in fixations and saccades, either aggregated in the form of a scan path or independent (Jacob & Karn, 2003; Poole & Ball, 2006). Fixations (i.e. the time spent on a certain area of the stimulus) are related to the amount of information processed and acquired, the interest raised by the target, its complexity or the participant's difficulty to encode it (Poole & Ball, 2006). Under the assumption that fixating an object, or an area means paying attention to it, fixation frequency reflects the importance of that object or area, while the duration of a fixation indicates the level of difficulty in selecting information from the stimulus (Jacob & Karn, 2003). On average, a fixation lasts 250 ms, but this measure ranges from 100 ms to 500 ms, depending on the viewed material. Saccades, the movement between fixations, are relevant as well since they indicate the difficulty of processing, especially if they are made backwards (Poole & Ball, 2006). Moreover, these movements reflect shifts in attention that can be either controlled or involuntary, indicating either higher order cognitive abilities or reflexive orienting (Eckstein, Guerra-Carrillo, Miller Singley, & Bunge, 2017). Saccades also vary in duration, depending on the stimulus, ranging from 30 ms in a reading task to 50 ms in a scene viewing task. Other complementary measures include inter featural saccade ratio, which indicates the level of generality in information processing (i.e., a higher ratio is indicative of more global processing style) and feature gaze duration, that is, the mean time spent looking at the features (longer time meaning more local processing).

Besides these frequently utilized measures, new research points to the emergence of other two parameters: pupil diameter and spontaneous blink rate. These parameters are not at all novel, but their measurement has been conducted manually or with other custom-made devices (Eckstein et al., 2016). However, eye trackers make these data easy to obtain and allow automated processing through specific software. Changes in pupil dilation reflect cognitive changes, according to Kahneman (1973, 2011), thus being the best index of attentional effort reflecting the usage of mental energy. Nonetheless, pupil dilation is also indicative of autonomic activity (Samuels & Szabadi, 2008). Autonomous processes include task-evoked changes indicative of mental activity (e.g. Sirois & Brisson, 2014) or arousal (Samuels & Szabadi, 2008), dilation being present throughout the period of cognitive load (Granholm, Asarnow, Sarkin, & Dykes, 1996). Moreover, pupillary dilation reflects the interplay between autonomous activity and conscious processing, especially under uncertainty (e.g. Preuschoff, Marius't Hart, & Einhauser, 2011). Not only this, but pupillary measures have been found to predict how much new information is used when readjusting existing beliefs (Nassar et al., 2012). Besides task-related arousal, psychologists have also studied pupillary responses during exposure to pleasing stimuli, such as erotic pictures (e.g. Rieger & Savin-Williams, 2012) or even music (e.g. Laeng, Eidet, Sulutvedt, & Panksepp, 2016). These studies usually look at interindividual differences, sex differences or intraindividual variability when exposed to a variety of pleasing stimuli. On the other hand, spontaneous blink rate has been regarded as a proxy of dopaminergic activity, reflecting functions like cognitive control and learning (e.g. van der Schaaf et al., 2014; Westbrook & Braver, 2016).

Advantages of using eye tracking in research

Currently, using the eye tracker presents several advantages, which places it among researchers' favorite methods. Compared to the input one participant can give using a keypad or a mouse, eye movement is distinctly faster and does not require training in advance (Sibert & Jacob, 2000). One task used in the study of attentional biases and emotion processing is the Dot probe task, which involves a quick motor response from the participant after being exposed to a target for less than one second. However, reaction time variables are vulnerable to the confounding effect of delayed response execution due to slowing or “freezing” (McNaughton & Corr, 2004), limitation that cannot be resolved by modifying the task but only by additional methodology (i.e., fMRI, ERP etc.) (Armstrong & Olatunji, 2012). For example, in the case of threatening stimuli, the presence of threat does not affect eye movement by increasing its latency, however response time in such case appeared to be affected (Nummenmaa, Hyönä, & Calvo, 2006). Moreover, eye tracking provides the researcher with a real-time assessment of ocular movements, which makes it suitable for studies in the field of attention, brain functioning, emotion processing, reading or reasoning (Mele & Federici, 2012). By continuously recording the eye gaze, it can be effectively used to measure selective attention (Awh, Armstrong, & Moore, 2006; Weiser, Pauli, Weyes, Alpers, & Muhlberger, 2008) Bradley and Mogg (2005) state that attentional biases have a greater possibility of being observed if the procedure allows for an elaborate processing, supporting Eizenman and colleagues (2003) affirmation that some aspects of attention are better measured by extending the stimulus presentation time. Nevertheless, allowing more time for processing may help overcome certain limiting conclusions, especially in psychopathology research. For example, Bradley and colleagues (1997) found that dysphoric participants showed no mood congruent bias when the stimuli were briefly presented (14 ms), which lead Sanchez and colleagues (2013) to hypothesize that a more extended exposure time (i.e. at least 1000 ms) may result in observing a bias in the case of depressed participants.

