

Neuroticism and the Effects of Emotional Arousal and Valence on Time Perception of Visual Stimuli

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Previous research has extensively examined the impact of stimulus properties on temporal perception, highlighting the inherently subjective nature of time perception and its susceptibility to influences of emotional content. The present study investigated the effects of emotional valence and arousal in visual stimuli on perceived duration, as well as the moderating role of individual differences in the personality dimension of neuroticism. We hypothesized that participants would overestimate the presentation duration of low-valence (negative emotion) stimuli and high-arousal stimuli relative to high-valence (positive emotion) stimuli and low-arousal stimuli. A two-interval discrimination paradigm employing the method of constant stimuli was used, in which participants compared the presentation duration of a picture with a fixed interval to another picture with systematically varied durations. Stimuli in Experiment 1 were varied in arousal level, while stimuli in Experiment 2 were varied in emotional valence. Participants completed a two-alternative forced choice (2AFC) task to judge which stimulus in each trial appeared to last longer, followed by an assessment of the neuroticism trait using the neuroticism subscale of the Big Five Inventory. Results indicated a significant temporal overestimation for high-arousal stimuli and low-valence stimuli. Both experiments suggested possible directional trends between neuroticism and temporal distortion elicited by emotional stimuli; however, these patterns did not reach statistical significance, possibly due to the brief stimulus exposure limiting trait-level emotional processing. Overall, the findings of the present study align with the attention-based and arousal-based internal clock model, suggesting that high-arousal and negative emotional content may heighten attentional focus on the stimulus, thus accelerating the pacemaker rate and increasing pulse accumulation, resulting in a subjective experience of expanded time.

Keywords: arousal, emotion, neuroticism, time perception, valence

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INTRODUCTION

The Subjectivity of Time Perception

Time perception is a core process of human cognition, yet it is remarkably subjective and malleable. Although physical time can be precisely measured using instruments such as clocks and watches, mental experience of time involves a complex cognitive process easily influenced by both the external environment and internal psychological states. Unlike sensory modalities such as vision or audition which rely on specific organs, time perception lacks a dedicated sensory system. Instead, individuals infer the passage of time through environmental changes and cognitive processes, which are susceptible to contextual and emotional influences. Emotional state has been shown to exhibit a significant impact on temporal judgments in our daily lives (Droit-Violet et al., 2011). Time tends to feel like flying during exciting and enjoyable moments, such as when going on a date or taking a vacation, making us think it passes more quickly than it actually does. On the other hand, when we are stuck in a dull or monotonous situation, time can seem to drag, leading us to believe less time has passed than it really has. These phenomena underscore the importance of examining the role of emotion in shaping subjective time perception and highlight the need for in-depth empirical investigation into its underlying cognitive mechanisms.

The Theoretical Account for Time Perception

Pioneering theorists in the field of time perception have advocated for the internal clock model as the foundational framework, which is grounded in the Scalar Expectancy Theory and suggests that individuals possess a timing mechanism composed of a pacemaker, an accumulator, and an attention-controlled switch (Gibbon, 1977; Gibbon et al., 1984; Treisman, 1963). When the timing process begins, the switch closes and allows pulses from the pacemaker to enter the accumulator. Once the interval ends, the switch opens and stops the flow of pulses. The total number of accumulated pulses infers the perceived duration, such that more pulses result in a perception of longer time. Building on this framework, several theories have been developed to explain temporal distortions in subjective time perception. Attention and arousal are suggested as two key mechanisms that play a central role in modulating the internal clock (Droit-Violet & Gil, 2009; Droit-Violet & Meck, 2007). The attention mechanism proposes that the switch may open when individuals are distracted, resulting in fewer pulses to be counted and a shorter perceived duration. In contrast, the arousal mechanism proposes that heightened arousal accelerates the pacemaker, generating more pulses and resulting in a longer perceived duration (Droit-Violet et al., 2011).

The Role of Physical Characteristics of a Stimulus in Modulating Perceived Duration

The influence of various physical properties in a stimulus on temporal distortion has been extensively investigated over the past several decades. Research examining stimulus properties has demonstrated that larger and brighter visual stimuli and larger numerical values tend to elicit time dilation effects, resulting in longer perceived duration than they objectively are (Xuan et al., 2007). Additional studies have shown that increased complexity in visual features and motion patterns is associated with extended subjective duration (Aubry et al., 2008; Schiffman & Bobko, 1974). Brown (1995) further reported that stimulus motion contributes to perceived temporal expansion, with faster movements exerting a more pronounced effect than slower ones. Such time expansion effect brought by object motion has also been found to depend on the actual physical motion of the object in space but not its relative motion with respect to the retina (Au et al., 2012). Beyond visual modalities, auditory stimuli have also been studied for their impact on time perception. For instance, Ono and Kitazawa (2010) found that when a temporal interval (marked by initial and terminal tones) was followed by a sequence of repetitive auditory stimuli, participants perceived the interval as shorter, indicating a compression effect.

