The Effect of State Anxiety on Time Perception: A Moderated Mediation Model of Cognitive Appraisal and Attentional Bias

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Abstract

This study investigated the effects of state anxiety on time perception and the mediating and moderating roles of attentional bias and cognitive appraisal therein. Sixty university students were recruited and randomly assigned to high and low state anxiety groups, with emotional induction procedures used to induce high and low state anxiety; the dot-probe paradigm was employed to measure attentional bias; a temporal reproduction task was used to measure time perception; and the Visual Analogue Mood Scale was utilized to assess cognitive appraisal. The results revealed: (1) State anxiety led to overestimation of the 2000 ms duration; (2) Attentional bias partially mediated the effect of state anxiety on 2000 ms time perception; (3) The mediating process through which state anxiety influenced time perception via attentional bias was moderated by cognitive appraisal: only when cognitive appraisal scores were high, that is, when individuals perceived anxiety as highly detrimental to mental health, did state anxiety affect 2000 ms time perception through attentional bias. The findings elucidate the internal processes underlying time perception in anxious individuals, enrich the explanatory perspective on how anxiety influences time perception through attentional bias, and provide important insights for ameliorating temporal distortion phenomena in anxious individuals through the modification of cognitive appraisal and attentional bias.

Full Text

How State Anxiety Influences Time Perception: A Moderated Mediation Model of Cognitive Appraisal and Attentional Bias

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Abstract

Anxiety is characterized by high arousal and attentional bias toward negative stimuli. These two core features of anxiety influence various subjective experiences, including time perception. However, the underlying mechanisms remain unclear. This study investigated how state anxiety affects time perception, with particular focus on the roles of attentional bias and cognitive appraisal.

Sixty college students were randomly assigned to either a high state anxiety group (n = 30) or a low state anxiety group (n = 30). A 2 (group) × 2 (stimulus type: negative vs. neutral) × 3 (duration: 2000 ms vs. 4000 ms vs. 8000 ms) mixed-design experiment was conducted, with attentional bias as the mediator, cognitive appraisal as the moderator, and time perception as the dependent variable. State anxiety was induced using a standardized procedure, time perception was measured via a time reproduction task, attentional bias was assessed with a dot-probe task, and cognitive appraisal was evaluated using Visual Analogue Mood Scales (VAMS).

The results revealed that: (1) State anxiety led to overestimation of the 2000 ms interval for negative stimuli; (2) Attentional bias partially mediated the relationship between state anxiety and time perception of 2000 ms; and (3) Cognitive appraisal moderated this mediating effect. Specifically, attentional bias mediated the influence of state anxiety on time perception only when cognitive appraisal scores were high (i.e., when individuals perceived anxiety as highly detrimental to mental health). When cognitive appraisal scores were low, this mediating effect was not observed.

These findings demonstrate that the effect of state anxiety on time perception follows a moderated mediation model. This model elucidates the mechanism through which state anxiety influences time perception in college students and suggests that modifying cognitive appraisal or attentional bias may help alleviate time distortion in anxious individuals.

Keywords: state anxiety; time perception; attentional bias; cognitive appraisal

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Do individuals in an anxious state perceive time as passing faster or slower? And if so, how does anxiety influence time perception? Time perception refers to an individual' s subjective estimation of the duration of a single event or the interval between two events (Huang, Liu, Li, Chen, & Huang, 2018; Huang, Li, & Zhang, 2003). A thorough investigation of this question will help clarify the internal processes underlying time perception in anxious individuals and may provide a novel perspective for understanding anxiety—if anxious individuals experience time differently, perhaps anxiety represents a "normal" response to their distorted internal temporal experience.

Research on time perception can be broadly categorized into two types: (1) retrospective timing, where participants are asked to estimate duration after completing a task; and (2) prospective timing, where participants are informed beforehand that they will need to make temporal judgments. These two paradigms involve distinct cognitive processes (Grondin, 2010). Retrospective timing primarily relies on memory processes (Block & Zakay, 1997; Zakay & Block, 1997, 2004), whereas prospective timing is mainly associated with stimulus arousal and attentional resource allocation (Zakay, 1993; Zakay, Nitzan, & Glicksohn, 1983). To date, research on anxiety' s effect on time perception has been limited, with most studies employing prospective timing paradigms and focusing on trait anxiety or clinical anxiety populations. These findings have been inconsistent, with only one study examining state anxiety reporting null results (Lueck, 2007). We argue that investigating state anxiety holds particular significance: it allows us to disentangle the established feedback loop between trait anxiety (or clinical anxiety disorders) and attentional bias toward negative stimuli (Eysenck, 1992, 1997), while also revealing time perception characteristics under more commonly experienced state anxiety in daily life.

