Review of the Research Techniques of Attention Bias

Ruohan Zhang*
School of Psychology, Beijing Sport University, Beijing, China
**Corresponding Author.*

Abstract: Attention bias refers to the preferential allocation of attentional resources toward salient stimuli such as threat-related or emotional cues. It is widely observed in emotional disorders, addictive behaviors, and various psychological conditions. To explore the mechanisms and neural underpinnings of attention bias, researchers have developed and applied a range of methodologies. This review systematically examines the major techniques currently used in attention bias research, including behavioral paradigms (e.g., dot-probe tasks, Stroop tasks), eye-tracking, electroencephalogram (EEG) and event-related potentials (ERP), functional magnetic resonance imaging (fMRI), transcranial magnetic stimulation (TMS), functional near-infrared spectroscopy (fNIRS), and virtual reality (VR) technology. Through representative empirical studies, the paper summarizes the strengths and limitations of each method in terms of temporal and spatial resolution, ecological validity, applicability, and operational complexity. While current technologies have enabled more comprehensive assessments of attention bias at both behavioral and neural levels, limitations remain, such as low ecological validity in controlled environments and insufficient integration across modalities. Future research may benefit from the integration of high-resolution neuroimaging, physiological feedback, and multimodal analysis to improve the precision and real-world relevance of attention bias assessments. This review aims to provide methodological guidance for advancing theoretical understanding and developing intervention strategies targeting attention bias.

Keywords: Attention Bias; Eye Tracking; Event-Related Potentials; Functional Magnetic Resonance Imaging; Functional Near-Infrared Spectroscopy; Transcranial Magnetic Stimulation

1. Introduction

In 1986, Mathews and Maethod first found attention bias in anxious individuals [1], which means that individuals show attention selective processing and high sensitivity when facing other specific stimuli, such as threatening stimuli and negative stimuli, compared with neutral stimuli. Posner and Petersen put forward the Attention component theory in 1990, pointing out that attention bias includes attention vigilance, attention to relieve difficulties, and attention avoidance [2]. Fox et al. [3] believe that there are two possible mechanisms for the emergence of attention bias: the first is that in the orientation stage, individuals are more sensitive to threatening stimuli, and their attention is attracted by threatening stimuli, so they show attention bias to threatening stimuli; The second is that threatening stimuli affect the time of attention maintenance or the ability of attention cancellation, which makes attention stay in the area where these stimuli are located for a long time, thus resulting in attention bias. Based on the understanding of the definition and possible mechanism, most researches related to attention bias choose special people as the research objects, and the research contents are mostly concentrated in emotional disorders, addictive behaviors, or fields related to health psychology. The study of attention bias can not only provide preventive monitoring for psychological disorders or unhealthy behaviors, but also provide development ideas for intervention methods. Therefore, it is of great practical significance and application value to explore attention bias and its related mechanisms. With the continuous development of science and technology, the related technologies for studying attention bias are constantly being iteratively updated. This paper aims to systematically integrate various research technologies of

attention bias and explore the advantages and disadvantages of this technology by analyzing the research in the related fields of attention bias, so as to provide methodological guidance for future research.

2. Research Techniques of Attention Bias

2.1 Behavioral Research Paradigm

The existing research mostly uses dot-probe tasks, Stroop tasks, visual search tasks, spatial cue tasks and negative priming paradigms to study attention bias. Among them, the dot-probe task reflects the attention bias by detecting the difference between the reaction time under the condition that the stimulus and the emotional stimulus are inconsistent, and the paradigm operation is simple; Stroop task is widely used in the study of emotional attention bias by analyzing the negative attention bias through the individual's reaction delay to negative words. Visual search task measures attention bias by comparing the time and speed of finding different target stimuli, which has high ecological validity; Spatial cue task proves the existence of attention bias effect by comparing threatening stimulus with neutral stimulus; The negative priming paradigm adds distracting stimuli, and the individual's inhibitory function on distracting stimuli is measured by controlling the emotional consistency between distracting stimuli in the priming stage and target stimuli in the detection stage [4]. At present, cognitive neuroscience research technology is often combined with a behavioral research paradigm to investigate the related neural mechanism of attention bias.