While the literature in colour psychology has demonstrated the link of colours to emotion for over a century (Jonauskaite & Mohr, 2025), studies have also identified a relationship between colour and time perception. For instance, Thönes et al. (2018) observed that blue stimuli tend to lengthen the perceived duration, potentially due to their association with positive affect and calming emotional states, whereas red stimuli are linked to heightened arousal and more intense emotional responses (Wilms & Oberfeld, 2017). These findings suggest that physical attributes can influence time perception not only directly, but also indirectly through their emotional connotations. Theoretical considerations in the current literature underscore the significance of examining how emotional content contributes to temporal modulation, and this leaves an important research direction for later researchers.

The Dimensions of Emotion and Their Effects on Time Perception

A growing body of research has demonstrated that emotional states significantly influence the perception of time. Central to this issue is the two-dimensional model of emotion by Russell and Lemay (2000), who categorized affective experiences along the axes of valence (the degree of pleasantness) and arousal (the level of physiological activation; also see Kauschke et al., 2019; Lang et al., 1993; Russell, 1980). Valence is typically classified into positive (high), neutral, and negative (low), while arousal is classified into weak (low), neutral, and strong (high; Metallinou et al., 2012). Over the past few decades, psychological research has examined how emotional stimuli such as affective words, facial expressions, and audio-visual content can distort temporal judgments (Droit-Volet et al., 2011; Eberhardt et al., 2020; Johnson & MacKay, 2018; Tipples, 2008). For instance, Tipples (2008) found that participants took longer time to evaluate angry facial expressions compared to neutral ones, suggesting that high emotional arousal could prolong perceived duration.

Similarly, Droit-Volet et al. (2011) reported that emotionally arousing films were judged to last longer than neutral ones, indicating a time dilation effect associated with high arousal. However, findings across studies remain inconsistent. Eberhardt et al. (2020) observed no significant differences in perceived time between anger and other emotional states, while Yin et al. (2021) reported that negative images were more likely to produce temporal underestimation compared to neutral stimuli. Moreover, Noulhiane et al. (2007) demonstrated that high-arousal emotional sounds were perceived as shorter in duration than low-arousal ones, further complicating the relationship between arousal and temporal distortion. A recent study by Zhang et al. (2024) investigated how varying intensities of withdrawal-motivation emotion influence subjective time perception across five distinct temporal tasks. Their findings revealed inconsistent effects across task types, underscoring the obscurity of the mechanism underlying how emotional valence and arousal influence time perception. The inconsistencies in findings in the literature highlight the need for further investigation to clarify the mechanisms by which emotional valence and arousal influence subjective time perception.

Neuroticism and Emotion Processing

Individuals with differing personality traits exhibit distinct patterns in emotional interpretation. Optimistic individuals tend to appraise events more positively, whereas those with a pessimistic mindset are more inclined to focus on negative aspects. These divergent cognitive-emotional responses underscore the role of personality in shaping emotional experience. Among the five core personality dimensions outlined in the Big Five Personality Model (Goldberg, 1993), neuroticism is characterized by a heightened susceptibility to negative emotional states, including anxiety, fear, loneliness, low self-esteem, and emotional instability (Jeronimus et al., 2014; Lüdtke et al., 2009; Riese et al., 2014; Specht et al., 2011). One defining feature of neuroticism is the tendency toward rapid emotional arousal and delayed inhibition (Eysenck & Eysenck, 2012). Empirical evidence suggests that individuals high in neuroticism are more likely to respond negatively to stressors and to perceive neutral or benign situations as threatening, often struggling to cope with minor frustrations (Widiger & Oltmanns, 2017). Neuroimaging studies have revealed a correlation between heightened neural activity in response to fearful facial expressions and high levels of neuroticism (Chan et al., 2009). Similarly, individuals scoring high in neuroticism demonstrated significant emotional responses to affective visual stimuli such as emotionally coloured images (Kehoe et al., 2011) and exhibited deeper cognitive processing of unpleasant emotional terms (Ku et al., 2020). Given their increased sensitivity to emotionally intense stimuli, it is plausible that individuals high in neuroticism may be more susceptible to emotional influences on time perception. This raises the question of whether neuroticism is associated with greater susceptibility to distorted time perception toward emotionally charged stimuli.

Research Objectives and Rationale of the Present Study

While considerable attention has been devoted to examining emotions and physical dimensions of the stimuli in time perception research, the

impact of emotion on time perception remains inconclusive. This highlights the value of investigating the independent contributions of emotional valence and arousal to better understand their distinct roles in shaping temporal experience. Moreover, a notable gap remains in understanding how neuroticism level might interact with each of the dimensions of emotion to shape time perception.

The present study aimed to examine the influence of emotional valence and arousal in visual stimuli on time perception. In addition to examining the effects of the two dimensions of emotional content, this study also explored whether the level of a person's neuroticism is associated with the magnitude of perceived time distortion brought by the emotion content contained in visual stimuli. To this end, two behavioural experiments were conducted, using the two-alternative forced-choice (2AFC) paradigm grounded in the method of constant stimuli in psychophysics (Schwartz & Krantz, 2019). In the two experiments, emotional visual stimuli with either varied valence levels or varied arousal levels were presented to healthy adult participants in randomized order. Participants were asked to compare the perceived durations of two sequentially presented stimuli. In Experiment 1, each trial involved the presentation of two images differing in arousal level, with the valence level controlled. The reference stimulus was displayed for a fixed duration, while the comparison stimulus varied in duration. Participants were instructed to judge which image appeared to be presented for a longer duration. Experiment 2 replicated this procedure using stimuli that differed in emotional valence, with the arousal level controlled. Following the completion of the time judgement tasks, participants completed the neuroticism subscale of the Big Five Personality Inventory to assess their level of neuroticism.

