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Cognitive and emotional mechanisms of time perception

Edited by
Huazhan Yin, Philip Gable and Zhijie Zhang

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Cognitive and emotional mechanisms of time perception

Topic editors
Huazhan Yin — Hunan Normal University, China
Philip Gable — University of Delaware, United States
Zhijie Zhang — Hebei Normal University, China

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EDITED AND REVIEWED BY
Eddy J. Davelaar,
Birkbeck, University of London,
United Kingdom

*CORRESPONDENCE
Philip A. Gable
pagable@gmail.com

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Editorial: Cognitive and emotional mechanisms of time perception

Philip A. Gable* and Timothy P. McCoy

Department of Psychological and Brain Sciences, University of Delaware, Newark, DE, United States

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Editorial on the Research Topic
Cognitive and emotional mechanisms of time perception

Over the years, major contributions have been put forth to clarify the emotional and cognitive aspects of time perception. Articles in the special issue on Cognitive and Emotional Mechanisms of Time Perception consider this question through several different lenses. Embedded throughout the manuscripts are themes that cut across multiple lines of research. These themes include mechanisms of time perception, the role of action in time perception, individual differences influencing time perception, and task differences measuring temporal distortion. Below we highlight articles relating to these themes and how they expand our understanding of time perception.

Mechanisms of time perception

One of the most common themes of the articles in the special issue is that many of the authors discuss mechanisms of how emotion influences time perception. Zhou et al. is a strong example of testing the potential mechanistic effects of arousal using both experimental manipulations of the mechanism and the observed mediational effects of the mechanism. Despite the rigorous mechanistic approach, the authors should be commended for noting an alternative view, that their results "could be interpreted as allowing individuals to prepare more for subsequent approaching behavior, rather than a byproduct of the increased arousal." (p. 9).

Another potential mechanism of time perception is noted in the review paper by Gable et al., which focuses on the role of motivation as a mechanism influencing time perception. Their review highlights a growing body of research showing that approach motivation tends to speed the passing of time, but withdrawal motivation tends to slow the passing of time. Along these lines, the paper by Matsuda and Nittono measured self-reported approach and avoidance reactions to their experimental stimuli.

While these papers stand as examples of mechanistic investigations, few studies of time perception clearly define a mechanism and experimentally or statistically test whether the mechanism plays a role in temporal changes. There is a growing need for research examining mechanisms of emotion-time perception interactions.

The role of action in time perception

Another common theme throughout this special issue is the role of action in time perception. For example, Ma et al. found that positive and negative faces caused greater CNV event-related potential amplitudes. Because the CNV is a neural measure of one's preparation to act, this would suggest that temporal estimates might be influenced by the motivation to act. These results also highlight the importance of applying physiological measures to study mechanisms of time perception. This theme is discussed by Matsuda and Nittono. Specifically, they highlight the benefit of using physiological measures like skin conductance when proposing arousal as a mechanism for alterations of time perception.

The role of action is suggested in two other articles (Jia et al.; Yue et al.). Jia et al. investigated temporal perception during immoral phrases. Participants were more likely to perceive immoral phrases as being displayed longer than neutral or disgusting phrases. The authors conclude that these results do not support arousal as a mechanism, but suggest that embodied reactions toward immoral phrases may cause the shift in time perception.

Yue et al. found that people tend to have a more positive bias toward the future self as opposed to the past self. It could be that people view themselves as moving toward a future self and away from a past self. However, He et al. raise the importance of cultural distinctions in views about time, noting that English speakers view time horizontally whereas Mandarin speakers view time vertically. This cultural perspective may influence whether individuals approach the future differently. As individuals move *forward* or *up* through time, they could feel like they are approaching a future self but withdrawing from a past self.

Individual differences influencing time perception

As with many psychological constructs, individual differences influence our sense of time. Individual differences are evident in the paper by Ma et al. demonstrating that emotional awareness plays a role in the perception of time. Differences emerged in their findings when comparing those who were most emotionally aware with those who were least emotionally aware.

Work by Weng et al. finds that individual pain reactions played an important role in determining people's responses during a time bisection task. The authors also highlight the importance of studying individual differences in time sensitivity, revealing that time sensitivity during a time bisection task was the leading factor influenced by longer administrations of pain.

Task differences measuring temporal distortion

The variety of tasks used to assess time perception may cause variance and inconsistencies across studies. For example, in this special issue, researchers used time estimation, time reproduction, and time bisection tasks. Sometimes tasks were retrospective, other times they were prospective. The time window investigated ranged from long time intervals (ranging from seconds to minutes) to short time intervals (in the range of hundreds of milliseconds). Indeed, Lin et al. highlight the unique properties of time distortion for sub- and supra-second durations of time perception, finding that color sensitivity differed between shorter vs. longer windows of time.

The papers in this special issue also highlight the variety of ways to measure time perception. For example, the paper by Droit-Volet and Gil was the first to introduce emotional faces to a novel temporal reproduction task. Notably, their results in the neutral (control) condition replicated prior results. This paper outlines the importance of future studies to replicate past effects when introducing new or derivative versions of time perception tasks.

Conclusion

This brief editorial fails to capture the breadth and depth of each of the articles in this special issue. You are invited to explore the expanse of knowledge from a collection of time researchers inquiring into how we perceive time and what alters our sense of time. These investigations serve to propel our understanding of time perception forward. We are hopeful this work will lead other researchers to expand upon the cognitive and affective mechanisms of time perception.

Author contributions

PG contributed as the lead author to the writing of this editorial. TM contributed as the co-author to the writing of this editorial. Both authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Valence of Temporal Self-Appraisals: A Comparison Between First-Person Perspective and Third-Person Perspective

Caizhen Yue[1†], Yihong Long[1†], Chaomei Ni[1], Chunhua Peng[2] and Tong Yue[3]*

[1]College of National Culture and Cognitive Science, Guizhou Minzu University, Guiyang, China, [2]Laboratory of Emotion and Mental Health, Chongqing University of Arts and Sciences, Chongqing, China, [3]Faculty of Psychology, Southwest University, Chongqing, China

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Huazhan Yin,
Hunan Normal University, China

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Cuihua Bi,
Sichuan Normal University, China
Feng Zhang,
Henan University, China

***Correspondence:**
Tong Yue
yue.suhong@163.com

†These authors have contributed equally to this work and share first authorship

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Mental time travel is one of the most remarkable achievements of mankind. On the one hand, people perceive past self, present self, and future self as a continuous unity; on the other hand, people have the ability to distinguish among the three types of temporal selves because there are different representations of them. In this study, we used an adapted temporal self-reference paradigm to explore the processing mechanism of different temporal selves. Temporal self-reference was performed from the first-person perspective in Experiment 1 and from the third-person perspective in Experiment 2. The results indicated that people showed a more positive bias toward future self compared with past self and present self no matter in the first-person perspective or third-person perspective. There was no difference in recognition rate among past self, present self, and future self. Compared with the first-person perspective, present self-processing in the third-person perspective was more abstract and generalized, which may reflect that the third-person perspective has the same distancing function as time. This study can deepen understandings on temporal self-appraisals from different perspectives.