Previous findings can be organized along two lines: (1) Anxiety induces underestimation in prospective timing. For instance, Whyman and Moos (1967) employed verbal estimation tasks and found that both high- and low-anxiety individuals underestimated durations of 15000 ms, 30000 ms, and 90000 ms. Mioni and colleagues (2016) used time production and reproduction tasks and found that trait-anxious individuals underestimated intervals of 500 ms, 1000 ms, and 1500 ms more than non-anxious controls. (2) Anxiety induces overestimation in prospective timing. Bar-Haim and colleagues (2010) used a time reproduction task to examine duration perception for fearful and neutral stimuli presented for 2000 ms, 4000 ms, and 8000 ms, finding that trait-anxious individuals overestimated the 2000 ms fearful stimuli compared to neutral stimuli. Yoo and Lee (2015) further investigated time perception in socially anxious individuals using verbal estimation tasks for stimuli varying in valence and arousal (positive high-arousal, positive low-arousal, negative high-arousal, negative low-arousal) presented randomly for 2000 ms, 4000 ms, or 6000 ms. They found that high socially anxious individuals overestimated negative high-arousal stimuli compared to other stimuli, whereas low socially anxious individuals overestimated positive low-arousal stimuli.

Subsequent researchers have offered different explanations for these divergent findings on underestimation and overestimation. Some propose that longer durations are prone to underestimation (e.g., Eisler, 1976; Eisler, Eisler, & Hellström, 2008), which may account for the universal underestimation of 15000 ms, 30000 ms, and 90000 ms intervals in Whyman and Moos' s (1967) study. Others explain overestimation in anxious individuals by suggesting that time perception distortions are related to changes in attentional functions (e.g., Mioni et al., 2016) or stimulus arousal (Bar-Haim et al., 2010; Yoo & Lee, 2015).

The Attentional Gate Model (AGM) provides a more comprehensive framework for explaining prospective timing distortions by integrating both arousal and attention (Zakay & Block, 1997). As illustrated in Figure 1 [Figure 1: see original paper], the model posits that a pacemaker emits pulses at a relatively constant rate, but this process is modulated by stimulus arousal—high-arousal stimuli increase the pacemaker' s pulse frequency. These pulses then flow to an attentional gate, where greater attentional resources allocated to timing result in more pulses passing through to the accumulator. Consequently, both highly arousing stimuli and increased attention to timing enhance perceived duration, leading to time overestimation (Zakay, 2005; Zakay & Block, 1997).

Figure 1. Attentional Gate Model (Zakay & Block, 1997)

Findings from anxiety and time perception research involving stimulus arousal have generally supported AGM, showing that anxious individuals overestimate the duration of high-arousal emotional stimuli (Bar-Haim et al., 2010; Yoo & Lee, 2015). However, whether attention' s role in the anxiety-time perception relationship aligns with AGM remains unclear. Furthermore, how exactly does attention influence time perception in anxious individuals? This study addresses these questions by examining attention' s role while controlling for stimulus arousal.

According to AGM, increased attentional resources allocated to timing allow more pulses to pass through the gate, resulting in greater time overestimation (Zakay, 2005; Zakay & Block, 1997). Numerous studies have demonstrated that anxiety induces attentional bias toward negative stimuli (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Karademas, Christopoulou, Dimostheni, & Pavlu, 2008; Koster, Leyman, Raedt, & Crombez, 2006; Van Bockstaele et al., 2014)—a tendency to prioritize or allocate more attentional resources to negative stimuli (see Lü, Niu, & Zhang, 2014). Therefore, increased attentional bias toward negative stimuli under anxiety means more attentional resources are allocated to the timed negative stimulus, which according to AGM, should lead to overestimation of negative stimuli durations. Based on this, we propose Hypothesis 1: State anxiety influences time perception of negative stimuli through attentional bias toward those stimuli; that is, attentional bias mediates the effect of state anxiety on time perception.

Furthermore, does anxiety-induced attentional bias depend on cognitive appraisal? In other words, if an anxious individual does not believe their anxiety has negative consequences—for instance, that it will not affect their physical or mental health (see Folkman, Lazarus, Dunkel-Schetter, Delongis, & Gruen, 1986, for the concept of cognitive appraisal)—will anxiety still produce attentional bias toward negative stimuli? Or might this bias be attenuated? Extensive research has shown that cognitive appraisal influences attentional resource allocation (Hajcak, Moser, & Simons, 2006; van Reekum et al., 2007; Wang & Mao, 2016). For example, Kim, Kim, and Kim (2016) found that reducing cognitive appraisal of negative emotions decreased attentional bias toward angry faces, whereas increasing such appraisal enhanced the bias. Jamieson, Nock, and Mendes (2012) found that altering cognitive appraisal of a stress task improved cardiovascular function and reduced attentional bias toward negative stimuli. In summary, anxiety does not necessarily produce attentional bias toward negative stimuli; this relationship is moderated by cognitive appraisal. Given that cognitive appraisal influences attentional bias, it may serve as a potential moderator in the relationship between anxiety and attentional bias, thereby constituting a boundary condition for the mediating role of attentional bias in anxiety' s effect on time perception. Therefore, we propose Hypothesis 2: The mediating process through which state anxiety influences time perception via attentional bias is moderated by cognitive appraisal (as shown in Figure 2 [Figure 2: see original paper]).