According to Droit-Violet (2014), exposure to threatening stimuli, typically characterised by high arousal or negative valence, initiates a series of physiological responses that prepare the individual for rapid defensive actions such as escape or attack. This heightened state of arousal accelerates the internal timing mechanisms of the cognitive system, enhancing readiness for incoming environmental demands. As a result, individuals might tend to overestimate the duration of these events, reflecting a distortion in perceived time under conditions of threat. In the present study, we hypothesized that stimuli characterized by high emotional arousal and stimuli characterized by low valence would elicit an overestimation of duration, relative to low arousal stimuli and high valence stimuli. We further hypothesized that neuroticism would be correlated to the magnitude of temporal distortion brought by emotional arousal and valence, reflecting the heightened sensitivity to emotionally charged stimuli among individuals with high neuroticism levels.

EXPERIMENT 1: METHOD

Participants

A total of thirty healthy undergraduate participants (mean age = 21.27 years, $SD = 1.28$ years) were recruited for the present experiment in the host university. All participants possessed normal or corrected-to-normal vision to clearly view the stimuli presented on the computer screen from a viewing distance of 60 cm. Based on self-reported responses, individuals with any known impairments in time perception or psychiatric conditions

affecting emotional processing were excluded. Prior to the experimental sessions, participants were provided with an information sheet describing the general procedure of the experiment and signed to provide informed consent in accordance with the ethical guidelines approved by the human research ethics committee of the host university. Both experiments in this study were conducted in accordance with the Declaration of Helsinki guidelines.

Stimuli

Open Affective Standardized Image Set (OASIS). In each experimental trial, stimuli sourced from the OASIS (Kurdi et al., 2016) were presented centrally on the screen (screen size = 52.704×29.646 cm; screen resolution = 1920×1080 pixels) at a resolution of 750×600 pixels, corresponding to physical dimensions of 20.3×16.3 cm. All image presentation and experimental procedures were implemented using MATLAB R2022a (MathWorks, MA), incorporating the Psychophysics Toolbox Version 3 (PTB-3) extension (Brainard, 1997; Pelli, 1997). A total of 64 images were selected for this experiment, encompassing a balanced representation of emotional content across both dimensions of arousal (high and low) and valence (positive and negative). In the original study by Kurdi et al. (2016), each image was rated on a 7-point scale for emotional valence and arousal by 822 samples with diverse demographic backgrounds, including variability in age, gender, geographic location, and socioeconomic status. In the present Experiment 1, image selection was guided by arousal ratings: high-arousal stimuli were defined by scores ranging from 4 to 5, while low-arousal stimuli were those with scores between 2 and 3. Valence ratings for all images in this experiment were constrained within the 'neutral' range of 3 to 5. The image set included a range of content categories such as objects, animals, landscapes, and human figures, systematically organized according to their valence and arousal scores. Examples of OASIS images included in the present study are shown in Figure 1.

Figure 1 Examples of selected emotional stimuli from the OASIS that were used in the present study: (A) high arousal, (B) low arousal, (C) positive valence, and (D) negative valence.



Big Five Inventory (BFI). The BFI (Benet-Martínez & John, 1998; John et al., 1991, 2008), a widely used personality assessment, comprises 60 items distributed across the five dimensions derived from the Five Factor Theory of Personality (McCrae & Costa, 2008): extraversion (8 items), agreeableness (9 items), conscientiousness (9 items), neuroticism (8 items), and openness (10 items). Participants were instructed to evaluate each statement using a 5-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*) to reflect their degree of agreement with each item. Each item begins with the phrase “I am someone who...” followed by a descriptive statement. For example, the neuroticism subscale includes items such as “is depressed and blue”, “can be tense”, “worries a lot”, “can be moody”, and “gets nervous easily” (Benet-Martínez & John, 1998; John et al., 1991, 2008). Reverse-scoring was applied to designated items before summing up the responses to obtain the total score for each dimension.

The reliability and validity of the BFI have been extensively validated. Internal consistency coefficients (Cronbach’s α) range from 0.79 to 0.88, and test-retest reliability coefficients span from $r = 0.79$ to 0.85 (Fossati et al., 2011; John & Srivastava, 1999; Soto & John, 2017). Convergent validity has been demonstrated through comparisons with other established personality measures including the TDA and NEO-FFI (John & Srivastava, 1999). Similar to several previous studies (John et al., 2008; Lu et al., 2022; Woon et al., 2021), the present study employed only the neuroticism subscale to assess participants’ level of neuroticism.