Keywords: temporal self-appraisal, first-person perspective, third-person perspective, self-reference paradigm, self-positive bias

INTRODUCTION

One of the most remarkable achievements of mankind is able to perform mental time travel (MTT), which refers to people's ability to mentally project oneself into the past or future (Endel, 2002; Rasmussen and Berntsen, 2013). MTT allows people to subjectively locate selves to the past time and places to reexperience their past, or to a future point-in-time to experience certain events (Liu et al., 2010). This shows that the self has temporal extension, possessing not only the present, but also the past and the future. Thus, MTT results in temporal self (Luo et al., 2013), which refers to past self, present self, and future self.

A person's past experience will affect his or her self-knowledge, and individual past experience and knowledge on past self will be gradually internalized by the individual, becoming a part of self-identity. Similarly, the individual's view of future self and imagination of future life will also affect the individual's present behaviors and bring relevant information into the self-identity

(D'Argembeau et al., 2012; Rubianes et al., 2021). Individuals perceive past self, present self, and future self as a unified and continuous unity, forming a stable self-identity (Northoff, 2017). For another, continuity does not mean the identical, and self-knowledge will be updated and reshaped as life circumstances constantly change. Therefore, in addition to feeling the temporal self-continuity, the ability to distinguish past self, present self, and future self is also an important part of self-processing (D'Argembeau et al., 2008).

Since human beings are capable of conducting MTT, individuals can project selves to different points in time, which means that there are different temporal distances correlated with the present, such as near distance (1 month later) and far distance (5 years later; Wilson et al., 2012; Luo et al., 2013). Studies have found that temporal distance is an important factor affecting people's self-perception. According to construal level theory (CLT; Trope and Liberman, 2003; Eyal et al., 2008), near self is associated with a low level of concrete construal, while distant self is associated with a high level of abstract construal. In more detail, near self is based more on concrete events and contains complex and contextualized self-representations; while distant self is characterized by abstraction, schema thinking, and textualization. This means that present self should be different from past self and future self. Studies in this area also found that people often treat past self and future self as "others" compared with present self (Pronin, 2008; Yang et al., 2020). A study of the neural mechanisms of temporal self also found that cortical midline structures (CMSs) were activated when participants reflected on present self, compared with past self or future self (D'Argembeau et al., 2010). These studies showed that people's present self-representations were more specific and contextual; while they were more abstract and generalized for distant past self and future self (Liberman et al., 2002; Wakslak et al., 2008).

As for the relevance between past self and future self, it has been found that the recall on past events can provide information for future self (Tanguay et al., 2020); many brain regions that support to memorize past events are also involved (Szpunar et al., 2007; Addis et al., 2009) when imagining future events that may happen. Studies in a wide range of fields have shown there was a striking similarity between remembering past events and imagining future events (D'Argembeau and Mathy, 2011; Szpunar et al., 2012), which suggested that the two temporal directions depended on a shared neural network and similar cognitive structure. Although past self and future self are very similar, there are important differences. Past events are something that happened, and the recall on them is limited by what happened; while future events do not happen and are more affected by imagining process (Perrin, 2016; Malek et al., 2017). That is, the recall on the past represents our ability to reexperience the past, while the future is the ability to "experience future in advance" by simulating it in our mind (Gilbert and Wilson, 2007). Thus, the mental structure of future events is cognitively more demanding than the corresponding structure of past events, for example, past events score higher on measures related to the recall (such as imagery and vividness), while future MTT is related to more schema-based constructions, future events score higher on variables related to self-schema and abstract knowledge (Berntsen and Jacobsen, 2008; Berntsen and Bohn, 2010; D'Argembeau and Mathy, 2011; Miles and Berntsen, 2011). Future MTT correlates with more brain activities than past MTT (Szpunar et al., 2007; Addis et al., 2009).

In addition to temporal distance, treating oneself from different perspectives can also affect how people perceive selves. Studies have found that the third-person perspective also has the distancing function compared with the first-person perspective (D'Argembeau and Van der Linden, 2004; Sutin and Robins, 2008), which leads people to interpret events at an abstract level (Libby et al., 2005). For example, compared with the first-person perspective, observing a person's behaviors from the third-person perspective may promote people to evaluate their own behaviors more objectively (Zhou et al., 2013), obtain lower emotional experience (Berntsen and Rubin, 2006), and reduce egocentric bias (Zhou et al., 2013). Some existing studies have shown that distant events are considered to have a different self-concept from current events, which leads that they are more often represented from the third-person perspective, and contain less sensory and contextual details (Libby and Eibach, 2002); similarly, future self is usually imagined from the third-person perspective (Pronin and Ross, 2006). This means that nearer present self tends to be viewed from the first-person perspective, while more distant past self or future self is usually viewed from the third-person perspective (Broemer et al., 2008).

Different temporal selves are involved in self-processing no matter from the first-person perspective or third-person perspective. One of the most common and forceful findings in this area is the self-positive bias (Watson et al., 2007; Chen et al., 2014), which refers to people's tendency to view oneself with an unrealistically positive attitude, that is, we generally think we have more positive (and less negative) traits and abilities (Fields et al., 2019). For example, studies have found that people generally recognize positive personality traits, reject negative personality traits, and rate positive trait adjectives as self-relevant, but rate negative trait adjectives as non-self-relevant, people tend to respond faster to self-positive adjectives than to negative adjectives (Watson et al., 2007; Chen et al., 2014). Moreover, the people's neural mechanism of the valence processing of self-relevant trait adjectives is not completely the same (Fossati et al., 2003; Brühl et al., 2014; van der Cruijsen et al., 2018; Zhang et al., 2020). This implies that self-positive bias not only reflects positive self-concept, but also indicates that there are differences in the processing of valence of different self-relevant trait adjectives.

People judge oneself positively at different points-in-time, but the positive degree of self can vary with different points-in-time. Temporal self-appraisal theory believes that people's appraisals on past self make them feel good about present self; in order to maintain positive self-view, people often tend to devalue past self. That is, even if there is no actual improvement in present self, people will make oneself feel better by devaluing past self. Temporal self-appraisal theory is supported by many researches. As opposed to devaluing past self, people usually view future self in a more positive light (Hershfield, 2011;

Szpunar et al., 2012), which indicates that people think they are getting better and better over time (Yang et al., 2017). Positive bias toward future self is also supported by a number of studies, for example, positive future events are remembered in more detail than negative future events (Gallo et al., 2011), and future events are rated as more emotionally positive than past events (Berntsen and Bohn, 2010), even as depressed individuals, they are very optimistic about their future selves (Sokol and Serper, 2017). These studies showed that, relatively speaking, people are the least positive toward past self, put present self in the middle, and are the most positive toward future self.