Figure 2. Moderated mediation model of state anxiety' s effect on time perception

The study employed an emotion induction procedure to elicit state anxiety, a dot-probe paradigm to measure attentional bias, a time reproduction task to assess time perception, and VAMS to evaluate cognitive appraisal. Bootstrap analysis was used to test the moderated mediation model examining how cognitive appraisal and attentional bias influence the relationship between state anxiety and time perception.

Method

Participants

Sample size was calculated using G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007). Following Cohen' s (1992) criteria for repeated-measures ANOVA, with parameters set for between-subjects repeated measures (effect size f = 0.14, = 0.05, power = 0.80, number of groups = 2, number of measurements = 6, correlation among repeated measures = 0.5), the required total sample size was 56. Accounting for 10% attrition, 60 college students were recruited from a Beijing university via campus posters. Participants registered online through a QR code on the poster. The final sample comprised 27 males and 33 females with a mean age of 21.78 years (SD = 2.73). Participants were randomly assigned to either the high state anxiety group (n = 30) or low state anxiety group (n = 30). Written informed consent was obtained, and the study was approved by the university' s ethics committee (approval number: 20160907).

Given that previous research has primarily examined trait anxiety or clinical populations, this study focused exclusively on state anxiety' s effect on time perception. Theoretically, random sampling and assignment should ensure participant homogeneity and prevent potential differences in trait anxiety levels between groups, thus obviating the need for trait anxiety screening. According to previous research, high trait anxiety is associated with elevated state anxiety (Spielberger, 1971). Therefore, if the high and low state anxiety groups differed significantly in trait anxiety, they should also differ in baseline state anxiety. Conversely, if no significant baseline differences exist, we can infer comparable trait anxiety levels between groups. Consequently, baseline state anxiety was measured and analyzed to ensure that group differences in time perception could not be attributed to trait anxiety differences.

Measures

(1) Emotion Induction
State anxiety was induced using a standardized procedure developed by Montorio et al. (2015). Participants read 25 Velten sentences designed to induce anxiety (high state anxiety group; e.g., "I am so tense that I cannot recall past events" or "This is so terrifying, I cannot stand the tension") or calmness (low state anxiety group; e.g., "I enjoy reading a book and savoring the tranquility and comfort" or "I feel leisurely and content") at a rate of 12 seconds per sentence for 5 minutes. This was followed by a 2-minute incubation period during which participants were instructed to immerse themselves in the induced emotional state through recall or imagination. Throughout the 7-minute procedure, anxiety-inducing music (Ligeti Project-Requiem) was played for the high state anxiety group, while calming music (Schoenberg' s Erwartung) was played for the low state anxiety group.

(2) State Anxiety Measurement
State anxiety levels were assessed using the Visual Analogue Mood Scales (VAMS; McCormack, Horne, & Sheather, 1988). Participants selected a number between 0 and 100 to subjectively rate "your current level of anxiety."

(3) Stimulus Materials
To control stimulus arousal, negative low-arousal and neutral low-arousal images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) were used as stimuli for both the dot-probe and time reproduction tasks (see Appendix). In addition to IAPS normative ratings, 49 informal participants (24 males, 25 females, M age = 20.44, SD = 2.29) rated each image' s valence, arousal, and familiarity on 9-point scales (1 = very negative to 9 = very positive; 1 = very low arousal to 9 = very high arousal; 1 = very unfamiliar to 9 = very familiar) to ensure suitability for Chinese college students.

For the dot-probe task, 16 negative-neutral low-arousal image pairs (e.g., 9102-6000, 2710-2579) were used. Paired-samples t-tests confirmed significant valence differences between negative and neutral low-arousal images, with no significant differences in arousal or familiarity (see Table 1). All image pairs were presented randomly.

For the time reproduction task, 16 different negative and neutral low-arousal images were used: 8 negative low-arousal images (e.g., 2205, 2722) and 8 neutral low-arousal images (e.g., 1616, 2220). Independent-samples t-tests on ratings from the 49 participants revealed significant valence differences but no significant arousal or familiarity differences (see Table 2). All images were presented randomly during the task.

