

## Eye-Tracking Manipulation in Decision-Making Research: Prospects for Altering Decision Behavior

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**Date:** 2022-02-24T00:00:00+00:00

### Abstract

Eye-tracking technology is widely employed in behavioral decision research due to its advantages of minimal invasiveness, high objectivity, and rich and accurate data acquisition. By manipulating eye-movement processes, decision outcomes can be altered in anticipated directions, thereby establishing a causal chain between decision processes and outcomes and providing insights for intervention research in decision-making. This paper introduces the fundamental methods and principles, common manipulation metrics, and effects of eye-movement manipulation in the field of behavioral decision research based on two categories of studies—exogenous manipulation and gaze-contingent manipulation—and analyzes and discusses the advantages and disadvantages of different manipulation categories. Important future directions for eye-movement manipulation research include accounting for differences in decision-makers' strategies and preferences in experimental design, enriching manipulation metrics and analytical methods through integration with approaches such as computational modeling, and extending the advantages of this methodology to other domains.

### Full Text

## The Prospect of Gaze Manipulation Technology in Decision-Making Research: Changing Decision Behavior

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## Abstract

Eye-tracking technology has been widely applied in behavioral decision-making research due to its advantages of low interference, high objectivity, and rich, accurate data collection. By manipulating eye movement processes, researchers can alter decision outcomes in expected directions, establishing a causal chain between decision processes and results, thereby providing insights for intervention studies. Based on two types of research—exogenous manipulation and gaze-contingent manipulation—this paper introduces the fundamental methods, principles, common manipulation indices, and effects of gaze manipulation in the field of behavioral decision-making, and analyzes and discusses the advantages and disadvantages of different manipulation categories. Future directions for gaze manipulation research include considering differences in decision-makers' strategies and preferences in experimental design, enriching manipulation indices and analytical methods through computational modeling and other approaches, and extending the advantages of this method to other domains.

**Keywords:** gaze manipulation technology, exogenous gaze manipulation, gaze-contingent manipulation, decision preference, causal link

Behavioral decision-making research focuses on how people make choices among different alternatives (Edwards, 1954), with applications ranging from daily life to management and economic behaviors: whether to vaccinate? Whether to reduce overexploitation for sustainable development? What type of investment product to choose? Since the 1950s, behavioral decision-making research has flourished (Weber & Johnson, 2009). During this period, the research focus has gradually shifted from “what choice is made” to “how the choice is made.” Correspondingly, research methodologies have evolved from outcome-based paradigms to process-based paradigms (Schulte-Mecklenbeck et al., 2017). The former typically manipulates stimulus attributes and builds mathematical models to infer final choice outcomes. Unlike outcome-based approaches, process-based paradigms focus on analyzing decision processes to enable direct inference of the underlying cognitive mechanisms (Schulte-Mecklenbeck et al., 2011). In recent years, process-based research has deepened, and eye-tracking technology, as a movement-based measurement technique, has been widely used in such studies (Ballco et al., 2019; Huddleston et al., 2018; Liu et al., 2021; Newell & Le Pelley, 2018; Uggeldahl et al., 2016) due to its significant advantages of low interference, high objectivity, rich and accurate data, wide applicability, low cost, and portability (Glöckner & Herbold, 2011; Orquin & Loose, 2013; Raptis et al., 2017).

The cornerstone of eye-tracking technology is the eye-mind hypothesis, which posits that the information being acquired by the eyes aligns with the information being processed by the brain. This technology uses eye movement indices to reflect the spatiotemporal encoding of visual information, enabling effective measurement of attention allocation and cognitive processing characteristics during decision-making (Schulte-Mecklenbeck et al., 2017). In decision-making eye-