Studies on self-reference showed that people encode self-relevant information more deeply, which is better than processing information about others (Fossati et al., 2004). Based on previous studies, people often treat past self and future self as "others" (Pronin, 2008), does that mean the individual more deeply processes present self compared with past self and future self? Given the positive bias of future self, will this positive bias be reflected not only in trait adjectives ratings, but also in the recognition task of trait adjectives? Because of the distancing mechanism of the third-person perspective, what is the difference on evaluating past self, present self, and future self between the third-person perspective and the first-person perspective? Based on this, this study adopted the revised temporal self-reference paradigm (specifically, participants were asked to conduct trait adjectives ratings on past self, present self, and future self, and received a surprising recognition task; Conway and Dewhurst, 1995; Yue et al., 2020), and used two experiments conducted from the first-person perspective and the third-person perspective to answer the above questions. We predicted that the recognition results of present self are better than those of past self and future self; whether in trait adjectives ratings or in the recognition, they show greater positive bias for future self. Due to the distancing mechanism in the third-person perspective, present self-processing in the third-person perspective may be different from that in the first-person perspective; specifically, we predicted that present self would be more positive than past self in the first-person perspective; while present self-processing was similar to past self and did not show any more positive bias than past self in the third-person perspective.

EXPERIMENT 1

Experiment 1 was conducted to investigate the memory effect of temporal self-appraisals from the first-person perspective. Participants were asked to make trait adjectives judgment of past self (the self 5 years ago), present self, and future self (the self 5 years later) from the first-person perspective and conducted a surprising recognition task. We predicted the positive bias of future self in trait adjectives ratings and recognition rates; in addition, the recognition rate of present self was higher than that of past self and future self.

Methods

Participants

In this within-participants-design experiment, we estimated the required sample size by using $f = 0.27$ as effect size input in G-Power 3.1.9 ($\alpha = 0.05$; Faul et al., 2007) to detect a medium-sized effect on the main outcomes. The calculation outcome suggested a required sample size of 24 for each experiment in this study. In Experiment 1, we recruited 37 healthy undergraduates (10 males and 27 females, with a mean age of 21.19 years; $SD = 0.97$) to participate in our study. All participants had normal or corrected-to-normal visions. They did not have a history of neurological disorders. All participants provided written informed consent, in accordance with the Declaration of Helsinki.

Materials

We selected a set of 240 Chinese adjectives to compose a list of stimuli for the encoding and recognition phases. The pleasure, meaningfulness, familiarity, and valence of the adjectives were considered and balanced based on the norms of Wang (2005). In all, 120 adjectives were presented at the encoding phase and the other 120 adjectives were used as lures at recognition. The study words were divided into six sub-lists (40 words each, 20 positive and 20 negative), matched on the basis of familiarity, meaningfulness, and pleasure from the norms of Wang (2005). These materials have been used in previous studies (Yue et al., 2020), there were no significant differences on pleasure, meaningfulness, and familiarity across the six groups of adjectives, there were significant differences in the valence (positive vs. negative) in each sub-list. The number of characters in each sub-list of adjectives is equal (each adjective is composed of two to four Chinese characters). Each sub-list was assigned to one of three encoding conditions (past self condition, present self condition, or future self condition) and counterbalanced across participants. Each sub-list was composed of half positive (e.g., generous and pleasant) and half negative (e.g., jealous and rude) traits. The order of presentation was randomized for each adjective for each participant, with trials from different conditions intermixed throughout the study.

The Inclusion of Other in the Self (IOS) scale (Aron et al., 1991) was used to measure the closeness of temporal self. The IOS scale consists of seven pairs of overlapping circles, with each pair overlapping slightly more than the preceding pair. The participants were asked to select the pair of circles that best portrays the relationship between past self (future self) and present self. Meanwhile, the seven-point scale was adopted to evaluate the frequency of recalling the past and imagining the future recollections (1 = never recall or imagine, 7 = very frequent).

Measures

To understand the positive self-view of participants, we took the practices (Sokol and Serper, 2017) to use the mean value of all positive adjective ratings (response times, recognition rates) of each participant plus the mean value of negative adjectives multiplied by (−1), to create a completion measure of a "positive self-view" that combines negative and positive adjectives. This mathematical process created three independent variables for the past, present, and future, respectively, namely past self-view, present self-view, and future self-view. Because negative adjectives were scored in reverse and combined with positive adjectives, variable scores can be positive or negative value.

Procedures

In the questionnaire stage, after the participants sat down in the laboratory, they were first asked to fill in the IOS scale. They rated the relation degree of the self 5 years ago and present self, as well as of present self and the self 5 years later. According to Ersner-Hershfield et al. (2009) and Liu et al. (2018), the IOS scale after adapting could effectively measure temporal self-continuity; participants were then asked to rate the frequency of recalling the past and imagining the future, after filling out the questionnaires, they were asked to perform in the experiment stage.

Encoding Task and Recognition Task

Participants practiced the encoding task to ensure that they understood the demands of the task. Then, they received instructions to encode adjectives in one of the three ways: past self condition (e.g., was I kind 5 years ago?), present self condition (e.g., am I kind now?), or future self condition (e.g., will I be kind 5 years later?). Every way represented one of the three conditions. Following a 4-s presentation of the adjectives, participants were asked to press the D key for "Always like this," F key for "Generally like this," J key for "Generally not like this," and K key for "Never like this." 120 adjectives were encoded in the task phase, and 40 adjectives (20 positive and 20 negative) were assigned to each of the three conditions. The presentation orders of different trials and conditions were counterbalanced across participants. After encoding task, participants answered a Raven's Standard Progressive Matrices test, starting from the "C" section for 6 min, to eliminate the effect of memory of the encoding task. They then decided if the adjective presented on the center of the screen had been shown in the previous task, by pressing the F key to classify it as an old word or pressing the J key to classify it as a new word. In this task, a total of 240 adjectives were tested: 120 adjectives were tested as encoded words that had been presented in the previous task, and another 120 adjectives were tested as new words. All stimuli presentation and behavioral response collection were controlled by E-prime 2.0, running on a 17-inch DELL LED display with a resolution of 1,024 × 768 and a refresh rate of 60 Hz.

Results

IOS Ratings and Frequency Ratings

The paired samples t-test indicated that there was no significant difference in IOS Ratings between past–present ($M = 4.22$, $SD = 1.16$) and present–future ($M = 4.27$, $SD = 1.43$), $t(36) = 0.25$, $p = 0.81$. A paired samples t-test was conducted using frequency as the dependent variable. Future frequency imagined by participants ($M = 5.32$, $SD = 0.92$) was significantly higher than frequency of recalling the past ($M = 4.76$, $SD = 1.30$), $t(36) = 2.57$, $p < 0.05$, $r = 0.24$.