Table 1. Valence, Arousal, and Familiarity Ratings for Dot-Probe

Task Images

Rating	Negative Low-Arousal	Neutral Low-Arousal	p
IAPS Valence M (SD)	2.99 (0.57)	5.15 (0.75)	<0.001
Chinese Sample Valence M (SD)	2.78 (0.49)	5.03 (0.79)	<0.001
IAPS Arousal M (SD)	4.80 (0.51)	4.72 (0.49)	
Chinese Sample Arousal M (SD)	5.31 (0.74)	5.15 (0.61)	
Chinese Sample Familiarity M (SD)	3.93 (0.78)	4.06 (1.13)	

Table 2. Valence, Arousal, and Familiarity Ratings for Time Reproduction Task Images

Rating	Negative Low-Arousal	Neutral Low-Arousal	p
IAPS Valence M (SD)	2.77 (0.66)	5.15 (0.06)	<0.001
Chinese Sample Valence M (SD)	2.94 (0.58)	4.91 (0.99)	<0.001
IAPS Arousal M (SD)	4.12 (0.32)	3.90 (0.50)	
Chinese Sample Arousal M (SD)	5.28 (0.37)	5.07 (0.94)	
Chinese Sample Familiarity M (SD)	4.17 (1.03)	4.39 (1.18)	

(4) Attentional Bias Measurement
Attentional bias was measured using a dot-probe paradigm. Each trial began with a fixation cross "+" presented centrally for 500 ms, followed by a pair of negative and neutral images appearing simultaneously on the left and right sides of the screen for 500 ms. After a 50 ms blank interval, a probe "*" appeared in the location previously occupied by one of the images. Participants were instructed to press the "F" key with their left index finger if the probe appeared on the left, or the "J" key with their right index finger if it appeared on the right, responding as quickly and accurately as possible. The trial ended after the response or after 2000 ms, followed by a 1000 ms inter-trial interval. The task included 8 practice trials (using non-experimental neutral images) and 64 experimental trials (16 image pairs × 4 repetitions, with each image appearing equally often on the left and right, and probes appearing equally often in negative and neutral locations). Trials where the probe appeared on the same side as the negative image were designated "congruent," while those where it appeared on the opposite side were "incongruent" (see Figure 3 [Figure 3: see original paper]). Attentional bias scores were calculated as the ratio of incongruent to congruent reaction times. Greater incongruent RTs or bias scores > 1 indicate attentional bias toward negative stimuli relative to neutral stimuli.

Figure 3. Dot-probe paradigm procedure

(5) Time Perception Measurement
Time perception was assessed using a time reproduction task (Bar-Haim et al., 2010). Each trial began with a fixation cross "+" presented for 800 ms, followed

by a negative or neutral image displayed centrally for 2000 ms, 4000 ms, or 8000 ms. After image offset, the prompt "计时开始" (Start timing) appeared, and participants pressed the spacebar to begin timing a blank interval. When participants believed the blank interval matched the previously presented image duration, they pressed the spacebar again, triggering the prompt "计时结束" (End timing). Participants were instructed to estimate time without external aids. The task included 5 practice trials (using non-experimental neutral images) and 48 experimental trials (3 durations × 16 images). Time perception was analyzed using the Time Perception Index (TPI; Mioni et al., 2016). TPI was calculated as the ratio of the Ratio for negative stimuli to the Ratio for neutral stimuli, reflecting relative time perception between negative and neutral stimuli. A TPI of 1 indicates equivalent perception; TPI $>$ 1 indicates overestimation of negative stimuli; TPI $<$ 1 indicates underestimation.

‡ Ratio refers to the mean reproduced duration divided by the standard duration (2000 ms, 4000 ms, or 8000 ms).

(6) Cognitive Appraisal Measurement
Folkman and Lazarus measured cognitive appraisal using 5-point scales (Folkman, Lazarus, Dunkel-Schetter, et al., 1986; Folkman, Lazarus, Gruen, et al., 1986). To enhance discriminability (Lozano, Garcíacueto, & Muñiz, 2008), this study used VAMS to assess cognitive appraisal by asking participants to rate "the degree to which you believe anxiety is harmful to mental health" on a 0-100 scale. Cognitive appraisal is conceptualized as a trait-level construct not influenced by state anxiety induction. However, because measuring cognitive appraisal involves concepts of "anxiety" and "harm," which could potentially interfere with state anxiety induction, this measure was administered at the end of the experimental procedure to control for unknown effects on the results.