Procedure

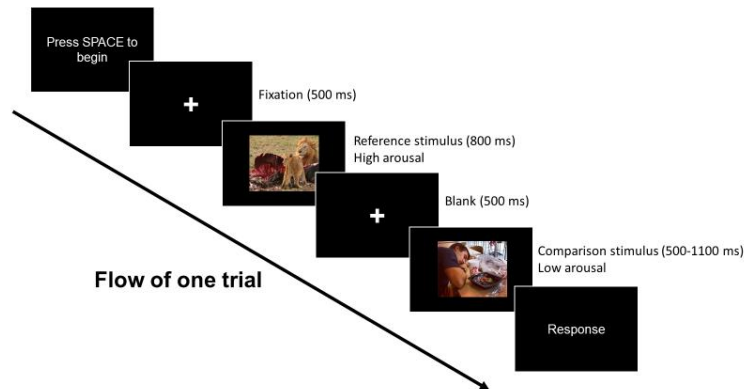
The objective of Experiment 1 was to examine how variations in emotional arousal influence individuals’ perception of temporal duration. The experiment took place in a controlled, sound-isolated environment in

the host university. Two blocks of trials (Block A and Block B) were conducted in this experiment. In each block, participants completed 112 trials in which a reference stimulus and a comparison stimulus were presented in each trial. Presentation duration of the comparison stimulus was systematically varied across 7 intervals (ranging from 500 to 1100 ms, at 100-ms increments) while that of the reference stimulus was held constant at 800 ms. In each trial in Block A, the reference stimuli were 16 high-arousal images, while the comparison stimuli were 16 low-arousal images. In Block B, the reference stimuli were another 16 low-arousal images, while the comparison stimuli were another 16 high-arousal images. Presentation order of the reference stimulus and comparison stimulus in the trials, and also the duration of comparison stimulus, were randomized across all the 112 trials.

Before the experiment, participants were briefed on the number of blocks and the estimated duration of the whole experiment. Participants were instructed to focus their attention on the visual stimuli and to respond quickly and accurately using designated keys on the keyboard. A screen message was displayed at the beginning of each block, guiding participants to press the spacebar to start the block. In each trial, a white fixation cross (each line with dimensions of 1×0.05 cm) appeared centrally on the screen to orient visual attention. After 500 ms, the fixation cross disappeared and was immediately replaced by the first image (either the reference stimulus or the comparison stimulus), presented at the same central location. Upon the end of presentation of the first image, another fixation screen of 500 ms succeeded, which was followed by the presentation of the second image in the trial. After the presentation of the pair of image stimuli, the response screen appeared and the participant pressed one of two designated keys on the keyboard to indicate which of the two images was presented with a longer duration. A press on the left-arrow key indicated that the participant perceived the first image as lasting longer, while a press on the right-arrow key indicated the second image was perceived to be longer. Figure 2 shows the flow of a trial in the experiment.

A training phase involving several practice trials was conducted before the start of each experiment, allowing participants to familiarize themselves with the task. To control for potential order effects, a counterbalanced design was employed so that half of the participants completed Block A first, followed by Block B, while the remaining half completed in the reversed order. A three-minutes resting period was provided before participants proceeded to the second block to minimize potential fatigue effects. The total duration of each block was approximately 20 minutes.

Figure 2 A diagram illustrating the flow of a trial in Experiment 1A. (The procedure was generally the same also in Experiment 1B, 2A and 2B.)



Data analysis

Data collected from the experiment were organized according to the seven stimulus durations of the comparison stimulus and were plot into graphs. The x-axis of the graph represents the seven stimulus durations, while the y-axis displays the percentage of trials in which participants judged the comparison stimulus to last longer than the reference stimulus. A cumulative normal curve was fitted to the seven data points for each participant using customized Excel spreadsheets, employing the method of least squares (Wolberg, 2006) to optimize the fit. The lower and upper bounds, the slope at the inflection point, and the intercept at the proportion of $y = 50\%$ of the fitted curve was determined. The point of subjective equality (PSE; Bock & Jones, 1968; Guilford, 1954), defined as the estimated point on the x-axis at which the participant would perceive the comparison stimulus to have a longer duration than the reference stimulus in 50% of trials (i.e., the intercept), was identified from the fitted psychometric curve. This value represents the estimated presentation duration of the comparison stimulus that was judged to have the same duration as the reference stimulus which was consistently presented for 800 ms. To ensure all analysed data were having satisfactory precision in the estimated PSE, we only included data of which the fitted psychometric curve had achieved a minimum R^2 value of 0.80.

For each block of the experiment, participant responses were used to derive one PSE which reflected their temporal judgment under that specific condition. After obtaining the PSEs from all the individual participants, a one-sample t -test was conducted to determine whether their mean PSE significantly differed from the reference duration of 800 ms for each block. In the case of Block A in which the presentation of high-arousal stimuli was fixed at 800 ms, a PSE significantly greater (smaller) than 800 ms would imply the low-arousal stimuli had led to time underestimation (overestimation) in comparison to the high-arousal stimuli; while in Block B, a PSE significantly greater (smaller) than 800 ms would imply the high-arousal had produced time underestimation (overestimation) in comparison to the low-arousal stimuli. On the other

hand, a PSE not significantly differ from 800 ms would imply no time distortion effect.

