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# A Review of Visual Attention Research Using Eye-Tracking Technologies

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## ABSTRACT

The purpose of this review paper was to examined the study on visual attentional bias processes and eye movements in this process and evaluate individuals' responses to positive and negative stimulus. The selective attention processes that individuals show to environmental stimuli and the eye movement behaviors. Accordingly, these are associated with autonomous defense mechanisms that occur during survival. This situation may differ according to various characteristics of the individual. Another differentiated situation is the individual's psychological well-being in the attention shift process. Many studies have shown that individuals with anxiety-related disorders or depression show more intense sensitivity to threatening stimuli. The eye-tracking method is important for characterizing and detecting individual differences reflected in the individual's attention switching process and attentional bias. Consequently, the differences in the reaction time of individuals with high levels of anxiety/depression were negative stimuli compared to other (positive, neutral) stimuli. Currently, the processes of attentional bias caused by threatening factors in individuals continue to be examined. Information on this situation are quite important for the detection and treatment processes of many psychological diseases. Therefore, the observation of eye movement behavior that is significant for the detection of other psycho-physiological conditions (cognitive, visual fatigue) that cause attentional bias.

**Keywords:** Eye tracking, attentional bias, anxiety, depression, addiction, eating disorder

## 1 Introduction

Attention, filtering out other perceptible information and selectively focusing on a piece of information creates a kind of arousal state that can deal with limited processing deficits [1]. Attention can be considered an internal force that spontaneously or voluntarily creates a mental, sensory or dynamic expectation and supports the perception of stimuli and the production of responses [2]. Additionally, according to the network attention model developed by [3], there are three interrelated and simultaneously differentiated components of attention (see Table 1), namely, alertness, orientation, and executive control. Understanding this model is important to the explanation of any attentional process, such as attentional bias. Another important phenomenon of attention is attentional shifting and orienting processes. For instance, the eyes and head can be used for look at an object voluntarily. This is mostly referring as overt attention. Additionally, there is no need for eye and head movement for covert attention. These processes are evolutionarily developed [4-5]. Attention in nature is the result of a long cognitive evolutionary

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process of living organisms, it is a fundamental activity that concerns the survival of all life forms. This process plays a role in regulating the complex mental process of humans during the perception of environmental stimuli. It includes all cognitive steps like decision-making skills. Amongst evolutionary processes, attention primarily affects the perception, selection and adjustment of environmental stimuli. It is decisive for the continuation and evolution of the species because it helps to settle at the desired point in the environment and to detect the prey of predators or potential competitors [6]. Cisler et al. (2010) in a comparison that examined attentional bias towards threatening and neutral stimuli, it was found that they presented a different distribution of attention towards threatening stimuli. The mechanism of attentional bias is understood by examining three interrelated aspects. The first is to observe the components of attentional bias, second, mechanisms for mediating the expression of these components, and finally, the stage of information processing in which mediated mechanisms operate. The components of attentional bias refer to observable traits and measure attentional bias (such as what attentional bias looks like). The observable characteristics of attention bias are stated as facilitated attention (more rapid recognition of a threatening stimulus than a neutral stimulus), difficulty in disengagement (longer separation time from the threatening stimulus compared to the neutral stimulus), and attentional avoidance (tendency to distract attention from the threatening stimulus and to deal with other stimuli) [7].

**Table 1:** Summary of attention networks model.

| Attention Networks | Components | Definition |
|---|---|---|
| Alerting | Sustained, Alertness | The ability to allocate attention for a long time. |
| Orienting | Divided and Selective Attention | The capability to limit attention to a specific potential sensory input. |
| Executive | Attention Shifts and Control | The ability to regulate attention. |

The World Health Organization has declared that depression and anxiety are mental disorders that have the highest prevalence among countries and cultures. While anxiety and depression disturb an individual's performance, a high percentage of people do not pay attention to them. Attentional bias towards threatening stimuli plays a significant role in the diagnostic and treatment processes of anxiety and depression-related diseases [7-8]. Today, thanks to technological advances, the amount of information that people get has increased and exposes them to more stimuli. The negative effects of this situation on people can turn into a variety of mental disorders. Another hypothesis regarding this issue is when other cognitive components are considered, it is reported that depression and anxiety-related disorders can interact with cognitive processes in a variety of ways [9].