2.2 Eye Tracking

Eye tracking is a technology that uses optical instruments to record and receive infrared rays reflected by the eyeballs, and then processes and analyzes video data. Eye tracking technology can more intuitively and effectively record the time information and spatial position of eye movement in time dimension and space dimension, so as to track the process of individual cognitive processing. Eye trackers can measure the direction, way, and order of eyes during a specific task. Therefore, eye tracking technology can comprehensively measure the three basic components of attention bias and ensure the comprehensiveness and accuracy of the measurement. In the eye movement research on the attention bias of college students who are addicted to mobile phones, the researchers found that the addiction group had a longer first gaze time and a longer total gaze time on mobile phone-related pictures before and after being separated from the mobile phone, that is, they showed attention bias to the mobile phone, while the normal user group showed a tendency to avoid attention to mobile phone clues after being separated from the mobile phone [5]; However, in an eye movement study to explore college students' attention bias to sports cultural elements, the researchers found that college students' total gaze time on sports museum exhibits was longer, and college athletes' first gaze time was longer than that of ordinary college students, that is, they showed attention bias to sports cultural elements [6]. In the above research, it can be found that the advantages of using eye tracking technology are simple operation, a light instrument, and high time resolution, and it can pay attention to multi-dimensional indicators, which is suitable for various research scenarios; However, eye tracking technology also has some shortcomings. In order to ensure the accuracy of measurement, it is necessary to strictly control the position of the subject's head. If the head moves during the experiment, the data may be missing, and there may be many different explanations for the same index measured.

2.3 Electroencephalogram (EEG) and Event-Related Potentials (ERP)

Electroencephalogram (EEG) is used to directly record the participants' neuroelectrical activities by wearing an EEG cap, which can be combined with behavioral experiments to analyze the neuroelectrical activities involved in attention bias, and can also be superimposed and averaged to obtain event-related potentials (ERP) to further study the neural indicators of attention bias. An ERP study on the attention bias of individuals with high autistic traits to threatening emotional faces found that, compared with the low autistic group, the peak value of P1 in the high autistic group was still significantly higher than that in the inconsistent condition, indicating that there was an early acceleration of attention orientation to threatening emotional faces; Another ERP study exploring the characteristics of badminton players' attention bias found that the expert group (badminton players who have been

trained for more than 5 years) chose the target stimulus faster in the test of attention bias ability, had stronger ability to distinguish information in space, had greater novelty in strange items and had stronger ability to ignore irrelevant information [7]. In the study of ERP with attention bias, it can be found that the advantages of EEG and ERP are that they can directly record the neural electrical activity, with high time resolution and a large amount of information; However, their shortcomings are low spatial resolution and ecological validity, and they can only record shallow nerve electrical activity.

2.4 Functional Magnetic Resonance Imaging (fMRI)

Functional magnetic resonance imaging (fMRI) is a technique that uses hemodynamic changes to observe the blood oxygen level-dependent (BOLD) signal when observing brain activities, which can directly reflect the basic state and changes of brain functional areas. It has the advantages of non-invasive, visibility, relatively high temporal and spatial resolution, no radiation, simplicity, and stability, and is increasingly widely used in brain science research [8,9]. An fMRI study to explore whether attention bias modification (ABM) can improve the negative attention bias of patients with residual depression found that the activation degree of amygdala and anterior cingulate cortex in the training group decreased when watching negative images passively compared with the placebo group [10]; In an fMRI study to explore the attention bias of spicy food cravings to spicy food clues [11], the researchers found that spicy food cravings had significantly more activation in the right cerebellum and left orbitofrontal cortex than non-cravings. In the above research, it can be found that functional magnetic resonance imaging technology has the advantages of high spatial resolution and is suitable for clinical research; However, the limitations are low temporal resolution and ecological validity, and it is difficult to infer the specific contribution of each brain region to cognitive processes such as attention bias.

2.5 Transcranial Magnetic Stimulation (TMS)

Transcranial magnetic stimulation (TMS) is a method of transmitting electrical stimulation through the human scalp. As a safe and non-invasive form of brain stimulation, TMS can uniquely examine and regulate the human nervous system and related cognitive and behavioral functions [12]. A study on the influence of high-frequency transcranial magnetic stimulation on the attention bias of patients with depression found that [13], after the treatment of drugs combined with high-frequency transcranial magnetic stimulation, the patients' fixation time on sad pictures was shortened, indicating that the negative attention bias was improved; However, some studies used high-frequency repetitive TMS (10Hz) to stimulate the left dorsolateral prefrontal cortex for five consecutive days. The results showed that high-frequency transcranial magnetic stimulation of the dorsolateral prefrontal cortex could significantly reduce the threatening attention bias of anxious individuals [14]. When transcranial magnetic stimulation is used to study attention bias, it can be found that the outstanding advantage of transcranial magnetic stimulation is that it can verify the causal relationship between brain function and attention bias, and the time resolution is high; However, its shortcomings are that the stimulation range is wide, the accuracy is difficult to meet, and the setting of stimulation parameters is complicated.