Four-Point Ratings in the Encoding Task

The 4-point rating scores were analyzed by a 3 × 2 repeated-measures ANOVA, with the encoding condition (past self vs. present self vs. future self) and valence of the adjectives (negative vs. positive). The main effect of the encoding condition was significant [$F(2,72) = 4.24$, $p < 0.05$, $\eta_p^2 = 0.11$]. The main effect of the valence of the adjectives was also significant [$F(1, 36) = 115.56$, $p < 0.001$, $\eta_p^2 = 0.76$]. The interaction effect of encoding condition × valence of the adjectives was significant [$F(2,72) = 13.76$, $p < 0.001$, $\eta_p^2 = 0.28$]. We performed simple effects analyses when this interaction was observed. The results showed that the positive valence scores were significantly higher than the negative valence scores of adjectives in the past self-condition [$F(1,36) = 43.56$, $p < 0.001$, $\eta_p^2 = 0.55$], present self-condition [$F(1,36) = 95.64$, $p < 0.001$, $\eta_p^2 = 0.73$], and future self-condition [$F(1, 36) = 110.59$, $p < 0.001$, $\eta_p^2 = 0.75$] (see **Table 1**).

The one-way repeated-measures ANOVA showed that the rating scores of positive self-views were significantly different [$F(2,72) = 13.76$, $p < 0.001$, $\eta_p^2 = 0.28$]. The *post hoc* analysis showed that future self scores' difference ($M = 1.14$, $SD = 0.66$) were significantly higher than present self ($M = 0.82$, $SD = 0.51$) and past self ($M = 0.65$, $SD = 0.60$; $ps < 0.05$), and present self was higher than past self ($p = 0.06$; see **Figure 1A**).

Response Times in the Encoding Task

The response times were analyzed by a 3 × 2 repeated-measures ANOVA, with the encoding condition (past self vs. present self vs. future self) and valence of the adjectives (negative vs. positive). The main effect of the encoding condition was significant [$F(2,72) = 6.60$, $p < 0.01$, $\eta_p^2 = 0.16$]. The main effect of the valence of the adjectives was also significant [$F(1,36) = 17.38$, $p < 0.001$, $\eta_p^2 = 0.33$]. The interaction effect of encoding condition × valence of the adjectives was significant [$F(2,72) = 9.17$, $p < 0.001$, $\eta_p^2 = 0.20$]. We performed simple effects analyses when this interaction was observed. The results showed that the positive valence RTs were significantly higher than the negative valence RTs of adjectives in the past self condition [$F(1,36) = 6.49$, $p < 0.05$, $\eta_p^2 = 0.15$] and future self condition [$F(1,36) = 33.51$, $p < 0.001$, $\eta_p^2 = 0.48$]. There was no

TABLE 1 | Descriptive statistical results of trait ratings, response times (ms) of trait ratings, and recognition under the first-person perspective.

		Past self	Present self	Future self
Trait ratings	Positive	3.01 (0.37)	3.03 (0.34)	3.14 (0.42)
	Negative	2.35 (0.41)	2.21 (0.32)	2.00 (0.36)
Response times	Positive	1,724 (478)	1,698 (485)	1,489 (418)
	Negative	1,847 (470)	1,768 (491)	1,763 (480)
Recognition	Positive	0.77 (0.16)	0.78 (0.17)	0.81 (0.14)
	Negative	0.77 (0.17)	0.75 (0.17)	0.72 (0.16)

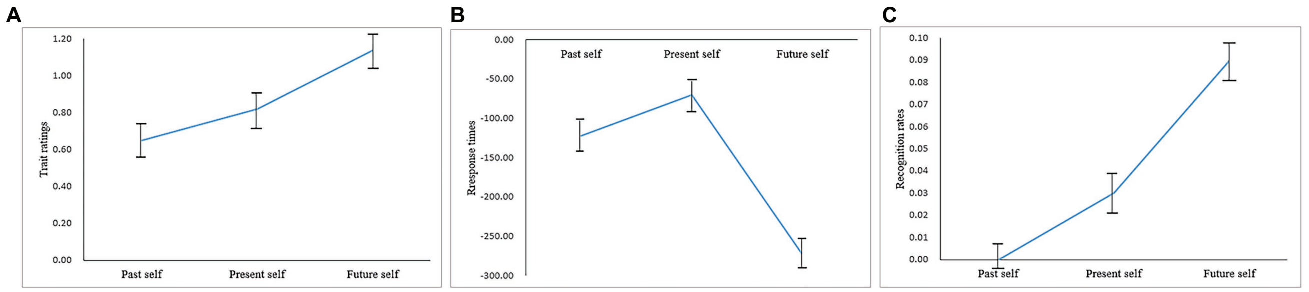

FIGURE 1 | Positive bias of different temporal selves under the first-person perspective, **(A)** trait ratings; **(B)** response times (ms) of trait ratings; **(C)** corrected recognition rates.

significant difference between positive and negative valence RTs in the present self-condition [$F(1,36) = 2.39$, $p = 0.13$].

The one-way repeated-measures ANOVA showed that the RTs of positive self-view were significantly different [$F(2,27) = 9.17$, $p < 0.001$, $\eta_p^2 = 0.20$]. The *post hoc* analysis showed that the past self RTs difference ($M = -70.05$, $SD = 275.70$) was significantly higher than the present self ($M = -122.57$, $SD = 292.77$) and future self ($M = -273.60$, $SD = 287.51$; $ps < 0.05$). There was no significant difference between past self and present self ($p = 0.26$; see **Figure 1B**).

Recognition Memory Performance

The corrected recognition scores were analyzed by a 3×2 repeated-measures ANOVA, with the encoding condition (past self vs. present self vs. future self) and valence of the adjectives (negative vs. positive). The main effect of the encoding condition was not significant [$F(2,72) = 0.24$, $p = 0.79$]. The main effect of the valence of the adjectives was significant [$F(1,36) = 4.43$, $p < 0.05$, $\eta_p^2 = 0.11$]. The interaction effect of encoding condition × valence of the adjectives was significant [$F(2,72) = 4.20$, $p < 0.05$, $\eta_p^2 = 0.11$]. We performed simple effects analyses when this interaction was observed. The results showed that the positive valence recognition scores were significantly higher than the negative valence recognition scores of adjectives in the future self condition [$F(1,36) = 16.20$, $p < 0.001$, $\eta_p^2 = 0.31$]. There was no significant difference between positive and negative valence recognition scores in the past self condition [$F(1,36) = 0.00$, $p = 0.96$] and present self-condition [$F(1,36) = 0.94$, $p = 0.34$].