tracking studies, fixation duration and fixation count are commonly used to reflect the difficulty and depth of information processing (Horstmann et al., 2009; Su et al., 2013), testing processing characteristics such as whether risk decisions involve “weighted summation” (Su et al., 2013) or whether intertemporal decisions involve “discounting calculations” (Zhang, 2016). Saccade distributions reflect how decision-makers search for and compare decision information (Khaw et al., 2018), testing whether processing is more attribute-based or alternative-based (Glöckner & Herbold, 2011; Russo & Doshier, 1983; Su et al., 2013). Scanpaths reflect the temporal-sequential properties of visual-cognitive processes, examining decision-makers’ overall dynamic eye movement patterns (Zhou et al., 2019; Noton & Stark, 1971; Zhou et al., 2016). Furthermore, to explore the relationship between decision processes and behavior, computational modeling can be used to predict behavior from eye movement patterns. For example, researchers have introduced attention variables into the drift diffusion model (DDM) to develop the attentional drift diffusion model (aDDM) (Krajbich et al., 2010; Krajbich & Rangel, 2011). This model’s core assumption is that decisions are driven by a stochastic evidence accumulation process, and attention can influence this process by introducing temporary drift bias toward the fixated option, meaning attentional bias leads to decision bias. Eye-tracking studies have demonstrated that this model accurately predicts fixation processes and can qualitatively explain the relationship between fixation patterns and decision behavior. Similarly, Chuk et al. (2020) proposed the switching hidden Markov model (SHMM) based on hidden Markov models (HMM) and combined it with eye-tracking data to analyze eye movement patterns in tasks involving cognitive state changes, providing quantitative measurement of differences in participants’ cognitive behaviors. Therefore, incorporating attention preferences revealed by eye-tracking data into computational modeling can further explain, at the level of cognitive computation, how processes affect decision outcomes.

Over the past decade, reviews have summarized the unique contributions of eye-tracking technology to analyzing decision processes and testing decision theories (Huang et al., 2020; Wei & Li, 2015; Orquin & Loose, 2013). Recently, with the maturation of gaze manipulation methods, eye-tracking technology has provided avenues for further exploring causal relationships between decision processes and outcomes and for changing decision behavior. The core idea is to manipulate decision processes through exogenous manipulation or gaze-contingent manipulation, thereby altering decision outcomes in expected directions. The real-time nature of eye movement processes offers significant advantages in manipulation studies: on one hand, key processes requiring manipulation can be identified directly through analysis of eye movement characteristics; on the other hand, using eye-tracking to monitor processes ensures manipulation accuracy and effectiveness. Such research has gradually emerged, providing new evidence for establishing links between decision processes and behavioral outcomes (Fisher, 2021; Liu et al., 2021; Shimojo et al., 2003; Sui et al., 2020), and offering insights for decision interventions from an information processing perspective. This paper reviews gaze manipulation studies across different behavioral deci-

sion domains, 梳理 ing the basic principles, common manipulation indices, and effects of gaze manipulation, analyzes and discusses the advantages and disadvantages of different manipulation categories, reveals the important theoretical and practical significance of gaze manipulation research in decision-making, and finally explores future directions for gaze manipulation research from the perspectives of experimental paradigm improvement, technological development, and application.

In the field of behavioral decision-making, gaze manipulation research can be divided into two main categories: (1) exogenous manipulation studies, which manipulate eye movements and influence decision outcomes by using external cues or changing the physical characteristics of options (Shimojo et al., 2003; Vriens et al., 2020); and (2) gaze-contingent manipulation studies, which monitor participants' autonomous eye movement patterns during decision-making and interrupt option presentation when certain thresholds are reached to manipulate eye movements and alter decision outcomes (Fisher, 2021; Liu et al., 2020; Newell & Le Pelley, 2018). Table 1 summarizes manipulation research categories, specific methods, principles, and main manipulation indices and research domains.