Procedure

The experiment was programmed using E-Prime 2.0. After entering the laboratory, participants completed the following sequence: (1) pre-induction state anxiety measurement; (2) emotion induction; (3) post-induction state anxiety measurement; (4) attentional bias measurement; (5) time perception measurement; (6) cognitive appraisal measurement; and (7) final state anxiety measurement. Following the experiment, participants watched a humorous video (selected from *Minions Shorts*) to restore emotional equilibrium.

Results

Emotion Induction Effect

Table 3 presents the emotion induction results for high and low state anxiety groups. The absence of significant baseline differences between groups indicates comparable trait anxiety levels, confirming that random sampling, assignment, and baseline measurement effectively controlled for trait anxiety confounds. Following induction, the high state anxiety group showed significantly elevated state anxiety compared to the low state anxiety group, demonstrating successful manipulation.

A 2 (group: high vs. low state anxiety) × 2 (measurement: pre-test vs. post-test) repeated-measures ANOVA on VAMS scores revealed a significant interaction, $F(1, 58) = 69.63$, $p < 0.001$, $^2 = 0.55$, a significant main effect of group, $F(1, 58) = 13.06$, $p = 0.001$, $^2 = 0.18$, and a marginally significant main effect of measurement, $F(1, 58) = 3.68$, $p = 0.060$, $^2 = 0.06$. Paired-samples t-tests showed that state anxiety increased significantly in the high state anxiety group, $t(29) = 6.22$, $p < 0.001$, $d = 1.14$, and decreased significantly in the low state anxiety group, $t(29) = -5.68$, $p < 0.001$, $d = 1.04$. Additionally, after completing the attentional bias, time perception, and cognitive appraisal measures, the high state anxiety group maintained significantly higher state anxiety than the low state anxiety group (M_high = 58.67, SD_high = 24.88; M_low = 35.67, SD_low = 28.05), $t(58) = 3.36$, $p = 0.001$, $d = 0.87$, indicating that the induction effect persisted throughout the experimental session.

Table 3. Emotion Induction Effects for High and Low State Anxiety Groups

Measurement	High State Anxiety	Low State Anxiety
Pre-test M (SD)	40.83 (30.42)	38.23 (29.33)
Post-test M (SD)	66.97 (25.87)	21.87 (23.41)
p	<0.001	

Cognitive Appraisal

An independent-samples t-test revealed no significant baseline difference in cognitive appraisal between high and low state anxiety groups (M_high = 83.00, SD_high = 20.66; M_low = 76.97, SD_low = 21.44), $t(57) = 1.10$, $p = 0.276$, $d = 0.29$, confirming that cognitive appraisal, as a trait-level construct, was not affected by state anxiety induction.

Attentional Bias

(1) Effect of State Anxiety on Attentional Bias
Trials with incorrect responses or reaction times < 200 ms or > 1200 ms were excluded (Mogg, Wilson, Hayward, Cunning, & Bradley, 2012), leaving 99.04% of trials for analysis. Mean RTs and standard deviations are presented in Table 4 . Results indicate that state anxiety influenced attentional bias, with the high state anxiety group showing significantly higher attentional bias scores than the low state anxiety group, reflecting greater attentional bias toward negative low-arousal stimuli.

A 2 (group) × 2 (probe position: incongruent vs. congruent) repeated-measures ANOVA revealed a significant interaction, $F(1, 58) = 5.67$, $p = 0.021$, $^2 = 0.09$, non-significant main effects of group, F(1, 58) = 0.23, p = 0.630, ^{2} = 0.004, and probe position, F(1, 58) = 1.18, p = 0.282, ^{2} = 0.02. Paired-samples t-tests showed that the high state anxiety group had significantly longer RTs for incongruent than congruent trials, t(29) = 2.66, p = 0.012, d = 0.48, whereas the low state anxiety group showed no significant difference, t(29) = -0.85, p = 0.400, d = 0.16. These results demonstrate that the high state anxiety group exhibited significant attentional bias toward negative low-arousal stimuli, while the low state anxiety group did not.

Table 4. Attentional Bias in High and Low State Anxiety Groups

Condition	High State Anxiety	Low State Anxiety
Incongruent RT M (SD)	423.29 (65.13)	410.66 (56.16)
Congruent RT M (SD)	416.39 (69.89)	413.24 (62.48)
Attentional Bias Score M (SD)	1.020 (0.035)	0.996 (0.037)

(2) Moderating Effect of Cognitive Appraisal on State Anxiety' s Influence on Attentional Bias

Moderation analysis was conducted using the PROCESS macro for SPSS 20.0 (Hayes, 2013). Model 1 was applied with 5000 bootstrap samples and a 95% confidence interval. Group served as the independent variable X (coded as high state anxiety = 0, low state anxiety = 1), attentional bias score as the dependent variable Y, and cognitive appraisal (VAMS score) as the moderator M. Results indicated a significant moderating effect of cognitive appraisal, p = 0.0467. When cognitive appraisal scores were high (M + 1SD = 100.00), the high state anxiety group showed significantly greater attentional bias toward negative low-arousal stimuli than the low state anxiety group (Effect = -0.0397, SE = 0.0129, t = -3.0806, p = 0.0032, 95% CI = [-0.0654, -0.0139]). When cognitive appraisal scores were low (M - 1SD = 58.95), no significant group difference emerged (Effect = -0.0024, SE = 0.0132, t = -0.1849, p = 0.8540, 95% CI = [-0.0290, 0.0241]).