While the Dot probe task has been the subject of constant innovation, the main limitation is that it provides only a snapshot of the processing some researchers are interested in measuring; nevertheless, the eye tracking methodology manages to overcome such disadvantage. In essence, eye tracking enables the assessment of more than two or three stimulus durations without overworking the participant, thus yielding a better picture of sustained information processing (Kellough, Beevers, Ellis, & Wells, 2008).

In terms of overt and covert attention, the eye tracking methodology provides a more comprehensive picture of these processes, as eye movements are more proximal to them than manual key presses. This type of technology allows direct measurement of overt attention, while informing about eye movements that have a closer relation with covert attention at the same time (Armstrong & Olatunji, 2012). One major strength of eye tracking is that it enables the assessment of early as well as later stages of attentional processing (that is, vigilance and avoidance), especially in the case of biases (Bangee, Harris, Bridges, Rotenberg, & Qualter, 2013). Attentional processes studied with this type of technology provide answers either to questions regarding these processes themselves or to queries pertaining to emotion regulation strategies. As such, eye tracking has been used both in psychopathological studies (e.g. anxiety and emotion regulation, Calvo & Avero, 2002) and in studies using non-pathological samples, illustrating the mechanisms underlying individual differences inherent to emotion regulation (e.g. Isaacowitz, 2005, 2006).

Another advantage of using eye tracking in psychological research is its suitability for instances when there are some communication barriers, which interfere with the ability to give instructions or receive answers. Such cases are studies with infants (e.g. Hunnius, de Wit, & Hofsten, 2011) or with individuals having certain disorders, for instance autism (Wagner, Hirsch, Vogel-Farley, & Nelson, 2013) or deafness (Emmorey, Thompson, & Colvin, 2008). For example, an interesting finding has sprung with the use of eye tracking on infant samples. It has been observed that babies older than 3 months of age process moving faces distinctively from static faces, that is dynamic faces processing shows a shift from the eye to the mouth region, whereas when looking at static faces, they focus on the eye region predominantly (Lewkowicz & Hasen-Tift, 2012). On the other hand, eye tracking and dynamic stimuli have also been used to observe and measure deficits in processing in the case of autistic children. For example, Hanley and colleagues (2012) found that children pertaining to the autistic spectrum disorder are characterized by diminished attention to salient facial cues (especially when using dynamic stimuli). Moreover, eye tracking can serve as a tool for neuro-disabled people who still have visual function. In this case, the gaze helps in selecting words and options on a screen. This technology not only helps in research but also in day-to-day life communication, by facilitating socialization and raising the level of independency (Lupu & Ungureanu, 2013).

Disadvantages of using eye tracking in research

One of the disadvantages in using eye tracking technology is its elevated cost, compared to more traditional methods, like the Dot probe paradigm. Also, the Dot probe can be used on a single computer, while the device used in eye tracking requires sometimes multiple operating systems and a complex hardware set up. More disadvantages were encountered in the past when using eye tracking, because the apparatus was difficult to operate, the participant needed to be physically constrained to the whole system, and the analysis of the data was reduced only to few parameters elaborately aggregated by the researcher (Jacob & Karn, 2002). Nowadays, advances in technology brought ease of use, portability and dedicated software for data analysis, nevertheless for a higher price.

Applications

Introducing new procedures and technology yields data that succeeds in complementing existing research or bring into question novel hypotheses. For instance, studies looking at categorization benefited from using eye tracking technology in learning how such classification is performed, both by adults and children. Quinn and colleagues (2007) reported that participants looked at an animal's head first when differentiating between species. Therefore, observing the gaze pattern offers novel insights on well-studied cognitive processing. Being able to use new instruments, such as eye tracking devices, unlocks the possibility of testing new research questions. Illustrating this is the study of visual exploration in the context of remembering autobiographical memories, which can provide a more ecological and reliable description of physiological activity occurring during the retrieval (El Haj, Nandrino, Antoine, Boucart, & Lenoble, 2017). El Haj and colleagues (2014) looked at eye movements during autobiographical retrieval and found that fixations are quite few, but saccades predominate in terms of duration and amplitude. They suggested that this type of recall triggers the same activity as visual imagery, fitting the assumption that memories do come to be relieved in the form of images (Conway, 2009).