**Table 1 Summary of Manipulation Research Methods**

Manipulation Category	Specific Method	Main Manipulation Index	Research Domain	Representative Studies
Exogenous Gaze Manipulation	Using external cues to guide participants to fixate on target options	Fixation count	Consumer decision-making	Vriens et al., 2020
	Changing physical properties of options: saliency (brightness, opacity, color), labels, size, etc., to guide fixation	Fixation count	Consumer decision-making	Peschel et al., 2019; Zuschke, 2020

Manipulation Category	Specific Method	Main Manipulation Index	Research Domain	Representative Studies
Gaze-Contingent Manipulation	Extending presentation time of options to guide fixation	Fixation duration	Cognitive decision-making	Shimojo et al., 2003; Nittono & Wada, 2009
			Consumer decision-making	Armel et al., 2008
	Interrupting eye movement when last fixation is on target option	Last fixation	Intertemporal decision-making	Fisher, 2021
			Consumer decision-making	Liu et al., 2020
Interrupting when fixation on option (dimension) reaches certain duration	Fixation duration	Fixation duration	Cognitive decision-making	Morii & Sakagami, 2015
			Moral decision-making	Ghaffari & Fiedler, 2018
			Intertemporal decision-making	Fisher, 2021; Liu et al., 2021
			Risk decision-making	Sui et al., 2020
			Cognitive decision-making	Qi et al., 2021; Newell & Le Pelley, 2018; Tavares et al., 2017

Manipulation Category	Specific Method	Main Manipulation Index	Research Domain	Representative Studies
			Moral decision-making	Pärnamets et al., 2015

## 2 Exogenous Gaze Manipulation Studies

Exogenous gaze manipulation studies can guide decision-makers to fixate more on target options or specific dimensions by setting external cues, changing physical characteristics of options (such as saliency, labels, size), or setting option presentation times, thereby altering decision outcomes in expected directions (Shimojo et al., 2003; Vriens et al., 2020). This technique can manipulate various eye movement indices, including fixation count and fixation duration.

### 2.1 Based on External Cues

Common exogenous gaze manipulation studies use external cues to guide decision-makers' attention and change decision preferences. Specifically, researchers randomly set target options and use external cues pointing to target options to guide participants to pay more attention to them, thereby manipulating eye movements and ultimately leading participants to choose target options more frequently. Such studies often use fixation count as a manipulation index. For example, in a food choice study, when participants chose between two similarly liked snacks, different external cues first appeared on screen: an arrow pointing right or left (experimental group), or two arrows pointing left and right simultaneously (control group). After the cues disappeared, two foods were presented on the left and right sides of the screen, and participants needed to choose their preferred option. Results showed that participants made more fixations on the cued target option and preferred it more (Vriens et al., 2020).

### 2.2 Based on Physical Features of Options

Given that stimulus-driven attention can change decision-makers' choice outcomes (Milosavljevic et al., 2012; Orquin & Loose, 2013), researchers can also conduct exogenous gaze manipulation from a bottom-up perspective by directly changing options' physical features, in addition to using external cues from a top-down perspective. The principle of such studies is to guide participants to fixate on target options by changing their physical features, thereby manipulating eye movements and ultimately making them choose target options more frequently. Common methods include: (1) enhancing option saliency, such as increasing brightness, reducing transparency (Milosavljevic et al., 2012; Zuckerman, 2020), or using prominent colors (Kunar et al., 2017); (2) adding labels (Orquin et al.,

2018; Peschel et al., 2019); and (3) enlarging option size (Zuschke, 2020). Such studies often use fixation count as a manipulation index.

For instance, Zuschke (2020) asked participants to choose their preferred chocolate type among different options. The experiment manipulated participants' eye movements by controlling the transparency of chocolate packaging colors. Results showed that lower transparency of packaging colors attracted more fixations and biased participants toward choosing chocolates with lower transparency packaging. Additionally, in experiments manipulating product size, he enlarged some chocolates by 20% and asked participants to choose their preferred type. Results showed that larger-sized chocolates attracted more fixations and biased participants toward choosing them. Similarly, in Peschel et al.'s (2019) study, participants needed to choose their preferred chocolate type among different options. Chocolates had "organic" symbol labels of different sizes on their packaging, and the experiment manipulated participants' fixations and choices by controlling label size. Results showed that chocolates with larger labels attracted more fixations and biased participants toward choosing them. In another experiment controlling label size and adjusting label color brightness, they found that when label size was large, participants fixated more frequently on chocolates with brighter labels and preferred them. In summary, studies manipulating eye movements based on physical features of options are common in consumer decision-making research, revealing how changing physical features can guide individuals' eye movement processes and influence their decisions. Such research provides effective insights for advertising design, product packaging, and shelf placement.