The one-way repeated-measures ANOVA showed that the corrected recognition scores of positive self-views were significantly different [$F(2,27) = 4.20$, $p < 0.05$, $\eta_p^2 = 0.105$]. The *post hoc* analysis showed that the future self recognition scores difference ($M = 0.09$, $SD = 0.14$) was significantly higher than the past self ($M = 0.00$, $SD = 0.16$) and present self ($M = 0.03$, $SD = 0.18$; $ps < 0.05$). There was no significant difference between past self and present self ($p = 0.42$; see **Figure 1C**).

Discussion

The results of experiment 1 showed that, in terms of explicit closeness, the participants thought the closeness between past self and present self was the same as the closeness between present self and future self. But people imagined the future more frequently than they recalled the past. This study also found that there was no difference in recognition rate among the three temporal selves, that is, the recognition rates of past self, present self and future self were the same, which did not verify our hypothesis.

As for the positive bias of self, this study found that in trait adjectives ratings, the score of positive self-appraisals was significantly higher than that of negative self-appraisals. The response times of positive trait adjectives in past self and future self were faster than that of negative trait adjectives, and there was no difference between positive trait adjectives and negative trait adjectives in present self condition. This result may reflect the effect of temporal distance. In terms of recognition rates, positive trait adjectives in the future self condition were significantly higher than negative trait adjectives, while there was no difference in recognition rate between positive and negative trait adjectives in the past self-condition and present self-condition, which may indicate that future self-concept is more composed of positive traits than past self and present self. Experiment 1 also compared the degree of positive self under three temporal self conditions. The positive bias of future self in trait adjectives rating scores, response times of trait adjectives ratings and recognition rate were larger, indicating that people were more optimistic and positive about future self.

EXPERIMENT 2

The results of experiment 1 found that future self preformed positive bias in the first-person perspective, and the recognition scores of past self, present self and future self were basically equal, and there were no significant differences among them. The third-person perspective was used in experiment 2 to verify the results of Experiment 1. It seems to be a kind of distancing mechanism due to the function of the third-person perspective (D'Argembeau and Van der Linden, 2004; Sutin and Robins, 2008). Existing researches showed that the distant events usually adopt the third-person perspective, which meant when viewing long-distance past self (the self 5 years ago) and future self (the self 5 years later), there was little difference by adopting the first-person and the third-person perspectives, while there was difference by adopting the first-person and the third-person perspectives by viewing present self.

Methods

Participants

In Experiment 2, we recruited 37 healthy undergraduates (16 males and 21 females, with a mean age of 20.95 years; $SD = 1.03$) to participate in our study. All participants had normal or corrected-to-normal visions. They did not have a history of neurological disorders. All participants provided written informed consent, in accordance with the Declaration of Helsinki.

Materials, Measurements, and Procedures

The materials and procedures were identical to Study 1. Only three experimental conditions were used in the third-person perspective, specifically, past self (e.g., do people think I was kind before 5 years?), present self (e.g., do people think I am kind now?), and future self (e.g., do people think I'll be kind in 5 years?).

Results

IOS Ratings and Frequency Ratings

The paired samples t-test indicated that there was no significant difference in IOS Rating between past–present ($M = 4.49$, $SD = 1.35$) and present–future ($M = 4.32$, $SD = 1.23$), $t(36) = 0.52$, $p = 0.61$. A paired samples t-test was conducted using frequency as the dependent variable. Future frequency imagined by participants ($M = 5.27$, $SD = 1.09$) was significantly higher than frequency of recalling the past ($M = 4.81$, $SD = 1.39$), $t(36) = 2.26$, $p < 0.05$, $r = 0.18$.

Four-Point Ratings in the Encoding Task

The four-point rating scores were analyzed by a 3×2 repeated-measures ANOVA, with the encoding condition (past self vs. present self vs. future self) and valence of the adjectives (negative vs. positive). The main effect of the encoding condition was not significant [$F(2,72) = 0.72$, $p = 0.49$]. The main effect of the valence of the adjectives was significant [$F(1,36) = 144.19$, $p < 0.001$, $\eta_p^2 = 0.80$]. The interaction effect of encoding condition × valence of the adjectives was significant [$F(2,72) = 8.774$, $p < 0.001$, $\eta_p^2 = 0.20$]. We performed simple effect analyses when this interaction was observed. The results showed that the positive valence scores were significantly higher than the negative valence scores of adjectives in the past self-condition [$F(1,36) = 74.09$, $p < 0.001$, $\eta_p^2 = 0.67$], present self-condition [$F(1,36) = 79.41$, $p < 0.001$, $\eta_p^2 = 0.69$], and future self-condition [$F(1,36) = 127.35$, $p < 0.001$, $\eta_p^2 = 0.78$] (see **Table 2**).

The one-way repeated-measures ANOVA showed that the rating scores of positive self-view were significantly different [$F(2,72) = 8.77$, $p < 0.001$, $\eta_p^2 = 0.20$]. The *post hoc* analysis showed that the future self scores difference ($M = 1.11$, $SD = 0.60$) was significantly higher than the past self ($M = 0.82$, $SD = 0.58$) and present self ($M = 0.73$, $SD = 0.50$; $ps < 0.05$). There was no significant difference between the past self and present self ($p > 0.05$; see **Figure 2A**).

Response Times in the Encoding Task

The response times were analyzed by a 3×2 repeated-measures ANOVA, with the encoding condition (past self vs. present self vs. future self) and valence of the adjectives (negative vs. positive). The main effect of the encoding condition was not significant [$F(2,72) = 0.91$, $p = 0.41$]. The main effect of the valence of the adjectives was significant [$F(1,36) = 49.57$, $p < 0.001$, $\eta_p^2 = 0.58$]. The positive valence RTs were significantly higher than the negative valence RTs of adjectives in the three-encoding condition. The interaction effect of encoding condition × valence of the adjectives was not significant [$F(2,72) = 1.98$, $p = 0.15$]. We performed simple effects analyses when this interaction was observed. The results showed that the positive valence RTs were significantly higher than the negative valence RTs of adjectives in the past self-condition [$F(1,36) = 19.89$, $p < 0.001$, $\eta_p^2 = 0.36$], present self-condition [$F(1,36) = 18.01$, $p < 0.001$, $\eta_p^2 = 0.33$], and future self-condition [$F(1,36) = 26.64$, $p < 0.001$, $\eta_p^2 = 0.43$].

The one-way repeated-measures ANOVA showed that the RTs of positive self-view were not significantly different [$F(2,72) = 1.98$, $p = 0.15$] (see **Figure 2B**).

TABLE 2 | Descriptive statistical results of trait ratings, response times (ms) of trait ratings, and recognition under the third-person perspective.