This review paper has covered the paradigms and the results obtained regarding the attentional bias proposed in the open literature. Moreover, it gives some information about significant of engineering skills such as image processing and machine learning in the attention studies. The paper is organized as follows. The paradigms and factors affecting attentional bias presented in the open literature are provided in Sections 2 and 3, respectively. Finally, the concluding remarks are reviewed in Section 4.

## 2 Paradigms and Stimuli for Attention Bias Measurement

In order to better understand the processes of formation and correction of attentional bias, various tests have been developed in relation to traditional neuropsychological methods. The most common are; Dot-Probe Test [10], Visual Search Test [11], Modified Stroop Test [12], Spatial Cueing Test [13] and Attentional Blink Test [14]. During the Dot-Probe test, two images are displayed simultaneously (around 500 ms), one negative and the other positive or negative. After the presentation of two images, a marker (star, etc.) is displayed on the side of one of the images. With the right and left arrow keys, the participant is asked to indicate the direction of the signal. Attention bias inferences are made by comparing the signal time following the negative stimulus and the time of the displayed signal after the positive/neutral stimulus. During the task, the reaction time to the negative stimulus signal should be shorter than the positive/neutral stimulus. Various types of words (threatening and neutral) are shown in the changed Stroop test. Participants are invited to indicate their color no matter what the word means. Attentional biases are determined by comparing reaction times to threatening and neutral words.

The Stroop task is one of the most common measurement methods for measuring attention bias in anxiety. However, it cannot be considered the most ideal method because of its interpretative problems. In

addition, the spatial distribution of attention is difficult to measure. Visual Search Test was developed by Treisman (1977). Participants are asked to identify a target stimulus that is integrated into a distracting stimulus matrix. The Spatial Cueing Test was designed by Posner (1980). Participants are asked to look at the Centre Point on the screen. A negative stimulus and another positive/neutral stimulus are randomly displayed on the right and left of the dot, then the attention bias is measured based on changes in demonstrated attention. The Spatial Cueing test assesses if presenting participants with a target in the same position as the previous index influences the reaction time and the correct response rate. The task consists of three valid, neutral and invalid sub-dimensions. Valid attempts are those in which the target is displayed in the same location as the presented flag. Neutral tests are tests with no sign after the target. Invalid tests are tests in which the target is in the opposite direction of the signal presented. As expected in the results, the average reaction time should be faster on valid tests than on invalid tests. The Attentional Blink test demonstrates a fast and distracting flow of visual presentations. Two target stimuli (two different letters) are embedded in this stimulus stream. At the end of the presentation, participants should indicate if they have seen the target stimuli. In the emotional version of this task, the threat level of one of the two target stimuli is variable (e.g., one stimulus is threatening and the other is neutral). The expected responses from the applied tasks are summarized in Table 2.

**Table 2.** Summary of paradigms and measurement for attentional bias.

| Process of Measure | Task | Index of Attentional Bias |
|---|---|---|
| Dot-Probe | Two stimuli at the same time, respond to target appearing after on threatening (congruent) or neutral (incongruent) location. | Faster or slower reaction times in threated trials. |
| Spatial Cuing | One single stimuli (negative or neutral) react to a cued or uncued target. | Latency in reaction time for the negative stimulus. |
| Visual Search | Finding the threatening target in a series of neutral distractors or finding the neutral target in a series of threatening distractors. | Faster reaction on trial with threating target stimuli, slower reaction on trial with neutral target stimuli. |
| Attentional Blink | Two stimulus (one of negative) in the slides of other stimulus. | Saliency and reaction time of the negative stimulus. |
| Modified Stroop | Name of the color of negative and neutral words. | Slower color naming for the negative words. |

Physiologic measures are also used to increase the validity and reliability of cognitive tests applied in attention studies. The eye-tracker method is the most widely used in studies on visual attention, and the other is the ERP (Event Related Potential) method with electroencephalography (EEG) [15]. In the eye tracker method, participants' responses to stimuli are examined by various metrics such as reaction times, saccade times, and fixation times [16]. In ERP studies, the N2-Posterior-Contralateral (N2PC) component, which is the most popular amongst the many ERP components, is used in attention studies [17].

## 3 Taxonomy of Previous Study

The data obtained with the eye tracking method makes it possible to measure the location where the eye is fixed in real-time during an experiment. These measures are important for understanding which cognitive processes are effective during the experiment [18].