Regarding decision making, eye tracking not only offers a wider perspective on these cognitive processes, but also enriches multidisciplinary research, integrating for example spatial perception. It can be used both indoors, in perceiving maps (Netzel et al., 2017), or outdoors to assess orientation (Kiefer, Giannopoulos, & Raubal, 2014) or even visual-motor coordination of drivers (Sun et al., 2016). Thus, this type of knowledge helps in aggregating models that describe how individuals reason about space or even in designing maps (Kiefer, Giannopoulos, Raubal, & Duchowski, 2017). Not only geography intersects with the field of reasoning, but also marketing, especially when it comes to choosing food (Graham, Orquin, & Visschers, 2012). This domain utilizes mainly eye tracking glasses, but there are also studies done in a laboratory setting. What the researchers want to observe is mainly how the labels, packaging and other information regarding the food influences the customer's decision (Mawad, Trias, Gimenez, Maiche, & Ares, 2015).

As mentioned earlier, eye tracking aids in overcoming standstills in certain research areas, such as psychopathology. Researchers focusing on attentional biases in depression theorized that the bias for mood-congruent stimuli occurs in later stages of processing, rather than in the orienting phase as in the case of anxiety related biases (Duque & Vazquez, 2014; Kellough, Beevers, Ellis, & Wells, 2008). However, without a methodology that allowed for longer stimulus exposure, little was known about the chronological development of attentional biases in depression, whereas knowledge about the constituent elements was still scarce (Armstrong & Olantuji, 2012). Since the inclusion of eye tracking in this field of research, issues like these have been clarified. That is, presenting the stimulus for a longer duration has made it possible for researchers to establish a time course of the attentional bias in depressed participants (Sanchez et al., 2013), and also to assess distinct components of visual attention (Duque & Vazquez, 2014). On the other hand, shorter exposure time is preferred when studying anxiety related biases, in part because increased awareness to the threatening stimuli manifests in the orienting phase (Mogg & Bradley, 2005). Still, the phenomenon has been studied with eye tracking devices that allowed for a conversion of the Dot probe task (Burris, Barry- Anwar, & Rivera, 2017). The button press has been replaced with eye tracking to measure not the latency to press the button, but the latency to fixate the probe, which increases the accuracy of the task (Price et al., 2014). As such, eye tracking taps more into the neural and attentional mechanism of biases in such disorders. Biases are studied with eye tracking not only in the case of emotional dysfunctionality, but also in disordered eating. People diagnosed with an eating disorder have been found to present attentional biases towards other people's display of emotion, like angry faces (e.g. Harrison et al., 2010; Kanakam et al., 2013), towards food cues (e.g. Giel et al., 2011; Schag et al., 2013) and even towards their own body image (e.g. Jansen, Nederkoorn, & Mulkens, 2004).

Besides aforementioned disorders, eye movements may serve in detecting early signs of cognitive pathology such as dementia or Alzheimer's disease, where the smooth pursuit of the gaze is impaired (Vidal, Turner, Bulling, & Gellersen, 2012). Neurological research showed that eye tracking has an important role, especially in improving knowledge about some disorders. For example, eye coordination deficits may be indicative of Parkinson's disease, Wilson's disease or multiple system atrophy (Gorges, Pinkhardt, & Kassubek, 2014). Facial emotion recognition is also studied in this field, for example in the case of epileptic patients, who are well known to present deficits in processing emotion. Hence, instruments measuring eye movement are useful in assessing how these deficits manifest (Gomez-Ibanez, Urrestarazu, & Viteri, 2014). Eye movements also reflect the progression of a disorder such as Huntington's disease (Georges et al., 2014; Veneri, Federico, & Rufa, 2014), or multiple sclerosis (Prasad & Galetta, 2010; Vidal et al., 2012). Eye tracking in these instances can be useful in monitoring the evolution of the problem, as well as the efficiency of the treatment.