Time Perception

(1) Effect of State Anxiety on Time Perception

Figure 4 [Figure 4: see original paper] displays time perception results for both groups. A 2 (group) × 3 (duration: 2000 ms, 4000 ms, 8000 ms) repeated-measures ANOVA on TPI revealed a significant interaction, F(2, 116) = 4.44, p = 0.014, ^{2} = 0.07, and non-significant main effects of group, F(1, 58) = 0.45, p = 0.506, ^{2} = 0.01, and duration, F(2, 116) = 0.77, p = 0.466, ^{2} = 0.01. Simple effects analysis showed that for the 2000 ms duration, the high state anxiety group had significantly higher TPI than the low state anxiety group, F(1, 58) = 7.14, p = 0.010, ^{2} = 0.11, with no significant group differences at 4000 ms or 8000 ms (ps > 0.05). One-sample t-tests comparing TPI to 1 revealed that only the high state anxiety group' s TPI for 2000 ms was significantly greater than 1, t(29) = 2.59, p = 0.015, d = 0.47, with no significant deviations in the remaining five conditions (ps > 0.05). These results indicate that state anxiety affects time perception specifically for 2000 ms intervals, with high state anxiety individuals overestimating negative low-arousal stimuli relative to neutral low-arousal stimuli, but has no effect on 4000 ms or 8000 ms intervals.

Figure 4. Effect of state anxiety on time perception
Note: Error bars represent standard errors.

(2) Mediating Role of Attentional Bias in State Anxiety' s Effect on Time Perception
Given that state anxiety only influenced time perception at 2000 ms, subsequent mediation and moderation analyses focused exclusively on this duration. Mediation analysis was conducted using the PROCESS macro (Model 4) with 5000 bootstrap samples and a 95% confidence interval. Group served as the independent variable X (high state anxiety = 0, low state anxiety = 1), time perception (TPI at 2000 ms) as the dependent variable Y, and attentional bias score as the mediator M. Results showed that the indirect effect did not include zero (Effect = 0.0220, SE = 0.0130, 95% CI = [0.0024, 0.0566]). Additionally, after controlling for attentional bias, the direct effect of state anxiety on 2000 ms time perception remained significant (Effect = -0.1017, SE = 0.0302, 95% CI = [-0.1621, -0.0413]). According to Zhao, Lynch, and Chen (2010), these results indicate that attentional bias partially mediates the effect of state anxiety on 2000 ms time perception, supporting Hypothesis 1.

(3) Moderated Mediation Effect of Attentional Bias and Cognitive Appraisal
Given that cognitive appraisal significantly moderated the effect of state anxiety on attentional bias, and attentional bias partially mediated the effect of state anxiety on 2000 ms time perception, moderated mediation analysis was conducted using PROCESS Model 7 with 5000 bootstrap samples and a 95% confidence interval. Group served as X (high state anxiety = 0, low state anxiety = 1), time perception (TPI at 2000 ms) as Y, attentional bias score as mediator M, and cognitive appraisal (VAMS score) as moderator W.

Results indicated a significant indirect effect (LLCI = 0.0000, ULCI = 0.0023), with a mediation effect size of 0.0009. After controlling for attentional bias, the direct effect of state anxiety on 2000 ms time perception remained significant (LLCI = -0.1641, ULCI = -0.0416). According to Zhao et al. (2010), attentional bias partially mediates the relationship between state anxiety and 2000 ms time perception.

Crucially, the mediating process was moderated by cognitive appraisal, supporting Hypothesis 2 (see Tables 5 and 6). When cognitive appraisal scores were high, attentional bias mediated the relationship between state anxiety and time perception. That is, for individuals who perceived anxiety as highly harmful to mental health, high state anxiety produced greater attentional bias toward negative low-arousal stimuli, which in turn led to overestimation of 2000 ms negative low-arousal stimuli. When cognitive appraisal scores were low, state anxiety did not influence attentional bias, and consequently did not affect 2000 ms time perception through this pathway.