### 3.1 Attentional Bias

Identifying the specific features of attention to a threatening stimulus is important for the psychophysiological measurement of anxiety and depression. Literature survey shows that there are many studies about the attentional bias. For example, Macdonald and Tatler (2017) carried out a study in which they examined the effects of eye movements and social perception during interaction in natural environments. Social roles were assigned to the participants by wearing a wearable eye tracker, and some were assigned the role of chef and some of them as a waiter. Consequently, it was observed that the average time to look at the given object was shorter when the roles were assigned than when the roles

were unassigned. The data obtained were interpreted as social contexts influencing eye behaviours [19]. Vazquez et al. (2018) conducted a study measuring the attention performance of patients with clinical depression before and after cognitive behavioural therapy and the application of positive psychology. Following the study, it was observed that after treatments were applied in attention performance and bias, positive outcomes were achieved relative to previous treatments [20]. A two-step research was conducted by Han et al. (2019). They focused on how the negative online news that people are exposed to on social media influences social confidence and helping behaviour. Following the first experience, they noticed that during the eye movement task performed, they were more inclined to show an attentional bias toward negative news and were more affected by it. In the second experiment, the positive news was presented to one group of participants as well as negative news to another group. The group with negative news was found to be less helpful in their behaviour. In the third phase of the experiment, headlines with neutral content were changed to negative, and one neutral and one negative were presented to participants. At the end of the third phase, participants were observed to display a negative cognitive bias, low aiding behaviour, and low social confidence after reading the negative headlines [21]. Hessels et al. (2019) investigated changes in one person's gaze as a function of the other person's facial expressions and the behaviour of the other person's gaze during face-to-face communication. The study was a two-step process. As a result of the first stage, during the communication, participants' eye movements were observed to be affected as they spoke and listened. Subsequent to the second phase, observed that eye movements did not change as a function of stimulus and that social context was more effective [22]. Shen et al. (2021) conducted a study to detect depression by analysing eye movement behaviour using the classification methodology. They collected information by asking participants to freely view three different emotional stimuli (happy, sad, neutral). Using the data classification method, they created a %77 successful estimation algorithm with the Support Vector Machine (SVM) [23].

### 3.2 Addiction

In recent years, substance addiction has increased. In particular, it is stated that substance abuse results from attentional bias that is characterized against substance-related stimuli [24-25]. The onset of lapse and relapse, which is common in addiction treatment processes, is explained by the dual process model. This model includes reflective and automatically evolving processes. Reflective processes require conscious decision-making. Methods such as cognitive behavioural therapy develop methods for preventing the reflexive process. Automated processes imply more attentive biases. It involves unconscious processes which make it difficult for people to concentrate on the environmental stimuli related to the substance and avoid paying attention to those stimuli [26]. Many studies have been and continue to be conducted with a view to developing methods to prevent the attentional bias that people develop with regard to substance-related stimuli. Parvaz et al. (2021) conducted a study on drug addicts to create a shift in bias with the Cognitive Reappraisal method of attention bias processes. Two groups of cocaine users and nonusers were included in this experiment. This experiment investigated spontaneous attentional bias toward drug-containing stimuli. This experiment was applied to the stimuli presented by closely monitoring the length of the participants' gaze and minimizing the expected confusion. Subsequent to the study, it was observed that the cognitive re-evaluation study applied during the experiment systematically reduced attention bias to substance-related stimuli [27].

### 3.3 Eating Disorders

Today, another behaviour pattern that has a high prevalence and has adverse physiological and psychological effects occurs with abnormal eating disorders [28]. Attention bias, which is a component of cognitive bias, is important for the diagnosis and prevention of eating disorders. Following studies on the efficacy of attention bias on eating disorders, studies have shown that people with eating disorders are sensitive to food stimuli [29]. Shafran et al. (2007) carried out an extensive study to explain the relationship between eating disorders and attentional biases in the first phase of the study, the clinical diagnosis of eating disorder (23 females) was studied, among them (19 females) they had a high level of anxiety, and as a control group; individuals with high, moderate and low anxiety (74 females) were included in the study.

In the second stage, persons with eating disorders (82 females) and healthy persons (44 females) were included. In both phases of the study, the probe point task was grouped and illustrated (in relation to food, form, and weight). Following the initial study, a related attentional bias was found in the images with negative diet and neutral weight in participants with eating disorders. At the end of the second step, the results indicated the results of the first step and, further, the attention bias to negative and neutral images was identified [30].