Procedural aspects

There is no universal way researchers use this type of methodology. The choice of apparatus is dependent on the examined hypotheses, some studies needing participants in the field while others want to use a laboratory setting. This choice also impacts the type of procedure that is followed, stimuli ranging from static to dynamic, animations versus real faces and real-life interactions versus stimuli viewed on a monitor. When the paradigm does not study emotion processing or regulation, the stimuli may consist of maps, pictures of food, or even of the self. In the study of attentional biases, emotional processing and regulation, the most prevalent type of stimulus used is a picture of an emotional expression, which is either comprised in a largely used database (i.e., International Affective Pictures System, Lang, Bradley, & Cuthbert, 1999) novel (Chien, 2011) or computer generated (Wieser et al., 2008). Compared to words, scenes and pictures carry more affective information and are preferred in studies regarding attentional processes (Glaser & Glaser, 1989). Nevertheless, the presentation of these pictures differs across studies, variations occurring in the picture dimension, the number of trials presented, ranging from as little as 16 (Owens et al., 2017) to as much as 210 (Jang, Kim, Kim, Lee, & Choi, 2016), as well as in the presentation time, which can be as low as 40 ms (Matsuda, Okanoya, & Myowa-Yamakoshi, 2013) or as high as 8000 ms, with a 1000 ms (Wadlinger & Isaacowitz, 2008) or even 20 s (Owens et al., 2017) fixation cue. There is also variance in the split of the stimulus presentation. Usually there is a period (up to 1000 ms) for the pre-trial, the actual stimulus presentation time (variable duration), and an end or transition period (up to 2500 ms) (e.g. Yrttiaho, Niehaus, Thomas, &

Leppanen, 2017). Occasionally, certain procedures use a random stimulus presentation (up to 2000 ms) in between pre-trial and the actual stimulus display (Duque & Vasquez, 2015; Yrttiaho et al., 2017).

Even though the majority of the studies in the field of emotion and cognition make use of pictures as stimuli, this is not to say that only images are used in this type of psychological research. For example, some researchers use short clips portraying emotion expression to catch a more dynamic representation of processing (e.g. Bal et al., 2010), erotic clips (Carvalho, Pereira, Barreto, & Nobre, 2016), or even other individuals' actions like jumping athletes to investigate attentional effort (Moran et al., 2016). Also, infant studies employ the procedure using real life stimuli, that is a person acting different emotions or behaviors (Gredeback, Johnson, & von Hofsten, 2010; Urakawa, Tokamoto, Ishikawa, Ono, & Nishijo, 2015).

Another aspect to consider, which is not always reported but is nevertheless important, is the sampling rate of the eye tracker. Explicitly, sampling rate represents the frequency at which eye data is collected, measured in hertz (Hz). Due to using a variety of eye trackers, a certain variability in sampling rates can be found. Most frequently, eye trackers have a sampling rate of 60 Hz (e.g. Owens et al., 2017), although lower and higher thresholds can be met, ranging from 30 Hz (Domes et al., 2009) to 1250 Hz (Schmid, Mast, Bombari, Mast, & Lobmaier, 2011). This frequency influences the amount of data found in the software output, as well as the computation methods and statistical analyses. For example, fixation times (1.5 s) can be split into three sections (500 ms, 1000 ms and 1500 ms) to be further analyzed (e.g. Jang, Kim, Kim, Lee, & Choi, 2016), but there is no universal procedure for computation and each study adapts this procedure to fit its objectives and hypotheses.

Conclusion

The present paper provides a thorough review of eye tracking technology use. Though not exhaustive, it advocates for the great utility of eye tracking in several fields of research, which makes it easy to believe that the usefulness of this instrument has yet to reach its limits. Tracking the eye movements refreshes existing studies on one hand and stimulates towards new discoveries on the other hand. Current literature shows that eye tracking has become a tool frequently used in infant studies, mainly looking at information processing mechanisms. Nevertheless, analyzing eye movements can help to early diagnose disorders such as autism, considering that this methodology can be implemented at any age or at any level of functioning. Moreover, eye tracking shows great potential in studies looking at maternal behaviors in relation to infants or toddlers. It can be used to investigate mothers' gaze in moments of child distress and also during attempts of emotion regulation. This could help gaining more insight into mothers' processing of unpleasant situations and their parenting behaviors associated with these situations. Additionally, there is little research regarding gaze tracking in adult personality disorders. Having in mind that personality disorders are linked to specific cognitive styles, it can be of great importance understanding how these influences visual processing. There has also been a steep increase in popularity for virtual reality systems, which have eye tracking features incorporated. Research can benefit from including such systems in hypotheses testing, given the richness of stimulation they provide by immersing the participant into a virtual world. Thus, virtual reality systems seem promising methodologies for the near future.