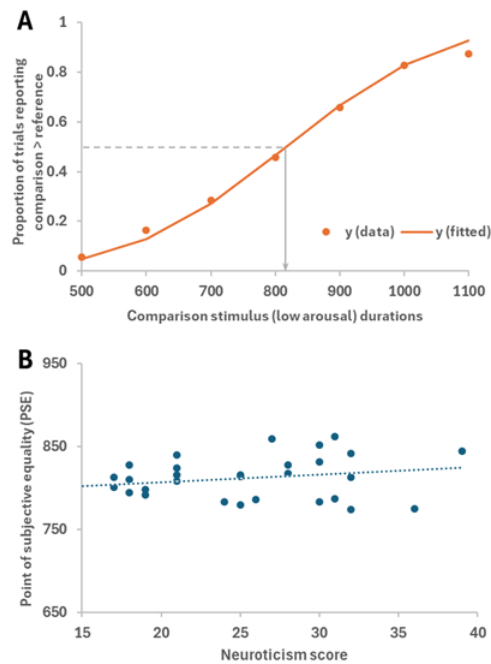
Lastly, neuroticism scores were calculated by summing the responses to the eight items comprising the neuroticism subscale after performing reverse-scoring for items which required so. The total score could range from 8 to 40, with higher scores indicating higher levels of neuroticism. To examine the association between neuroticism and time distortion induced by the emotional stimuli, Pearson correlation coefficients were computed. Statistical analyses of the *t*-tests and correlations were performed using IBM SPSS 29.0 (IBM Corporation, New York, USA).

EXPERIMENT 1: RESULTS

Results of Experiment 1A

In Block A of Experiment 1, the presentation duration of low-arousal stimuli was manipulated while the duration of high-arousal stimuli was fixed at 800 ms. From the one-sample *t*-test, the average PSE ($M = 811.38$, $SD = 25.99$; Figure 3A) was found to be significantly greater than 800 ms [$t(29) = 2.397$, $p = 0.023$], implying that the low-arousal stimuli had led to underestimation of time. In other words, participants perceived the high-arousal stimuli as lasting for a longer duration than the low-arousal ones. To examine the relationship between neuroticism level ($M = 25.13$, $SD = 6.40$) and the magnitude of time distortion brought by the low-arousal stimuli (Figure 3B), Pearson correlation between the neuroticism scores and the PSEs was computed. Although the correlation was positive, suggesting a potential tendency for individuals with higher neuroticism scores to experience stronger time underestimation effect brought by the low-arousal stimuli, the result did not reach statistical significance [$r = 0.223$, $p = 0.235$].

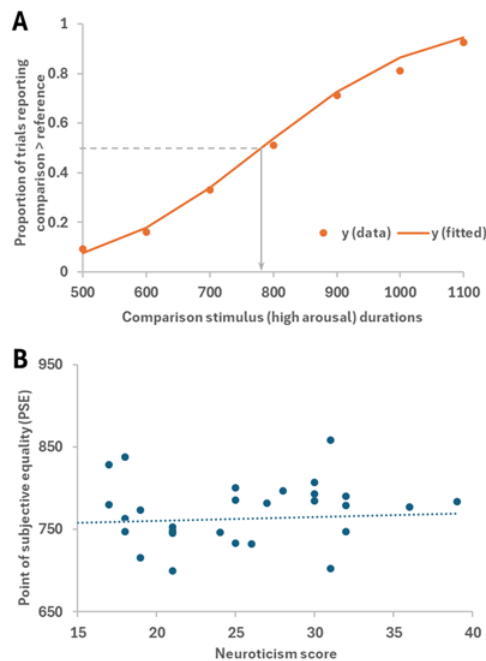
Figure 3 (A) The mean proportion of trials in which the low-arousal comparison stimulus was judged to last longer than the 800-ms high-arousal reference stimulus in Experiment 1A. The dotted line extending from the proportion of 0.5 projects the estimated PSE on the x-axis. (B) Scatter plot illustrating the relationship between participants' neuroticism scores and their PSEs (which reflect the magnitude of time distortion).



Results of Experiment 1B

Block B of Experiment 1 was designed to be a control experiment to test the same hypothesis under a reversed stimulus configuration relative to Experiment 1A. The specific change was that the presentation duration of the low-arousal stimuli was held constant at 800 ms, while the duration of the high-arousal stimuli was varied. The objective was to demonstrate the time overestimation effect brought by high-arousal stimuli, which would indicate consistency of findings across experimental conditions. One-sample *t*-test revealed that the mean PSE in Experiment 1B ($M = 762.79$, $SD = 55.83$; Figure 4A) was significantly smaller than the value of 800 ms [$t(29) = -3.651$, $p = 0.001$], demonstrating a time overestimation effect brought by the high-arousal stimuli. To explore whether neuroticism level was associated with the magnitude of the time distortion (Figure 4B), Pearson correlation was computed. The results indicated no significant relationship between neuroticism scores and the time distortion effect [$r = 0.052$, $p = 0.787$].