Popien et al. (2015) investigated the response of people with and without eating disorders to food-related stimulation. Participants were provided with high and low-calorie images. During the experiment, which lasted about 8 minutes, eye measurements were taken in both groups using an eye tracer. At the end of the study, it was observed that participant with binge eating was more likely to react to images containing food, regardless of whether they were high in calories or low, compared to controls [31]. Jose et al. (2022) compared individuals with High Body Dissatisfaction (HBD) to healthy individuals with Low Body Dissatisfaction (LBD), examining whether patients with Anorexia Nervosa (AN) have longer fixation duration and greater number of fixations in weight-related body regions. In this work, 66 women (25 with LBD, 18 with HBD and 23 AN) were participated in the experimental study. All of the participant were immersed in a virtual world with an avatar that had been embodied by their body measured. Participant's eye movement metrics was recorded with eye tracker features of the virtual reality headset. During the experiment researchers were focused on the area of interest of the weight related of scene and compared with non-related areas. Researchers were focused on the eye movements of participants and compared with whether their gaze on weight-related areas of the scene or not weight-related areas. Consequently, participant with anorexia nervosa have long duration and high number of fixation on weight-related areas than other groups of participant [32].

### 3.4 Cognitive Load

Eye tracking methods has shown to be effective for detecting cognitive load in attention studies. In the open literature, there are many studies about the correlation between cognitive load and attention. For example, Marandi et al. (2018) investigated the consideration of age-related long-term cognitive performance on eye fatigue. In this study, they observed longer fixation time, shorter saccade time and lower performance in other cognitive tests in older adults [33]. Yamada and Kobayashi (2018) developed an automatic learning model to detect auditory cognitive tasks and mental intensity using an eye monitoring method. In their model, mental fatigue was identified at 91% [34]. Wang et al. (2019) conducted a study to estimate eye fatigue by obtaining data from virtual glasses containing eye trackers using optometric testing methods. In this study, different measurements such as positive-negative relative congruence, pupil dilation, and corneal angle difference in both eyes were considered. Additionally, 105 participants aged 19-51 with normal vision were subjected to the four-step test. Consequently, data on the increase in eye fatigue at each step were modelled with the vector support machine algorithm [35]. Li et al. (2020) developed a virtual reality environment using commercial machinery. A portable eye tracker is installed for participants to be included in the simulation environment. The blinking rate, blinking time, pupil diameter, and eye position were chosen to determine and classify mental fatigue according to the applied method. The findings of the study include information on the potential for the detection of mental fatigue to reduce the risk of workplace accidents [36]. Lin et al. (2021) investigated eye movement behaviours in their study using a visual fatigue questionnaire, a critical fusion frequency, and an ocular follow-up device. Thirty-three respondents were included in the study. Test participants' scores were analysed using the regression analysis method. As a result of the study, it was reported that eye movement behaviours are a determining factor in detecting visual fatigue and a suitable method in studies conducted for this purpose [37]. Zheng et al. (2021) studied the relationships between visual fatigue questionnaire, contrast sensitivity, accommodative and vergence methods and eye fatigue and its subjective symptoms. It should be noted that 104 young participants (79 women, and 25 men) were included in this study. The results showed that visual fatigue was strongly associated with the ability to encode visual details at the binocular level [38].

# 4 Conclusions

The study of eye movements is known to have started following Javal (1879) first noticed differences in eye movements of individuals while reading a text. The first eye-monitoring device was developed by Huey (1908) [39]. Buswell (1937) was the first to document differences in eye behaviour when reading orally and quietly. Today, eye-monitoring devices; are used in different fields of scientific research such as neuroscience, experimental psychology, marketing and engineering. Fields of this type use an eye-tracking methodology to investigate visual/cognitive processes. In the field of clinical psychology, it is seen that the most common method used to modify the negative attentional bias in individuals is the dot-probe method. In this study, investigations about the use of the eye tracker in the detection and treatment processes of various psychopathological conditions are presented. Based on the studies, we see that the detection of eye movement behaviours is important for the detection of unconscious processes in the attention processes of people suffering from certain disorders.

# 5 Declarations

## 5.1 Study Limitations

None.

## 5.2 Acknowledgements

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## 5.3 Funding Source

None.

## 5.4 Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## 5.5 Authors' Contributions

**Ozgun Ahmet EFETURK** contributed with the paper writing and revisions.

**Gizem TURGUT** contributed with the paper writing and revisions.

**Hamid ASADI DERESHGI** contributed with the paper writing and revisions.

**Aziz YILMAZ** contributed with the paper writing and revisions.

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