In light of the fact that eye tracking is versatile and because it can be implemented through a variety of methodologies, the choice of apparatus depends on the researchers' objectives and available resources. Eye trackers have brought important contributions, regardless of the implemented paradigm, in the theoretical, methodological and practical aspects of research. There is no doubt that this type of technology comes with its own set of limitations, nevertheless the benefits of using it outweigh by far the costs. From improving old procedures to creating new ways of testing and assessing psychological phenomena, eye tracking seems to have a steep evolution that will only help bring more knowledge about the human mind.

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REFERENCES

Armstrong, T., & Olatunji, B.O. (2012). Eye tracking of attention in the affective disorders: A meta-analytic review and synthesis. *Clinical psychology review*, *32*(8), 704-723.

Awh, E., Armstrong, K.M., & Moore, T. (2006). Visual and oculomotor selection: links, causes and implications for spatial attention. *Trends in cognitive sciences*, *10*(3), 124-130.

Bal, E., Harden, E., Lamb, D., Van Hecke, A.V., Denver, J.W., & Porges, S.W. (2010). Emotion recognition in children with autism spectrum disorders: Relations to eye gaze and autonomic state. *Journal of autism and developmental disorders*, *40*(3), 358-370.

Bangee, M., Harris, R.A., Bridges, N., Rotenberg, K.J., & Qualter, P. (2014). Loneliness and attention to social threat in young adults: Findings from an eye tracker study. *Personality and Individual Differences*, *63*, 16-23.

Bradley, M.M., Cuthbert, B.N., & Lang, P.J. (1999). Affect and the startle reflex. *Startle modification: Implications for neuroscience, cognitive science, and clinical science*, 157-183.

Bradley, B.P., Mogg, K., & Lee, S.C. (1997). Attentional biases for negative information in induced and naturally occurring dysphoria. *Behaviour research and therapy*, *35*(10), 911-927.

Burris, J.L., Barry-Anwar, R.A., & Rivera, S.M. (2017). An eye tracking investigation of attentional biases towards affect in young children. *Developmental psychology*, *53*(8), 1418.

Calvo, M.G., & Avero, P. (2002). Eye movement assessment of emotional processing in anxiety. *Emotion*, *2*(2), 105.

Carvalho, J., Pereira, R., Barreto, D., & Nobre, P.J. (2016). The Effects of Positive Versus Negative Mood States on Attentional Processes During Exposure to Erotica. *Archives of sexual behavior*, 1-10.

Chien, S.H.L. (2011). No more top-heavy bias: Infants and adults prefer upright faces but not top-heavy geometric or face-like patterns. *Journal of Vision*, *11*(6), 13-13.

Conway, M.A. (2009). Episodic memories. *Neuropsychologia*, *47*(11), 2305-2313.

Domes, G., Lischke, A., Berger, C., Grossmann, A., Hauenstein, K., Heinrichs, M., & Herpertz, S.C. (2010). Effects of intranasal oxytocin on emotional face processing in women. *Psychoneuroendocrinology*, *35*(1), 83-93.

Duchowski, A.T. (2002). A breadth-first survey of eye-tracking applications. *Behavior Research Methods, Instruments, & Computers*, *34*(4), 455-470.

Duque, A., & Vázquez, C. (2015). Double attention bias for positive and negative emotional faces in clinical depression: Evidence from an eye-tracking study. *Journal of Behavior Therapy and Experimental Psychiatry*, *46*, 107-114.

Eckstein, M.K., Guerra-Carrillo, B., Singley, A.T.M., & Bunge, S.A. (2016). Beyond eye gaze: What else can eyetracking reveal about cognition and cognitive development? *Developmental cognitive neuroscience*.

Eizenman, M., Lawrence, H. Y., Grupp, L., Eizenman, E., Ellenbogen, M., Gemar, M., & Levitan, R. D. (2003). A naturalistic visual scanning approach to assess selective attention in major depressive disorder. *Psychiatry research*, *118*(2), 117-128.

El Haj, M., Delerue, C., Omigie, D., Antoine, P., Nandrino, J.L., & Boucart, M. (2014). Autobiographical recall triggers visual exploration. *Journal of Eye Movement Research*, *7*(5).

El Haj, M., Nandrino, J.L., Antoine, P., Boucart, M., & Lenoble, Q. (2017). Eye movement during retrieval of emotional autobiographical memories. *Acta Psychologica*, *174*, 54-58.