Table 5. Analysis of Cognitive Appraisal' s Moderating Effect on Group' s Influence on Time Perception

Effect	coeff	SE	t	p	95% CI
	<0.001				[0.9184, 1.0273]
					[-0.0228, 0.1248]
					[-0.0001, 0.0012]
					[-0.0018, 0.0000]

Table 6. Conditional Indirect Effects of State Anxiety on Time Perception at Different Levels of Cognitive Appraisal

Cognitive Appraisal	Effect	Boot SE	95% CI
M - 1SD			[-0.0143, 0.0289]
M + 1SD			[0.0015, 0.0561]
			[0.0013, 0.0917]

Discussion

This study examined state anxiety's effect on time perception and the roles of attentional bias and cognitive appraisal. Given that previous research has focused primarily on trait anxiety or clinical populations, with few studies investigating state anxiety despite its unique significance for disentangling feedback loops between trait anxiety and attentional bias (Eysenck, 1992, 1997) and for revealing time perception characteristics under commonly experienced state anxiety, this research randomly sampled college students, assigned them to high and low state anxiety groups, and sequentially measured attentional bias, time perception, and cognitive appraisal using dot-probe, time reproduction, and VAMS tasks.

Theoretically, random sampling and assignment should ensure participant homogeneity and prevent trait anxiety differences between groups. Baseline state anxiety measurement confirmed no significant pre-induction differences, further verifying comparable trait anxiety levels. Thus, random sampling, assignment, and baseline measurement effectively controlled for trait anxiety confounds.

The findings revealed: (1) State anxiety caused overestimation of 2000 ms intervals but did not affect 4000 ms or 8000 ms intervals; (2) Attentional bias partially mediated the relationship between state anxiety and 2000 ms time perception; and (3) This mediating process was moderated by cognitive appraisal. These findings are discussed below.

State Anxiety’ s Effect on Time Perception

State anxiety influenced time perception, with high state anxiety individuals overestimating negative low-arousal stimuli relative to neutral low-arousal stimuli, but only for 2000 ms durations. This finding aligns with previous research on trait anxiety and clinical populations (Bar-Haim et al., 2010; Fox, Russo, Bowles, & Dutton, 2001; Georgiou et al., 2005) and supports AGM’ s theoretical prediction that emotional stimuli produce greater time overestimation than neutral stimuli (Droit-Volet, Brunot, & Niedenthal, 2004; Effron, Niedenthal, Gil, & Droit-Volet, 2006; Gil, Niedenthal, & Droit-Volet, 2007). The absence of effects at 4000 ms and 8000 ms may reflect Fraisse’ s (1981, 1984) distinction between perceptual and symbolic timing systems: intervals around 2-3 s are regulated by the perceptual system, whereas longer intervals rely on symbolic systems and memory-based experiences. The 2000 ms duration falls within the perceptual system range, while 4000 ms and 8000 ms represent longer durations subject to symbolic control, potentially explaining differential effects.

This study extends Bar-Haim et al.’ s (2010) findings by more rigorously controlling for arousal. They found that anxious individuals overestimated 2000 ms threatening (high-arousal negative) stimuli relative to neutral (low-arousal neutral) stimuli but did not disentangle arousal and attention effects. According to AGM, both high arousal and attentional resources influence prospective time perception (Zakay, 2005; Zakay & Block, 1997). Threatening stimuli’ s high arousal could cause overestimation, but anxious individuals’ attentional bias toward threatening stimuli could also contribute. By using consistently low-arousal stimuli, this study resolved this confound and identified attentional bias, rather than arousal, as the mediator of state anxiety’ s effect on time perception.

Mediating Role of Attentional Bias

Attentional bias partially mediated the relationship between state anxiety and time perception, supporting Hypothesis 1 and providing empirical support for AGM. While AGM has received substantial support regarding arousal effects, research on attentional resources has faced methodological challenges in controlling attention allocation. Researchers have typically used external methods (instructing participants to allocate specific amounts of attention) or internal methods (dual-task paradigms manipulating non-timing task difficulty), but neither approach precisely distinguishes attention allocation to timing versus non-timing tasks or across stimulus dimensions (Burle & Casini, 2001; Chaston & Kingstone, 2004; Maeers, 2010; Tamm, Uusberg, Allik, & Kreegipuu, 2014). This study resolved this issue by directly measuring attentional bias toward negative low-arousal stimuli in a single task. As predicted, attentional bias partially mediated state anxiety’ s effect on time perception for negative low-arousal stimuli. High state anxiety individuals exhibited attentional bias toward negative low-arousal stimuli, which in turn led to time overestimation. By controlling arousal, this study provides clear evidence supporting AGM’ s attentional mechanism: greater attentional resources allocated to timing result in greater time overestimation (Zakay, 2005; Zakay & Block, 1997).