		Past self	Present self	Future self
Trait ratings	Positive	3.00 (0.38)	2.93 (0.32)	3.12 (0.35)
	Negative	2.19 (0.29)	2.20 (0.31)	2.01 (0.32)
Response times	Positive	1,707 (433)	1,752 (433)	1,620 (475)
	Negative	1,892 (460)	1,904 (463)	1,881 (505)
Recognition	Positive	0.81 (0.16)	0.81 (0.12)	0.85 (0.11)
	Negative	0.79 (0.13)	0.80 (0.13)	0.77 (0.17)

Recognition Memory Performance

The corrected recognition scores were analyzed by a 3×2 repeated-measures ANOVA, with the encoding condition (past self vs. present self vs. future self) and valence of the adjectives (negative vs. positive). The main effect of the encoding condition was not significant [$F(2,72) = 0.12$, $p = 0.88$]. The main effect of the valence of the adjectives was significant [$F(1,36) = 6.08$, $p < 0.05$, $\eta_p^2 = 0.15$]. The interaction effect of encoding condition × valence of the adjectives was significant [$F(2,72) = 3.39$, $p < 0.05$, $\eta_p^2 = 0.09$]. We performed simple effect analyses when this interaction was observed. The results showed that the positive valence recognition scores were significantly higher than the negative valence recognition scores of adjectives in the future self condition [$F(1,36) = 11.65$, $p < 0.01$, $\eta_p^2 = 0.24$]. There was no significant difference between positive and negative valence recognition scores in the past self condition [$F(1,36) = 0.59$, $p = 0.45$] and present self condition [$F(1,36) = 0.32$, $p = 0.58$].

The one-way repeated-measures ANOVA showed that the corrected recognition scores of positive self-views were significantly different [$F(2,72) = 3.39$, $p < 0.05$, $\eta_p^2 = 0.09$]. The *post hoc* analysis showed that the future self recognition scores difference ($M = 0.08$, $SD = 0.14$) was significantly higher than past self ($M = 0.02$, $SD = 0.13$) and present self ($M = 0.01$, $SD = 0.13$; $ps < 0.05$). There was no significant difference between past self and present self ($p = 0.89$; see **Figure 2C**).

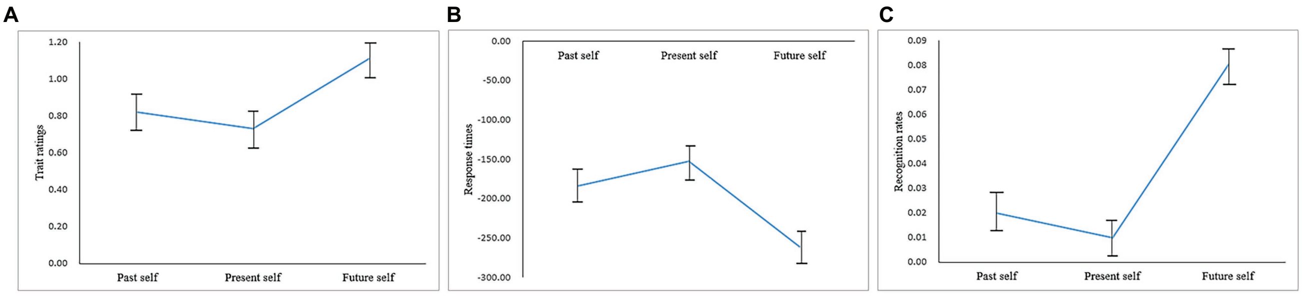

FIGURE 2 | Positive bias of different temporal selves under the third-person perspective, **(A)** trait ratings; **(B)** response times (ms) of trait ratings; **(C)** corrected recognition rates.

Discussion

The results of Experiment 2 basically verified the results of experiment 1. Specifically, people imagined the future more frequently, and there was no difference in the recognition rate of the three temporal selves, and they showed positive bias toward future self. But experiment 2 also found some interesting differences from experiment 1, mainly in present self. This may reflect the distancing function of the third-person perspective.

GENERAL DISCUSSION

This study found that, compared with past self and present self, people showed a greater positive bias toward future self, which was reflected not only in the response times of trait adjectives ratings, but also in the recognition rates. Contrary to our hypothesis, our study found there was no difference in recognition rates of past self, present self, and future self in the temporal self-reference paradigm. Present self-processing was similar to distant self-processing under the third-person perspective (D'Argembeau and Van der Linden, 2004) and did not show more positive bias than past self, which was different from the first-person perspective.

On explicit measures of closeness, the results showed no difference between past–present closeness and present–future closeness. But on the frequency, people imagined the future more frequently than they recalled the past. This result was consistent with the findings of previous studies (Smallwood et al., 2009). Studies have found that people thought about the future much more than they did in the past (Anderson and McDaniel, 2019), and the frequency of thinking about the future was about three and a half times as high as they did about the past (Baumeister et al., 2020). Researchers suggested that future thinking, especially goal processing (Ernst et al., 2018), may be a core component of human thinking (Suddendorf et al., 1997), which should reflect that thinking about the future is more adaptive than thinking about the past (Baumeister et al., 2020), and thinking about the future will prompt individuals to prepare for future actions, including decisions and executive needs (Baumeister et al., 2016).

Contrary to our predictions, the two experiments in this study found there was no difference in recognition rates between past self, present self, and future self. Studies on the self-reference effect have found that although we have an advantage in processing self-relevant information (Symons and Johnson, 1997), our cognitive processing of close others is as good as that of selves (Mashek et al., 2003; Lee et al., 2016), which indicated that people can incorporate the views and information of close others into the self (Aron et al., 1991; Ketay et al., 2019). The results of this study suggested that even when we see the distance between the past and the future as the "others" (Pronin, 2008), similarly, we see the distant self as the "close others." In fact, our selves involve temporal extension from the present to the past and the future (Northoff, 2017).

The results of this study also expanded the research on self-positive bias (Fields et al., 2019). No matter in past self, present self, or future self, people all tended to rate positive traits as self-relevant, while negative traits as self-irrelevant. The response times to positive trait adjectives were faster than those to negative trait adjectives. Consistent with previous research results (Sharot et al., 2007), this study also found that although positive self-bias existed in both the first-person and the third-person perspectives, positive self-bias will be larger in the future. In other words, people were more positive and optimistic about their future selves (Newby-Clark and Ross, 2003), which reflected that people liked to perceive their continuous progresses. Different from past self and present self, people's recognition rates of future self were higher than those of negative self, indicating that people's future self-concept was composed of more positive traits. This suggested that people's positive bias toward future self was not only reflected in emotions, but also in the cognitive structure of future self, which may indicate that we were free to perceive future self based on our wishes, hopes, and plans (Pronin and Ross, 2006), and this positive memory would help build personal and social resources (Talarico et al., 2008).