Figure 4 (A) The mean proportion of trials in which the high-arousal comparison stimulus was judged to last longer than the 800-ms low-arousal reference stimulus in Experiment 1B. The dotted line extending from the proportion of 0.5 projects the estimated PSE on the x-axis. (B) Scatter plot illustrating the relationship between participants' neuroticism scores and their PSEs (which reflect the magnitude of time distortion).



EXPERIMENT 1: DISCUSSION

The results of Experiments 1 provided empirical support for our first hypothesis that emotional arousal in visual stimuli is associated with perceived time distortion. In Experiment 1A, participants demonstrated a tendency to underestimate the presentation duration of low-arousal images, while in Experiment 1B they demonstrated an overestimation of time for high-arousal images. Together, these findings suggest that emotional arousal modulates perceived time. The results obtained from both experimental blocks are consistent with prior research demonstrating that the emotional content of visual stimuli can influence time perception (Droit-Volet et al., 2011; Tipples, 2008). Specifically, our findings are consistent with earlier findings that high arousal stimuli are perceived as lasting longer than low-arousal stimuli (Droit-Volet et al., 2004; Langer et al., 1961; Waits & Sharrock, 1984). Moreover, studies employing virtual reality films and emotional auditory stimuli have shown association between elevated arousal levels and increased perceived durations across both short and long intervals (Droit-Volet et al., 2020). Furthermore, Zhou et al. (2021) investigated the relationship between arousal and temporal dilation using faces of different attractiveness levels and found that temporal dilation effect was significantly influenced by arousal, even when the task of interpreting sentences with emotion-suppressed terms was employed to regulate emotional responses. These empirical findings

support the notion that arousal plays a critical role in modulating subjective time perception.

Although our second hypothesis regarding the correlation between neuroticism and the magnitude of time distortion reported non-statistically significant results, the trend of potential positive relationship between neuroticism and time distortion in Block A might be noteworthy. The observation might suggest a potential relationship between neurotic traits and susceptibility to temporal misjudgement elicited by emotional visual stimuli. Although non-statistically significant results caution against over-interpretation, the result might reflect a trait-level sensitivity to internal affective states rather than a response to external stimulus variation, providing a compelling reason for further investigation.

EXPERIMENT 2: METHOD

Participants

Twenty-four healthy undergraduate participants (mean age = 21.25 years, $SD = 1.45$ years) were recruited for this experiment with the same criteria in Experiment 1. Written informed consent was obtained from the participants before the start of the experiment.

Stimuli and procedure

Experiment 2 was also composed of Block A and Block B. A total of 64 images were picked from the OASIS database (Kurdi et al., 2016) with a similar procedure as in Experiment 1. In this experiment, we confined the arousal ratings of the selected images within the 'neutral' range of 3 to 5, while identifying images with high valence (i.e., containing positive emotion) which had valence ratings between 5 and 6.5, and images with low valence (i.e., containing negative emotion) at ratings between 1.5 and 2.5. Examples of images used in Experiment 2 are shown also in Figure 1. Consequently, 16 low-valence images and 16 high-valence images were presented in Block A, while another 16 low-valence and another 16 high-valence images were presented in Block B. In Block A, the low-valence (high-valence) images served as the comparison (reference) stimuli; while in Block B, the high-valence (low-valence) images served as the comparison (reference) stimuli.

Neuroticism levels in this experiment were also assessed using the same BFI neuroticism subscale applied in Experiment 1 (Benet-Martínez & John, 1998; John et al., 1991, 2008). The procedure in this experiment was identical to that in Experiment 1.

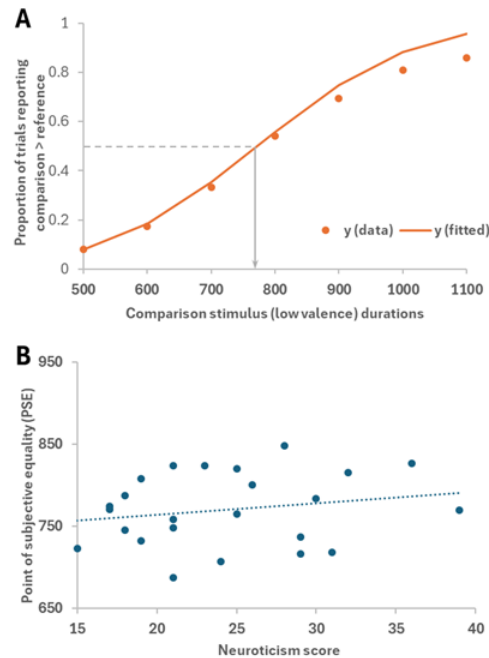
EXPERIMENT 2: RESULTS

Results of Experiment 2A

In Block A of Experiment 2, the presentation duration of high-valence stimuli was held constant at 800 ms (reference stimuli), while the duration of low-valence stimuli was varied (comparison stimuli). The mean PSE ($M = 770.32$ ms; $SD = 44.12$ ms; Figure 5A) was found to be significantly smaller than 800 ms [$t(23) = -3.295$; $p = 0.003$], suggesting that the low-valence stimuli (i.e., negative emotion) elicited a time overestimation effect, in comparison to the high-valence stimuli (i.e., positive emotion) presented at a constant duration. To examine the relationship between neuroticism level and the magnitude of time distortion brought by low-

valence stimuli (Figure 5B), Pearson correlation between neuroticism scores and PSEs was computed (Figure 5B). While the direction was found to be positive, suggesting a potential tendency for individuals with lower neuroticism scores to experience stronger time overestimation effect brought by the low-valence stimuli, the analysis did not report a significant correlation [$r = 0.201$; $p = 0.346$].