### 2.3 Based on Forced Exposure

Another common method for manipulating eye movements by changing option characteristics is forced exposure, which extends the presentation time of target options to guide participants' fixations, thereby manipulating eye movements and ultimately biasing choices toward predetermined targets. Such studies often use fixation duration as a manipulation index. For example, Shimojo et al. (2003) manipulated the exposure time of target faces in a facial attractiveness judgment study, presenting target faces for longer durations (900 ms) than non-target faces (300 ms), and found that participants tended to perceive target faces as more attractive. Similarly, Nittono and Wada (2009) used abstract figures as experimental materials and asked participants to choose the more attractive picture between two images. The experiment manipulated target and non-target options with presentation durations of 900 ms and 300 ms respectively, and found that participants chose target options at a rate higher than chance (50%). When people have no negative emotions toward options, forced exposure can promote positive evaluation or liking of target options; however, when facing options that evoke negative emotions, forced exposure has the opposite effect. For instance, Armel et al. (2008) asked participants to choose between liked or disliked foods. Results showed that when forced exposure

manipulated target options that participants liked, they preferred target options; however, when manipulated target options were disliked, the probability of choosing target options decreased by 7%. Beyond consumer decision-making, recent intertemporal decision-making research has also used forced exposure to change participants' choice preferences by manipulating presentation durations of different option dimensions: when participants chose between receiving a smaller amount of money sooner ("smaller-sooner," SS option) and a larger amount later ("larger-later," LL option), the monetary and time dimensions were presented alternately on screen, with each dimension presentation lasting 2 seconds and 0.5 seconds respectively. After at least 5 seconds of alternating presentation, participants made their choice. When the target dimension was the monetary dimension, results showed that this manipulation increased the proportion of people choosing the LL option (Fisher, 2021). Thus, forced exposure is an effective exogenous gaze manipulation method that has been successfully applied in multiple domains including cognitive decision-making, consumer decision-making, and intertemporal decision-making.

In summary, exogenous gaze manipulation methods are diverse. Researchers can manipulate eye movements and guide participants' choice preferences using cue orientation, enhancing physical features of options, or extending option presentation durations. Such studies are simple and convenient to operate and have been widely used in decision-making research. From an application perspective, the conclusion that manipulating exogenous stimuli can influence participants' natural choice preferences provides insights for product design. For example, based on research findings on manipulating physical features, changing food packaging to bright colors or enlarging label sizes can increase consumer attention to products and boost sales.

However, exogenous gaze manipulation studies have some limitations. First, although this method can strengthen participants' preferences for target options, demand effects may occur during the process (Newell & Le Pelley, 2018). Participants might guess the research purpose—that they are being guided to choose target options—because target options have longer presentation times or more prominent physical features. Therefore, exogenous gaze manipulation may cause participants to consciously choose target options according to experimental demands, thereby affecting result credibility. Second, not all exogenous stimuli theoretically related to decision processes can influence decision outcomes. For example, according to the gaze cascade effect and drift diffusion model assumptions, first fixation should influence choice outcomes, but exogenous gaze manipulation experiments have not found that manipulating this index can change decision results (van der Laan et al., 2015). Thus, although exogenous gaze manipulation technology is widely used, its reliability, credibility, and application scope are somewhat affected by interference such as demand effects.