Emmorey, K., Thompson, R., & Colvin, R. (2008). Eye gaze during comprehension of American Sign Language by native and beginning signers. *Journal of Deaf Studies and Deaf Education*, *14*(2), 237-243.

Giel, K.E., Friederich, H.C., Teufel, M., Hautzinger, M., Enck, P., & Zipfel, S. (2011). Attentional processing of food pictures in individuals with anorexia nervosa—An eye-tracking study. *Biological Psychiatry*, *69*(7), 661-667.

Glaser, W.R., & Glaser, M.O. (1989). Context effects in Stroop-like word and picture processing. *Journal of Experimental Psychology: General*, *118*(1), 13.

Gorges, M., Pinkhardt, E.H., & Kassubek, J. (2014). Alterations of eye movement control in neurodegenerative movement disorders. *Journal of ophthalmology*, *2014*.

Gomez-Ibañez, A., Urrestarazu, E., & Viteri, C. (2014). Recognition of facial emotions and identity in patients with mesial temporal lobe and idiopathic generalized epilepsy: an eye-tracking study. *Seizure*, *23*(10), 892-898.

Graham, D.J., Orquin, J.L., & Visschers, V.H. (2012). Eye tracking and nutrition label use: A review of the literature and recommendations for label enhancement. *Food Policy*, *37*(4), 378-382.

Granholm, E., Asarnow, R.F., Sarkin, A.J., & Dykes, K.L. (1996). Pupillary responses index cognitive resource limitations. *Psychophysiology*, *33*(4), 457-461.

Granka, L.A., Joachims, T., & Gay, G. (2004, July). Eye-tracking analysis of user behavior in WWW search. In *Proceedings of the 27th annual international ACM SIGIR conference on Research and development in information retrieval* (pp. 478-479). ACM.

Gredebäck, G., Fikke, L., & Melinder, A. (2010). The development of joint visual attention: a longitudinal study of gaze following during interactions with mothers and strangers. *Developmental science*, *13*(6), 839-848.

Harrison, A., Sullivan, S., Tchanturia, K., & Treasure, J. (2010). Emotional functioning in eating disorders: attentional bias, emotion recognition and emotion regulation. *Psychological medicine*, *40*(11), 1887-1897.

Hanley, M., McPhillips, M., Mulhern, G., & Riby, D.M. (2013). Spontaneous attention to faces in Asperger syndrome using ecologically valid static stimuli. *Autism*, *17*(6), 754-761.

Hunnius, S., de Wit, T.C., Vrins, S., & von Hofsten, C. (2011). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition and Emotion*, *25*(2), 193-205.

Isaacowitz, D.M. (2005). The gaze of the optimist. *Personality and social psychology bulletin*, *31*(3), 407-415.

Isaacowitz, D.M. (2006). Motivated gaze: The view from the gazer. *Current Directions in Psychological Science*, *15*(2), 68-72.

Jacob, R.J., & Karn, K.S. (2003). Eye tracking in human-computer interaction and usability research: Ready to deliver the promises. *Mind*, *2*(3), 4.

Jang, S.K., Kim, S., Kim, C.Y., Lee, H.S., & Choi, K.H. (2016). Attentional processing of emotional faces in schizophrenia: Evidence from eye tracking. *Journal of abnormal psychology*, *125*(7), 894.

Jansen, A., Nederkoorn, C., & Mulkens, S. (2005). Selective visual attention for ugly and beautiful body parts in eating disorders. *Behavior research and therapy*, *43*(2), 183-196.

Just, M.A., & Carpenter, P.A. (1976). Eye fixations and cognitive processes. *Cognitive psychology*, *8*(4), 441-480.

Kahneman, D. (1973). *Attention and effort* (Vol. 1063). Englewood Cliffs, NJ: Prentice-Hall.

Kahneman, D. (2011). *Thinking, fast and slow*. Macmillan.

Kanakam, N., Krug, I., Raoult, C., Collier, D., & Treasure, J. (2013). Social and emotional processing as a behavioral endophenotype in eating disorders: a pilot investigation in twins. *European Eating Disorders Review*, *21*(4), 294-307.

Kellough, J.L., Beevers, C.G., Ellis, A.J., & Wells, T.T. (2008). Time course of selective attention in clinically depressed young adults: An eye tracking study. *Behavior research and therapy*, *46*(11), 1238-1243.

Kiefer, P., Giannopoulos, I., & Raubal, M. (2014). Where am I? Investigating map matching during self-localization with mobile eye tracking in an urban environment. *Transactions in GIS*, *18*(5), 660-686.