Figure 5 (A) The mean proportion of trials in which the low-valence comparison stimulus was judged to last longer than the 800-ms high-valence reference stimulus in Experiment 2A. The dotted line extending from the proportion of 0.5 projects the estimated PSE on the x-axis. (B) Scatter plot illustrating the relationship between participants' neuroticism scores and their PSEs (which reflect the magnitude of time distortion).

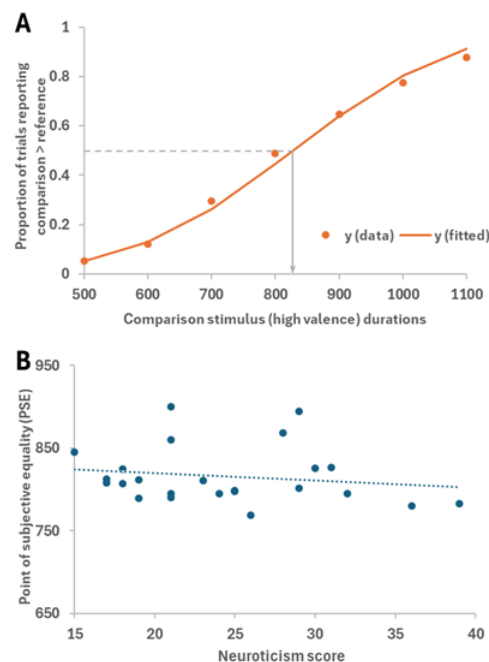


Results of Experiment 2B

In Block B of Experiment 2, the presentation duration of the low-valence stimuli was held constant at 800 ms while that of the high-valence stimuli was manipulated. This design served as a reversal of the configuration used in Experiment 2A, allowing for a complementary test of the same hypothesis. The mean PSE ($M = 816.31$ ms; $SD = 34.52$ ms; Figure 6A) was significantly higher than the reference of 800 ms [$t(23) = 2.315$, $p = 0.030$], indicating a time underestimation effect brought by the high-valence stimuli. To explore whether neuroticism level was associated with the magnitude of the time distortion (Figure 6B), Pearson correlation was computed between neuroticism scores and PSEs. The correlation was negative but did not reach statistical significance [$r = -0.164$, $p = 0.444$]. While the direction of effect may hint at a potential relationship suggesting individuals with lower neuroticism levels might tend to experience stronger time underestimation effect with high-valence stimuli (positive

emotion), such notion remains speculative due to the failure in achieving statistical significance.

Figure 6 (A) The mean proportion of trials in which the high-valence comparison stimulus was judged to last longer than the 800-ms low-valence reference stimulus in Experiment 2A. The dotted line extending from the proportion of 0.5 projects the estimated PSE on the x-axis. (B) Scatter plot illustrating the relationship between participants' neuroticism scores and their PSEs (which reflect the magnitude of time distortion).



EXPERIMENT 2: DISCUSSION

A primary aim of Experiment 2 was to examine the effect of emotional valence on time perception while controlling for arousal level. Consistent with our first hypothesis, the results provided robust evidence that emotional valence embedded in visual stimuli can induce distortions in perceived duration. In Block A, participants overestimated the duration of low-valence (negative emotion) images in comparison to the high-valence images, as reflected by the mean PSE being significantly shorter than the reference duration of 800 ms. Consistently, Block B revealed that high-valence (positive emotion) images led to a temporal underestimation in comparison to the low-valence images. These findings suggest that negative emotional content could elicit temporal overestimation, supporting that emotional valence modulates subjective time perception.

The present results are consistent with prior empirical work investigating the differential effects of emotional valence on temporal estimation. For instance, Angrilli et al. (1997) employed temporal reproduction and verbal estimation tasks in visual modalities and found that images with negative emotion were perceived as longer in duration than positive ones under high arousal conditions, but not under low

arousal. Their findings suggest that attentional and emotional mechanisms may play distinct roles on time perception. Extending this research, Noulhiane et al. (2007) reported that auditory stimuli with negative emotion were judged to last longer than positive ones. Furthermore, other researchers have reported that emotional facial expressions were consistently judged as lasting longer than neutral expressions (Droit-Violet et al., 2004; Gil et al., 2007). Altogether, these findings provide converging evidence supporting the role of emotional valence in modulating perceived duration.