Another interesting finding of this study was that present self-processing in the first-person perspective was different from present self-processing in the third-person perspective. Specifically, from the first-person perspective, there was no difference between the response times to positive trait adjectives and negative trait adjectives of present self, while the response times to the positive trait adjectives were faster than the negative trait adjectives of past self and future self. In the third-person perspective, positive trait adjectives of past self, present self, and future self were judged faster than negative trait adjectives. In addition, present self in the first-person perspective was higher than past self in the trait adjectives rating of positive self-view, indicating that present self was more positive than past self in the first-person perspective. In the third-person perspective, there was no difference between present self and past self, indicating that present self did not show more positive bias than past self. We thought this result reflects the distancing function of temporal distance and the third-person perspective. Present self-representation was more specific and contextualized from the first-person perspective (Wakslak et al., 2008), with more internal states and emotions (Broemer et al., 2008), and more realistic and variable (Wilson et al., 2012). Therefore, the cognitive processing of trait adjectives under present self condition was more complex. However, based on construal level theory (CLT; Trope and Liberman, 2003; Eyal et al., 2008), people's representations of more distant past self and future self were more abstract and generalized and showed an ignorance for the internal state of the self (Pronin, 2008), activating a more general self-concept. Because positive information was more effective than negative information in attracting attention (Zhou et al., 2013), the response times of positive trait adjectives were faster than those of negative trait adjectives. We believed that this inference also applied to present self in the third-person perspective, because the third-person perspective had the same distancing function (D'Argembeau and Van der Linden, 2004; Sutin and Robins, 2008).

This study explored the positive bias of future self from the first-person and the third-person perspectives and found that the present self-processing in the third-person perspective was different from the present self-processing in the first-person perspective, which promoted our understanding of temporal selves. However, this study also has some limitations. First, in the selection of participants, previous studies have shown that the third-person perspective played a greater role in the self-development of adolescents (Crone and Fuligni, 2020; Yue et al., 2021). Therefore, whether the conclusions of this study can be extended to other participant groups needs to be further discussed. Second, in terms of perceiving contents, previous studies have found that, with the growth of individuals, people form more differentiated self-concept (academic, physical and prosocial, etc.), which are different in different fields and different social backgrounds (Harter, 2015; van der Cruijsen et al., 2018). Therefore, whether the conclusions of this study can be extended to different domains of self needs to be further studied. Third, previous studies have shown that the self can be divided into individual self, relational self, and collective self in terms of the selection of the perspectives of self (Sedikides et al., 2011), so whether the research conclusion of temporal self based on individual self can be applied to temporal self based on collective self also needs in-depth explorations (Topcu and Hirst, 2020).

In conclusion, this study found that people will imagine the future more frequently. In both the first-person and the third-person perspectives, people showed more positive bias toward future self than past self and present self. In recognition, there was no difference between past self, present self and future self, indicating that even if people treated past self and future self as "others," we still treated past self and future self as "close others." Present self of the third-person perspective was different from that of the first-person perspective due to the distancing function of the third-person perspective. The former was more abstract and generalized, while the latter was more specific and situational.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Guizhou Minzu University agreed to carry out the study, and all the procedures involved were in line with the sixth revision of the Helsinki Declaration. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CY and TY designed the experiments. CY, CN, and YL carried out the experiments. CY, CN, and CP analyzed the sequencing data. CY and YL drafted the initial manuscript and revised the manuscript. All authors approved the final manuscript as submitted and agreed to be accountable for all aspects of the work.

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The Spread of the Lengthening Time Effect of Emotions in Memory: A Test in the Setting of the Central Tendency Effect

Sylvie Droit-Volet[1]* *and Sandrine Gil*[2]

[1] Université Clermont Auvergne, CNRS, Laboratoire de Psychologie Sociale et COgnitive (LAPSCO), Clermont-Ferrand, France, [2] Université de Poitiers, CNRS, Centre de Recherche sur la Cognition et l'Apprentissage (CeRCA), Poitiers, France

The aim of the present study was to test how the perception of an emotional stimulus colors the temporal context of judgment and modifies the participant's perception of the current neutral duration. Participants were given two ready-set-go tasks consisting of a distribution of short (0.5–0.9 s) or long sample intervals (0.9–1.3 s) with an overlapping 0.9-s interval. Additional intervals were introduced in the temporal distribution. These were neutral for the two temporal tasks in a control condition and emotional for the short, but not the long temporal task in an emotion condition. The results indicated a replication of a kind of Vierordt's law in the control condition, i.e., the temporal judgment toward the mean of the distribution of sample intervals (central tendency effect). However, there was a shift in the central tendency effect in the emotion condition indicating a general bias in the form of an overestimation of current intervals linked to the presence of a few emotional stimuli among the previous intervals. This finding is entirely consistent with timing mechanisms driven by prior duration context, particularly experience of prior emotional duration.

Keywords: time, emotion, memory, context, central tendency effect

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University of South Australia, Australia

****Correspondence:***
Sylvie Droit-Volet
sylvie.droit-volet@uca.fr

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INTRODUCTION

For decades, the number of studies devoted to time and emotion has been constantly growing. Most of these have examined the perception of the duration of emotional stimuli (facial expressions, emotional pictures, or sounds) and their immediate effect on time judgment (Droit-Volet and Meck, 2007; Lake, 2016; Droit-Volet, 2019). Although time distortions embedded in an emotional phenomenon are complex, investigators have observed that threatening stimuli produce an increase in estimated durations. This lengthening effect is thought to result from the arousal dimension of significant stimuli, which in turn accelerates the internal clock system during the measurement of time. When the clock system runs faster, more time units are produced and the current stimulus duration is judged longer. Transient inhibition or activation of dopaminergic neurons would explain the lengthening or shortening of time estimates (Cheng et al., 2016; Soares et al., 2016). These studies have investigated the immediate effect of emotion on time judgment, but not how the prior temporal experience of an emotional stimulus influences the time measurement of other encountered stimuli. Naturally, some experiments have been conducted on the temporal memory of emotional events (Cocenas-Silva et al., 2012, 2013). However, these works have addressed the memory retention of the duration of emotional stimuli, but not the dependence of the current temporal judgment on knowledge of past duration events with a certain emotional color. The aim of the present study was therefore to test how the perception of an emotional stimulus colors the temporal context of judgment and modifies the participant's decision on the current stimulus duration.