### 3 Gaze-Contingent Manipulation Studies

Gaze-contingent manipulation studies adopt gaze-based manipulation methods that are less detectable to participants, reducing demand effects on experimental results and overcoming some limitations of exogenous gaze manipulation studies. The basic idea of such research is to randomly set target options in advance, use eye-trackers to monitor participants' autonomous eye movement patterns in real time, and when their eye movement patterns meet trigger conditions, experimental stimuli disappear and a choice interface appears, requiring participants to make choices, thereby influencing participants' behavior (Newell & Le Pelley, 2018; Pärnamets et al., 2015). Commonly manipulated eye movement indices in such studies include last fixation and fixation duration (Fisher, 2021; Liu et al., 2020; Liu et al., 2021), with fixation duration manipulation being most common. Currently, this technology is widely used in consumer decision-making, intertemporal decision-making, risk decision-making, moral decision-making, and cognitive decision-making to explore causal relationships between fixation and decision outcomes in each domain.

#### 3.1 Based on Last Fixation

First, gaze-contingent manipulation studies can manipulate last fixation to change choice preferences. Specifically, researchers set target options and track decision-makers' autonomous eye movement processes. After decision-makers have fixated on both options for a certain time, when they refixate the target option, the eye movement process is interrupted for manipulation, making the last fixation land on the target option. Consequently, participants may be more inclined to choose the target option. This method has been effectively applied in consumer and moral decision-making. In consumer decision-making research, two foods with similar preference levels were presented on the left and right sides of the screen, and participants' eye movements were tracked. When the eye-tracker detected that participants had fixated on both foods for at least 500 ms each, and then fixated on the randomly set target food for 50 ms, options stopped being presented and participants selected their preferred food. Results showed that participants chose the target food at a rate greater than 50% (Liu et al., 2020), indicating that manipulating last fixation can influence decision-makers' choice preferences. In moral decision-making research, participants were presented with moral dilemmas with options on the left and right sides of the screen. When the eye-tracker detected that participants had fixated on options for certain durations (750 ms for target options, 250 ms for non-target options), and they refixated the target option, options stopped being presented and participants selected their preferred option. Results showed that participants were biased toward choosing the last fixated option (Ghaffari & Fiedler, 2018). However, in cognitive decision-making, manipulating eye movements based on last fixation did not achieve expected effects. For example, Morii and Sakagami (2015) used abstract pictures as experimental materials, presented them on the left and right sides of the

screen, and when the eye-tracker detected that participants had fixated on both options and then refixated the target option, options stopped being presented and participants selected the more attractive picture. However, results showed that participants' choices did not bias toward the predetermined target option.

We propose that differences in the effectiveness of last fixation-based gaze manipulation across studies may depend on decision task characteristics. Compared to cognitive decision-making, in consumer and moral decision-making experiments, choice outcomes have greater impact on participants: in consumer decision-making, participants are required to eat the food they choose; in moral decision-making, participants may consider researchers' opinions of them and be influenced by social desirability. Therefore, they are more likely to concentrate attention and think carefully during decision-making. When gaze manipulation interrupts their thought process, the last fixated option may have a stronger recency effect (Atkinson & Shiffrin, 1968; Cowan, 1993), thereby achieving the expected manipulation effect.

### 3.2 Based on Fixation Duration

In addition to last fixation, fixation duration-based gaze manipulation methods are also common in gaze-contingent manipulation studies. The basic principle of such research is to preset fixation durations for target and non-target options (with target option duration significantly longer than non-target), track decision-makers' autonomous eye movement processes, and when fixation durations on both target and non-target options reach set thresholds, stop presenting options and prompt decision-makers to choose. Manipulation objects can be divided into two main categories: fixation duration on options and fixation duration on dimensions. In option-based manipulation studies, researchers randomly select target options, and decision prompts are triggered when participants' fixation durations on both target and non-target options reach thresholds. Such manipulation methods have proven effective across different decision-making categories, showing that manipulating fixation duration on options can increase the proportion of target options being chosen. In dimension-based manipulation studies, researchers randomly select a dimension of options as the target dimension, and decision prompts are triggered after participants fixate on both target and non-target dimensions for certain time thresholds. Such research shows that manipulating fixation duration on dimensions can make participants more likely to choose options where the target dimension is superior.