Moderating Role of Cognitive Appraisal

Cognitive appraisal moderated the effect of state anxiety on attentional bias and, consequently, the mediating pathway through which state anxiety influences time perception, supporting Hypothesis 2 and the model depicted in Figure 2. Specifically, when cognitive appraisal scores were high (i.e., individuals perceived anxiety as highly harmful to mental health), high state anxiety produced greater attentional bias toward negative low-arousal stimuli, leading to overestimation of 2000 ms negative low-arousal stimuli. When cognitive appraisal scores were low, state anxiety did not affect attentional bias, and thus did not influence time perception through this mechanism. This suggests that when environmental stimuli trigger anxiety, individuals who appraise anxiety as harmful attend more to self-threatening negative information and subjectively experience this threat as lasting longer, potentially activating a "stress response." Conversely, those who appraise anxiety as harmless do not perceive self-threat, attend less to negative information, and do not experience prolonged subjective duration.

Previous research has shown that cognitive appraisal can alter sympathetic nervous system activation (Smith, 1989; Tomaka, Blascovich, Kelsey, & Leitten, 1993), which influences subjective time perception (Gable & Poole, 2012; Tse, Intriligator, Rivest, & Cavanagh, 2004; Uusberg, Naar, Tamm, Kreegipuu, & Gross, 2018). However, few studies have examined how cognitive appraisal functions in anxiety' s effect on time perception. This study provides new empirical evidence for this mechanism.

Collectively, these findings illuminate the internal processes of time perception in state-anxious individuals and clarify the roles of cognitive appraisal and attentional bias when processing negative environmental stimuli. These results not only explain time perception characteristics in everyday anxiety but also offer a new perspective for understanding anxiety: perhaps anxious individuals become more anxious because they experience time differently, creating a vicious cycle that may develop into anxiety disorders (Eysenck, 1997). More importantly, these findings suggest potential interventions for time distortion in anxious individuals: (1) modifying cognitive appraisal by reducing beliefs about anxiety' s harmfulness or training cognitive reappraisal to establish more adaptive appraisals; and (2) implementing attentional bias modification (Van Bockstaele et al., 2014) to reduce bias toward negative stimuli or increase bias toward neutral/positive stimuli.

Contributions and Future Directions

This study' s primary contributions are twofold. First, by directly measuring attentional bias in a single task, it resolved methodological challenges in controlling attentional resources allocated to timing, providing clear support for

AGM' s hypothesis that increased attention to timing leads to time overestimation. Second, it identified cognitive appraisal as a boundary condition for the mediating role of attentional bias in anxiety' s effect on time perception, revealing the internal processes of time perception in anxious individuals and offering important insights for interventions targeting time distortion through cognitive appraisal and attentional bias modification.

Future research should address several limitations. First, this study measured only one type of cognitive appraisal—beliefs about anxiety' s harmfulness to mental health—though Folkman and colleagues later distinguished between primary and secondary appraisal (Folkman, Lazarus, Dunkel-Schetter, et al., 1986; Folkman, Lazarus, Gruen, et al., 1986). Future work should examine how different types of cognitive appraisal moderate the mediated pathway, testing the generalizability of current findings across appraisal dimensions.

Second, to disentangle the feedback loop between trait anxiety and attentional bias (Eysenck, 1992, 1997), this study sampled healthy college students and induced state anxiety experimentally. While this approach reveals time perception characteristics under typical state anxiety, future research should test the moderated mediation model in trait-anxious and clinical populations. Additionally, although random sampling, assignment, and baseline measurement effectively controlled trait anxiety confounds, future studies could include trait anxiety as a covariate or simultaneously manipulate both trait and state anxiety to examine their interactive effects on time perception.

Third, this study examined durations of 2000 ms, 4000 ms, and 8000 ms based on previous research, finding that the moderated mediation effect only emerged at 2000 ms. Future research should explore a broader range of durations, such as shorter intervals (1000 ms, 500 ms) or slightly longer ones (3000 ms), or conduct finer-grained analyses around 2000 ms (e.g., 1500 ms, 1800 ms, 2200 ms, 2500 ms) to systematically delineate the temporal boundaries of these effects.

Conclusion

This study demonstrates that: (1) State anxiety leads to overestimation of 2000 ms intervals for negative relative to neutral low-arousal stimuli; (2) Attentional bias partially mediates the effect of state anxiety on 2000 ms time perception; and (3) This mediating process is moderated by cognitive appraisal, such that the mediation only occurs when individuals perceive anxiety as highly harmful to mental health.

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Note: Figure translations are in progress. See original paper for figures.