Although the present findings offer interesting insights, they do not permit definitive conclusions regarding our second hypothesis concerning the relationship between neuroticism level and time distortion in response to emotional visual stimuli. Interestingly, data in both blocks suggested a trend of relationship that individuals with lower, rather than higher, neuroticism level tend to be more susceptible to time distortion effects elicited by both low-valence stimuli and high-valence stimuli. The results raise a possibility that neuroticism personality might be related to the magnitude of time distortion brought by the emotional valence contained in visual stimuli. However, given that these correlations did not reach statistical significance, the current data are insufficient to substantiate a conclusive relationship. Nonetheless, it may indicate a potential avenue for future research. Studies employing a larger sample size with more diverse levels of neuroticism may help to detect subtle individual differences and clarify the role of neuroticism in time perception.

GENERAL DISCUSSION

The main objective of the present study was to examine the independent effects of emotional arousal and valence on time perception and explore how these effects might be related to the personality factor of neuroticism. Findings from Experiment 1 provide empirical support for the hypothesis that high-arousal stimuli could lead to temporal overestimation, whereas low-arousal stimuli could produce an underestimation. These results are consistent with predictions derived from the literature. The observed arousal-based distortions in time perception are grounded in the internal clock model, which posits that increased physiological arousal accelerates the pacemaker rate, thus generating a greater number of temporal pulses which leads to an extended subjective duration (Burle & Casini, 2001; Gil & Droit-Violet, 2012; Treisman, 1963). Unlike previous studies that employed emotional stimuli categorized by complex criteria such as pleasantness or unpleasantness combined with varying levels of arousal (e.g., Buetti & Lleras, 2012; Noulhiane et al., 2007), the present Experiment 1 controlled for valence at a medium level across conditions. This isolates the effect of arousal on time perception. Together with the use of the method of constant stimuli in the experiment, our experiment contributed to an objective and precise assessment on the magnitude of time distortion.

The results of Experiment 2 also support the hypothesis that emotional content influences time judgment, indicating that high-valence (positive emotion) stimuli lead to underestimation of perceived duration, whereas low-valence (negative emotion) stimuli lead to overestimation. These findings align with theoretical models that posit emotional valence as a

modulating factor in subjective time perception. Most previous studies have reported a mixed effect of valence and arousal levels regarding the temporal distortion effect associated with emotional content (e.g., Angrilli et al., 1997; Buetti & Lleras, 2012; Yamada & Kawabe, 2011). The findings of the present Experiment 2 might be one rare piece of evidence which isolated the role of emotional valence on time perception. The observed valence-based temporal distortion effects might be grounded by the theory of attentional-gate model proposed by Zakay and Block (1997), which suggests that attention plays a key role in modulating the flow of time pulses to the internal clock. Since stimuli with negative emotion (such as scary and disgusting images) could heighten vigilance or threat experienced by a person, stronger attention is directed toward the stimuli, keeping the attentional gate open for longer. As a result, negative visual stimuli tend to lead to a longer perceived duration. Conversely, the positive stimuli (such as relaxed and joyful images) could reduce attentional engagement towards them. Consequently, less attention is directed towards the stimuli, and the attentional gate remains closed or narrow, leading to temporal underestimation.

In addition to examining the influence of emotional arousal and valence on time perception, the present study also explored the relationship between neuroticism and temporal distortion elicited by visual stimuli of varied arousal levels and varied valence levels. Findings from both experiments suggest there might be a potential link between individual differences in neuroticism and the magnitude of time distortion brought by emotional arousal and valence. However, the failure in reaching statistical significance in the correlations may suggest that trait-level neuroticism might not reliably predict how individuals perceive time toward emotionally charged stimuli. One possible explanation, as derived from the findings reported by Lewis and Miall (2003), is related to the fact that the emotional visual stimuli used in the present study were presented in brief durations within the range of 500 ms to 1100 ms, primarily engaging the low-level perceptual timing mechanisms rather than the higher-order cognitive or emotional appraisal processes. Within such brief exposure durations, temporal judgments are typically governed by automatic processes, whereas the effect of neuroticism on emotion processing might require a longer processing time to emerge, potentially due to delayed regulatory mechanisms and cognitive biases (Chen et al., 2023; Silverman et al., 2019). Although emotional contents might have influenced temporal perception in the present experiments, it was too brief to allow personality traits such as neuroticism to exert an observable influence on time perception. An alternative explanation concerns the limited statistical power due to small sample sizes in both experiments. A larger sample is likely to include participants with a broader range of levels, and more variations, in the neuroticism personality dimension, which allows a more powerful test on the correlational relationship. To extend the investigation of the present study, future research could employ a larger sample size and extend the presentation duration of visual stimuli to allow personality traits sufficient time to exert effects on processing the emotional content.

In conclusion, the present study offers new insights to the understanding of how emotional arousal and valence independently influence subjective time perception. In Experiment 1, participants

consistently perceived high-arousal images as lasting longer than low-arousal ones, indicating the significant role played by emotional arousal in modulating temporal judgments. Furthermore, in Experiment 2, images with low valence (negative emotion) were judged to last longer than positive images, underscoring the impact of emotional valence on temporal distortion. Beyond these primary findings, the study provides suggestive insights into the role of neuroticism in shaping time perception of emotional stimuli. Overall, the present study contributes to the broader literature on the interplay between emotional processing, personality traits, and time perception.

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