In intertemporal decision-making research, Fisher (2021) manipulated fixation duration based on options. The experiment randomly selected SS or LL options as target options. Once participants fixated on an option for a certain duration (1.2 seconds for target options, 0.3 seconds for non-target options), that option disappeared from the screen. When both options disappeared, participants made their decision. Results showed that when the LL option was the target option, the proportion of participants choosing the LL option increased compared to other conditions. Similarly, Liu et al. (2021) also manipulated

participants' fixation duration based on options. After participants fixated on target options for at least 2000 ms and each area of interest for at least 50 ms, options disappeared and participants made their decision. Results showed that manipulating fixation duration on target options biased participants toward choosing them. In dimension-based manipulation studies, when the eye-tracker detected that participants fixated on target dimensions for 2000 ms and each area of interest for at least 50 ms, options disappeared and participants made their decision. Results found that manipulating fixation duration on target dimensions made the probability of choosing options superior on that dimension exceed 50%. These findings show that manipulating participants' fixation duration on target dimensions can bias them toward options superior on that dimension. In risk decision-making, Sui et al. (2020) also conducted gaze manipulation based on both options and dimensions. In this study, participants chose between two risk options with expected value differences no greater than 10. When the eye-tracker detected that participants fixated on target options for 1500 ms and each area of interest for 100 ms (Study 1), or fixated on target dimensions for 1000 ms and each area of interest for 100 ms (Study 2), options disappeared and participants made their choice. Results showed that in risk decision-making, increasing participants' fixation duration on target options or dimensions could change their choice preferences in expected directions.

Additionally, option-based gaze manipulation technology has been applied to basic cognitive decision-making and more complex moral decision-making research. In cognitive decision-making, Tavares et al. (2017) asked participants to choose which of two lines with different tilt angles was closer in tilt to a line segment they had seen before the experiment. Results showed that manipulating fixation duration on target options effectively guided participants to choose them. Similarly, Newell and Le Pelley (2018) and Qi et al. (2021) replicated Tavares et al.'s (2017) findings in picture recognition tasks. Moreover, in more complex moral decision-making, option-based gaze manipulation methods can still effectively influence decision preferences. Pärnamets et al. (2015) asked participants to choose the morally correct option in dilemmas such as "murder is sometimes justified" versus "murder is never justified," with target options randomly determined by researchers. When participants fixated on target options for 750 ms and non-target options for 250 ms, options stopped being presented and participants made their choice. Results showed that participants were biased toward target options, revealing a causal relationship between fixation duration and moral decision-making. Thus, fixation duration-based gaze manipulation has proven effective across multiple decision-making domains. However, such methods are prone to timeout trials, affecting experimental efficiency.

Overall, because gaze-contingent manipulation studies are less detectable to participants, they partially overcome demand effects associated with exogenous manipulation. Gaze-contingent manipulation studies can manipulate eye movements based on options or dimensions and have been widely applied in basic cognitive decision-making and more complex risk, intertemporal, consumer, and moral decision-making. These findings have important theoretical significance

for establishing causal chains between decision processes and outcomes and provide important real-world implications for improving various decisions individuals make in daily life. For example, in daily intertemporal decision-making, increasing exposure to long-term options and their superior dimensions may effectively reduce individuals' impulsivity and avoid short-sighted behavior.