Kiefer, P., Giannopoulos, I., Raubal, M., & Duchowski, A. (2017). Eye tracking for spatial research: Cognition, computation, challenges. *Spatial Cognition & Computation*, *17*(1-2), 1-19.

Laeng, B., Eidet, L.M., Sulutvedt, U., & Panksepp, J. (2016). Music chills: The eye pupil as a mirror to music's soul. *Consciousness and cognition*, *44*, 161-178.

Lewkowicz, D.J., & Hansen-Tift, A.M. (2012). Infants deploy selective attention to the mouth of a talking face when learning speech. *Proceedings of the National Academy of Sciences*, *109*(5), 1431-1436.

Lupu, R.G., & Ungureanu, F. (2013). A survey of eye tracking methods and applications. *Bul Inst Polit Iasi*, 71-86.

Matsuda, Y.T., Okanoya, K., & Myowa-Yamakoshi, M. (2013). Shyness in early infancy: approach-avoidance conflicts in temperament and hypersensitivity to eyes during initial gazes to faces. *PloS one*, *8*(6), e65476.

Mawad, F., Trías, M., Giménez, A., Maiche, A., & Ares, G. (2015). Influence of cognitive style on information processing and selection of yogurt labels: Insights from an eye-tracking study. *Food Research International*, *74*, 1-9.

McNaughton, N., & Corr, P.J. (2004). A two-dimensional neuropsychology of defense: fear/anxiety and defensive distance. *Neuroscience & Biobehavioral Reviews*, *28*(3), 285-305.

Mele, M.L., & Federici, S. (2012). Gaze and eye-tracking solutions for psychological research. *Cognitive processing*, *13*(1), 261-265.

Mitchell, J.F., Sundberg, K.A., & Reynolds, J.H. (2007). Differential attention-dependent response modulation across cell classes in macaque visual area V4. *Neuron*, *55*(1), 131-141.

Mogg, K., & Bradley, B.P. (2005). Attentional bias in generalized anxiety disorder versus depressive disorder. *Cognitive therapy and research*, *29*(1), 29-45.

Moran, A., Quinn, A., Campbell, M., Rooney, B., Brady, N., & Burke, C. (2016). Using pupillometry to evaluate attentional effort in quiet eye: A preliminary investigation. *Sport, Exercise, and Performance Psychology*, *5*(4), 365.

Nassar, M.R., Rumsey, K.M., Wilson, R.C., Parikh, K., Heasly, B., & Gold, J.I. (2012). Rational regulation of learning dynamics by pupil-linked arousal systems. *Nature neuroscience*, *15*(7), 1040-1046.

Netzel, R., Ohlhausen, B., Kurzhals, K., Woods, R., Burch, M., & Weiskopf, D. (2017). User performance and reading strategies for metro maps: An eye tracking study. *Spatial Cognition & Computation*, *17*(1-2), 39-64.

Nguyen, T.H.D., Richards, M., El-Nasr, M.S., & Isaacowitz, D.M. (2015). A Visual Analytic System for Comparing Attention Patterns in Eye-Tracking Data. *Eye Tracking and Visualization (Proceedings of ETVIS 2015)*.

Nummenmaa, L., Hyönä, J., & Calvo, M.G. (2006). Eye movement assessment of selective attentional capture by emotional pictures. *Emotion*, *6*(2), 257-268.

Owens, M., Harrison, A.J., Burkhouse, K.L., McGeary, J.E., Knopik, V.S., Palmer, R.H., & Gibb, B.E. (2016). Eye tracking indices of attentional bias in children of depressed mothers: Polygenic influences help to clarify previous mixed findings. *Development and psychopathology*, *28*(2), 385-397.

Poole, A., & Ball, L.J. (2006). Eye tracking in HCI and usability research. *Encyclopedia of human computer interaction*, *1*, 211-219.

Prasad, S., & Galetta, S.L. (2010). Eye movement abnormalities in multiple sclerosis. *Neurologic clinics*, *28*(3), 641-655.

Preuschoff, K., Marius't Hart, B., & Einhäuser, W. (2011). Pupil dilation signals surprise: Evidence for noradrenaline's role in decision making. *Frontiers in neuroscience*, *5*.

Price, R.B., Siegle, G.J., Silk, J.S., Ladouceur, C.D., McFarland, A., Dahl, R. E., & Ryan, N.D. (2014). Looking under the hood of the dot-probe task: an fMRI study in anxious youth. *Depression and anxiety*, *31*(3), 178-187.