2.6 Functional Near-Infrared Spectroscopy (fNIRS)

Functional near-infrared spectroscopy (fNIRS) technology is an innovative and non-invasive tool that is used to monitor the hemodynamic changes of the cerebral cortex and to objectively describe the changes of the cerebral cortex after exercise by data such as brain activation and functional connection [15]. In a fNIRS study [16], which focuses on the difference of food attention bias between overweight and obese people and normal weight people, the researchers found that the blood oxygen activation of orbitofrontal cortex in normal weight group was significantly higher than that in low energy food map and neutral map, and the blood oxygen activation of dorsolateral prefrontal cortex in overweight and obese group was significantly higher than that in neutral map. The higher activation of attention control-related brain regions in the normal weight group may help to adopt food control strategies earlier. Another study on female college students' attention bias to body pictures [17] found that

under the same conditions of dot-probe tasks, the activation of blood oxygen in the orbitofrontal cortex of female college students with fat negative body self when watching fat pictures was significantly greater than that of thin pictures and neutral pictures, and the activation of this brain region may help them to detect the location of fat pictures earlier and produce attention alert. When using fNIRS to study attention bias, its advantages are high time resolution, high ecological validity, high tolerance to movement, and safety and non-invasive; However, its shortcomings are low spatial resolution and limited penetration depth, which can only measure superficial signals of the cortex.

2.7 Virtual Reality (VR)

Virtual reality (VR), as an advanced computer simulation technology, presents users with multi-dimensional sensory feedback such as vision, hearing and touch by integrating hardware devices such as head-mounted display devices, data gloves and multi-modal sensors, so that users can gain a strong sense of presence and realism in the interaction process, thus realizing the interactive effect of deep immersion [18]. At present, many studies have introduced VR into psychotherapy to explore the improvement of attention bias by cognitive training in virtual reality scenes. A study on the influence of psychotherapy based on virtual reality technology on negative attention bias of depressed individuals [19] found that VR psychotherapy can effectively alleviate depression and anxiety symptoms, and the negative attention bias has been significantly improved before and after treatment, but there is no significant difference between the intervention group and the control group. However, some studies combined VR with traditional cognitive neuroscience technology to explore the characteristics of attention bias of people with special needs under the blending of old and new technologies. A study to explore the attention bias of methamphetamine addicts combined eye movement with VR, and the results showed that the severe methamphetamine addiction group was more active in eye movement response to drug-related clues, and the efficiency of attention transfer was lower. The obvious advantages of using virtual reality technology to study attention bias are high ecological validity, more suitable for real attention bias in real situations, high dynamics, free movement of subjects, and high compatibility of VR with other experimental equipment; However, its limitations are that it is difficult to synchronize data, it is difficult to realize the diversification of subjects, and there are many uncontrollable factors in complex scenes.

3. Future Directions

Although the existing research techniques on attention bias have been very diverse and perfect, most of them still have some limitations, such as low ecological validity and difficulty in meeting the temporal and spatial resolutions at the same time. Future research can break through the technical bottleneck in the following aspects and promote the ecological and accurate development of attention bias research.

First of all, high-precision neuroimaging technology can be introduced into the study of attention bias in the future, which can improve the spatial resolution while ensuring the temporal resolution. For example, fMRI with field strength above 7T is used to pay attention to the role of tiny brain regions in attention bias.

Secondly, in the future, we can try to make a longitudinal follow-up study of attention bias, to investigate the dynamic changes in its occurrence, development, and transformation, as well as the possible predictive factors in these processes, or to investigate the stability of the intervention effect of attention bias correction training.

In addition, emerging technologies such as biofeedback and computational modeling can be introduced into future research to improve the intervention methods of attention bias. Biofeedback technology can provide personalized intervention strategies for special groups, and computational modeling can quantify the cognitive process and its mechanisms involved in attention bias more accurately, thus providing a more accurate basis for the intervention of attention bias.

Finally, future research can deeply integrate multi-modal technologies, record data synchronously, conduct joint analysis, provide more comprehensive, multi-level, and multi-dimensional dynamic indicators of attention bias, make up for the deficiency of single technology, and be conducive to the improvement of ecological validity.

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