However, gaze-contingent manipulation studies have certain limitations. For instance, because option information presentation depends on participants' actual fixations, participants' eye movement conditions may fail to meet trigger thresholds in some trials: within the maximum presentation time for options, fixation duration may not reach the set threshold, causing trial failure and affecting experimental efficiency. In the reviewed articles, invalid trials accounted for 3% to 25% of total trials, yet few studies explained this variation in eye movement processes across trials. Among these studies, Liu et al. (2020) had the smallest proportion of timeout trials, and their experimental materials had undergone preference testing beforehand, with decision-makers choosing among options without significant preference differences in subsequent experiments. Therefore, we propose that one reason for many timeout trials in gaze-contingent manipulation studies may be that most research does not consider decision-makers' actual preferences and individual differences, using uniform stimulus materials that allow participants' prior preference differences for options to affect manipulation effectiveness. Second, because gaze-contingent manipulation studies intervene in eye movements during participants' fixation processes, participants make choices in non-natural states that differ from everyday decision-making, making such studies...

#### 4 Summary and Outlook

Early research in behavioral decision-making focused only on relationships between input and output variables, neglecting the puzzle of "how people actually make decisions." Process technologies such as eye-tracking have opened the "black box" of decision cognition, making special contributions to analyzing decision processes and testing decision theories. Furthermore, gaze manipulation technology manipulates eye movement processes through exogenous manipulation or gaze-contingent manipulation methods, systematically changing experimental participants' decision behavior preferences and establishing causal chains between decision processes and outcomes. The two types of manipulation studies share the same fundamental purpose but have different characteristics, making them suitable for different research scopes. Future researchers should choose appropriate methods according to actual research designs.

Exogenous gaze manipulation manipulates eye movements by changing option presentation methods or physical properties, thus purposefully directing participants' fixations to target options from the initial stage of the decision process, thereby influencing decision eye movement processes and outcomes. Exogenous manipulation methods are relatively diverse and can manipulate many eye movement indices, but experimental designs require changing options' physical fea-

tures or presentation durations, making them prone to demand effects. Such manipulation studies have simple option frameworks and designs, are easy to generalize, and their results have important practical implications. Therefore, in consumer behavior research, exogenous gaze manipulation technology can be used to explore what marketing methods can effectively promote customer purchasing behavior and improve advertising design effectiveness.

Gaze-contingent manipulation studies do not change option attributes but directly intervene in decision eye movement processes to influence decision outcomes, acting more on intermediate decision processes. Such studies do not need to change option presentation methods or physical properties, making it difficult for participants to identify target options or guess research purposes. However, manipulation methods are relatively singular, and because option presentation depends on participants' actual fixations, timeout trials easily occur, causing trial failure. Gaze-contingent manipulation studies can test and compare decision models based on processes. For example, in intertemporal decision-making, classic discounting models such as the discounted-utility model (DU, Samuelson, 1937) assume more option-based processing eye movement patterns, while non-discounting models such as the trade-off model (Scholten & Read, 2010) assume more dimension-based processing eye movement patterns. Intertemporal decision-making research has effectively changed decision preferences through dimension-based gaze manipulation, indirectly supporting non-discounting model assumptions. Additionally, research manipulating fixation duration to change choice preferences provides direct experimental evidence for attention models like aDDM that assume "option value is overestimated by excessive attention."

Gaze manipulation research has important significance: at the theoretical level, by manipulating eye movement processes assumed by different decision theories and exploring links between processes and outcomes, it can test and compare decision models at the process level, providing direct experimental evidence for theoretical model assumptions based on decision processes. At the practical level, manipulating eye movement processes to change decision outcomes can make decision behavior change in expected directions without altering option values or violating participants' free choice will, offering insights for improving real-world decision quality from an information processing perspective.