Quinn, P.C., Westerlund, A., & Nelson, C.A. (2006). Neural markers of categorization in 6-month-old infants. *Psychological Science*, *17*(1), 59-66.

Rieger, G., & Savin-Williams, R. C. (2012). The eyes have it: Sex and sexual orientation differences in pupil dilation patterns. *PloS one*, *7*(8), e40256.

Samuels, E.R., & Szabadi, E. (2008). Functional neuroanatomy of the noradrenergic locus coeruleus: its roles in the regulation of arousal and autonomic function part I: principles of functional organisation. *Current neuropharmacology*, *6*(3), 235-253.

Sanchez, A., Vazquez, C., Marker, C., LeMoult, J., & Joormann, J. (2013). Attentional disengagement predicts stress recovery in depression: An eye-tracking study. *Journal of Abnormal Psychology*, *122*(2), 303.

Schag, K., Teufel, M., Junne, F., Preissl, H., Hautzinger, M., Zipfel, S., & Giel, K.E. (2013). Impulsivity in binge eating disorder: food cues elicit increased reward responses and disinhibition. *PLoS One*, *8*(10), e76542.

Schmid, P.C., Mast, M.S., Bombari, D., Mast, F.W., & Lobmaier, J.S. (2011). How mood states affect information processing during facial emotion recognition: an eye tracking study. *Swiss Journal of Psychology*.

Sibert, L.E., & Jacob, R.J. (2000, April). Evaluation of eye gaze interaction. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems* (pp. 281-288). ACM.

Sirois, S., & Brisson, J. (2014). Pupillometry. *Wiley Interdisciplinary Reviews: Cognitive Science*, *5*(6), 679-692.

Spering, M., & Carrasco, M. (2015). Acting without seeing: eye movements reveal visual processing without awareness. *Trends in neurosciences*, *38*(4), 247-258.

Urakawa, S., Takamoto, K., Ishikawa, A., Ono, T., & Nishijo, H. (2015). Selective medial prefrontal cortex responses during live mutual gaze interactions in human infants: an fNIRS study. *Brain topography*, *28*(5), 691-701.

van der Schaaf, M.E., van Schouwenburg, M.R., Geurts, D.E.M., Schellekens, A.F.A., Buitelaar, J.K., Verkes, R.J., & Cools, R., 2014. Establishing the Dopamine Dependency of Human Striatal Signals during Reward and Punishment Reversal Learning. *Cereb. Cortex* 24, 633– 642. doi:10.1093/cercor/bhs344.

Veneri, G., Federico, A., & Rufa, A. (2014). Evaluating the influence of motor control on selective attention through a stochastic model: the paradigm of motor control dysfunction in cerebellar patient. *BioMed research international*, *2014*.

Vidal, M., Turner, J., Bulling, A., & Gellersen, H. (2012). Wearable eye tracking for mental health monitoring. *Computer Communications*, *35*(11), 1306-1311.

Wadlinger, H.A., & Isaacowitz, D.M. (2008). Looking happy: the experimental manipulation of a positive visual attention bias. *Emotion*, *8*(1), 121.

Wagner, J.B., Hirsch, S.B., Vogel-Farley, V.K., Redcay, E., & Nelson, C.A. (2013). Eye-tracking, autonomic, and electrophysiological correlates of emotional face processing in adolescents with autism spectrum disorder. *Journal of autism and developmental disorders*, *43*(1), 188-199.

Wedel, M., & Pieters, R. (2008). A review of eye-tracking research in marketing. In *Review of marketing research* (pp. 123-147). Emerald Group Publishing Limited.

Westbrook, A., & Braver, T.S. (2016). Dopamine does double duty in motivating cognitive effort. *Neuron*, *89*(4), 695-710.

Wieser, M.J., Pauli, P., Alpers, G.W., & Mühlberger, A. (2009). Is eye to eye contact really threatening and avoided in social anxiety? —An eye-tracking and psychophysiology study. *Journal of anxiety disorders*, *23*(1), 93-103.

Xue, J., Quan, C., Li, C., Yue, J., & Zhang, C. (2017). A crucial temporal accuracy test of combining EEG and Tobii eye tracker. *Medicine*, *96*(13).

Yrttiaho, S., Niehaus, D., Thomas, E., & Leppänen, J.M. (2017). Mothers' pupillary responses to infant facial expressions. *Behavioral and Brain Functions*, *13*(1), 2.