As Lahey and Oxley (2016) stated, future decision-making research using eye-tracking technology still has great potential. Gaze manipulation technology can bring new discoveries to behavioral decision-making research and promote decision theory development and application. We believe that future gaze manipulation research in decision-making should focus on exploring the following aspects:

First, to address limitations in existing gaze manipulation research, future studies could improve experimental paradigms in several ways. Most existing manipulation studies do not consider how participants' use of different decision strategies affects experimental results. According to Simon' s (1982) bounded

rationality assumption, organisms need to adjust strategies according to decision environment structure to cope with environmental challenges (Gigerenzer & Gaissmaier, 2011). For gaze manipulation research, in risk and intertemporal decision-making studies, both dimension-based and option-based manipulations can effectively change participants' choice preferences, indirectly confirming that participants may use mixed processing strategies during decision-making (Sui et al., 2020). Under different experimental parameter conditions, participants may adopt different decision strategies. Using single manipulation methods without distinguishing strategies may cause some trials to fail. Second, most gaze manipulation studies implicitly assume that participants have approximately equal preferences for options, thus using uniform, self-selected stimulus materials in most research, ignoring individual differences in choice preferences. In reality, if participants have prior preference differences for experimentally set options, they may have attentional biases toward certain choices, making autonomous decision eye movement processes difficult to reach manipulation trigger conditions and causing trial failure. To address these issues, future research should fully consider decision strategies and choice preference differences among participants in decision-making. For example, since different strategies used by decision-makers can be represented by different eye movement patterns (Horstmann et al., 2009; Zhou et al., 2016; Zhou et al., 2018), researchers could test participants' decision strategies and preferences under different parameter conditions before formal experiments and set specific experimental materials for each participant (Zhou, Liang, et al., 2019) to eliminate effects of individual differences and experimental parameter specificity on gaze manipulation effectiveness.

Second, to address the relatively singular eye movement indices manipulated in current gaze manipulation research, researchers need to further develop and enrich gaze manipulation indices and analytical methods. We believe that combining computational modeling and machine learning technology can provide pathways for establishing key manipulation indices. Computational modeling is superior to general analytical methods in establishing relationships between hidden decision variables in each trial and actual decision preferences, thus enabling dynamic decision process modeling (Scheibehenne & Pachur, 2015). Therefore, adding eye movement process data as important predictive variables in decision models can improve model explanatory power (Zhou, Zhang, et al., 2019) and build integrated decision models combining outcome and process data. For gaze manipulation research, combining with computational modeling can effectively establish key eye movement indices with highest explanatory power for decision outcomes, thereby improving gaze manipulation research effectiveness. Additionally, machine learning may provide new ideas for gaze manipulation research. Machine learning technology can make predictions from large datasets, thus establishing decision models based on machine learning algorithms has broad prospects (Bhatia & He, 2021). As user gaze datasets continue to grow, the combination of machine learning and eye-tracking research will continuously improve (Król & Król, 2017; Shojaeizadeh et al., 2019). Existing research has combined machine learning and eye-tracking technology to predict behavior

from eye movement indices. For example, Eivazi and Bednarik (2011) used eye movement data-based classification methods to predict participants' problem-solving. Future manipulation research could use machine learning methods to efficiently remove redundancy from massive data and precisely establish effective gaze manipulation indices.

Third, from an application perspective, gaze manipulation research could be extended to decision-making problems in human resource management and other fields. Affected by the COVID-19 pandemic, many industries have abandoned traditional work models and turned to online operations (Cleland et al., 2020; Dannenberg et al., 2020). Due to many objective factors, communication effectiveness between job seekers and interviewers in online recruitment is often inferior to face-to-face interviews (Jones & Abdelfattah, 2020). Non-verbal information may significantly affect online interview outcomes (Zhang & Xu, 2016). If gaze manipulation is introduced into interview research, on one hand, exogenous gaze manipulation technology could be used to explore the influence of non-verbal factors (such as clothing, lighting) on interviewer ratings, providing suggestions for improving online interview effectiveness. On the other hand, relevant moderating variables (such as time pressure, participant emotions, cognitive load) could be added to explore how such factors affect interview effectiveness. A consumer decision-making study found that under cognitive load and time pressure, increasing target food brightness could prompt participants to choose it (Milosavljevic et al., 2012). Accordingly, gaze manipulation research could also be used to explore how to improve interview effectiveness through exogenous cues under factors like time pressure.

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