According to the Bayesian theoretical approach, the human mind processes the properties of a stimulus in combination with those of previously processed information. Our perception of the world is considered to be endlessly modulated and optimized by inferences derived from previous experience with it. The mind is considered as a "Bayesian optimizer" (e.g., Tenenbaum et al., 2011). In the time perception domain, a Bayesian perceiver does not judge a stimulus duration (measured by an internal clock) solely on the basis of its mere isolated value (which would be constant across successive trials). He/she produces a subjective estimate (posterior) that results from the currently perceived stimulus (likelihood) weighted with the prior experience (prior) (Shi et al., 2013; Freestone and Church, 2016). The influence of prior temporal distribution on time judgment was observed many years ago by Karl von Vierordt (1868) in his studies using the reproduction task (Fortin and Rousseau, 1998; Lejeune and Wearden, 2009; Bausenhart et al., 2016). In this task, a participant is given a series of trials with different target durations (e.g., from 1 to 7 s), with a single duration being presented and reproduced per trial. Vierordt's studies showed that shorter durations are reproduced as longer than they really are, whereas longer durations are reproduced as shorter. This typical result, replicated in numerous experiments, is now known as Vierordt's law. This law accounts for the outcome of temporal judgment toward the mean of the distribution of sample durations, and illustrates the effect of knowledge (priors) in the measurement of current time. Broadly speaking, evidence shows that this result observed on the temporal dimension of the processing of information is common to the whole of our sensory system, consistently with the *central tendency effect* (Hollingworth, 1910; for a review see Glasauer and Shi, 2021).

More recently, Jazayeri and Shadlen (2010) developed a paradigm that makes it possible to further examine the effect of temporal context on time judgment in a reproduction task called the ready-set-go task (see section "Materials and Methods"). As in all reproduction tasks, participants have to reproduce temporal intervals, with a sample interval being proposed in each trial. The originality of their paradigm lies in the fact that participants are given two separate tasks with different distributions of sample intervals, one with short intervals ranging from 494 to 847 ms and the other with long intervals from 847 to 1,200 ms. Crucially, one sample interval (847-ms interval) overlaps the two distributions. According to certain results, the same overlapping interval appeared to be estimated shorter when presented with short sample intervals than with long sample intervals. This confirms the prior-dependent bias and suggests that participants adopt a "Bayesian strategy to reproduce time intervals" (Jazayeri and Shadlen, 2010, p. 1021). This paradigm has since been used in other studies that have found similar results (e.g., Karaminis et al., 2016; Hallez et al., 2018; Zimmermann and Cicchini, 2020).

The original aim of the present study was to test the role of prior emotional durations on present time judgment. We therefore used Jazayeri and Shadlen's paradigm and introduced certain intervals in the form of high-arousal emotional stimuli (i.e., facial expressions, one of the most emotional stimuli used in the literature) into the distribution of sample intervals. In this context, it was necessary to exclude the possibility of emotional reactions triggered during the emotion interval, rather than knowledge of the intervals themselves, from affecting the judgment of subsequent sample intervals. First, it is easy to observe that previous studies on timing of emotional stimuli have randomly alternated the presentation of neutral and emotionally charged stimuli and have nevertheless revealed a significant difference in the estimated durations of the two types of stimuli. At the experimental level, this suggests that there is no emotional contagion *per se* within the trials performed (Hess et al., 1998). Second, by way of an additional precaution, we used a long interval between two trials ranging from 4 to 6 s. Indeed, it has been demonstrated that the effect of an emotional picture on time estimates (lengthening of time) is no longer observed after 2 s (for a review, see Droit-Volet, 2019). This therefore ensured that the emotional reaction to a stimulus was restricted to the corresponding trial.

In summary, the lengthening effect of isolated emotional stimuli compared to neutral stimuli on time judgments has been widely demonstrated. In Jazayeri and Shadlen's paradigm, the introduction into the distribution of sample intervals of intervals associated with an angry facial expression that induces a temporal overestimation could therefore change the temporal context, thus shifting the mean of the temporal distribution in memory toward a longer value. Since the perception of the current duration is thought to be weighted by prior experience, the duration of the current interval would be judged to be longer with emotional than neutral priors. If this hypothesis was correct, we predicted that when the emotional intervals are introduced into the distribution of short sample intervals (short task) and not into that of long intervals (long task), a lengthening bias will be observed in the short condition, with the result that the "Vierordt effect" will be modified. In particular, in Jazayeri and Shadlen's study, the sample interval (0.9-s) common to the two temporal distributions (short and long) was judged shorter in the short than in the long interval distribution (central tendency effect). In the present study, with the inclusion of an emotional context that would produce an overestimation bias, the overlapping interval should not be judged shorter even if it is part of a short temporal distribution. The central tendency effect depending on the duration range would therefore disappear in favor of an emotional context effect, in contrast to a non-emotion condition in which only neutral intervals were presented in both distributions.

MATERIALS AND METHODS

Participants

The final sample consisted of 80 participants (mean age = 19.78, SD = 2.89). Two additional participants were excluded from this sample because they did not understand the instructions and considered the task to be a reaction time task. The participants were first and second-year psychology students at the French Clermont Auvergne University (UCA) who participated in the study in return for course credits. They signed a consent form that was approved by the UCA Research Ethics Committee (IRB00011540-2019-32).

Material

The participants responded alone in a room in our laboratory in front of a computer. The events presented on the computer were programmed using e-prime software. The facial expressions used were the faces of three different women expressing either neutrality or anger. These faces were in black and white and came from Ekman and Friesen (1976) Pictures of Facial Affect (**Figure 1**).

Procedure

The procedure used was an emotion-based version of the ready-set-go procedure used by Jazayeri and Shadlen (2010). As illustrated in **Figure 1**, in this task, the participants were instructed to look at a white dot in the center of the computer screen and to maintain their visual fixation throughout the trial. A small gray circle then became visible on the left. After a delay randomly chosen between 0.25 and 0.85 s, two circles (ready and set) were presented successively for 100 ms, separated by a sample temporal interval. The participants had to immediately reproduce this sample interval. Successive trials were separated by an inter-trial interval going from 4 to 6 s. The reproduced interval was therefore the duration between the set cue and the participant's key-press. In our emotion-based version of this procedure, a neutral facial expression was always presented during the sample intervals, except for the additional "emotional" intervals, which were either neutral or emotional as a function of the emotion condition (control vs. emotion).

The participants were given two successive ready-set-go tasks (Short vs. Long): one with the distribution of short sample intervals, and the other with the distribution of long sample intervals. The task-order was counterbalanced between subjects. Three trial demonstrations were given at the beginning of each task. One sample interval overlapped these two temporal distributions. The same interval duration of 0.9 s was thus included in the two different temporal contexts. For the Short task, the five sample intervals to be reproduced were 0.5, 0.6, 0.7, 0.8, and 0.9 s, and for the Long task 0.9, 1.0, 1.1, 1.2, and 1.3 s. A sixth emotional interval was added. The duration of this emotional interval was randomly chosen between 0.5 and 0.9 s for the Short task and between 0.9 and 1.3 s for the Long task. Each task was composed of 54 trials, i.e., nine blocks of six trials: the five sample intervals and the emotional interval. The trial order was random within each trial block. This made a proportion of emotional intervals of 0.16 per task.

The participants were arbitrarily assigned to either the control group or the emotion group. For the control group, the neutral

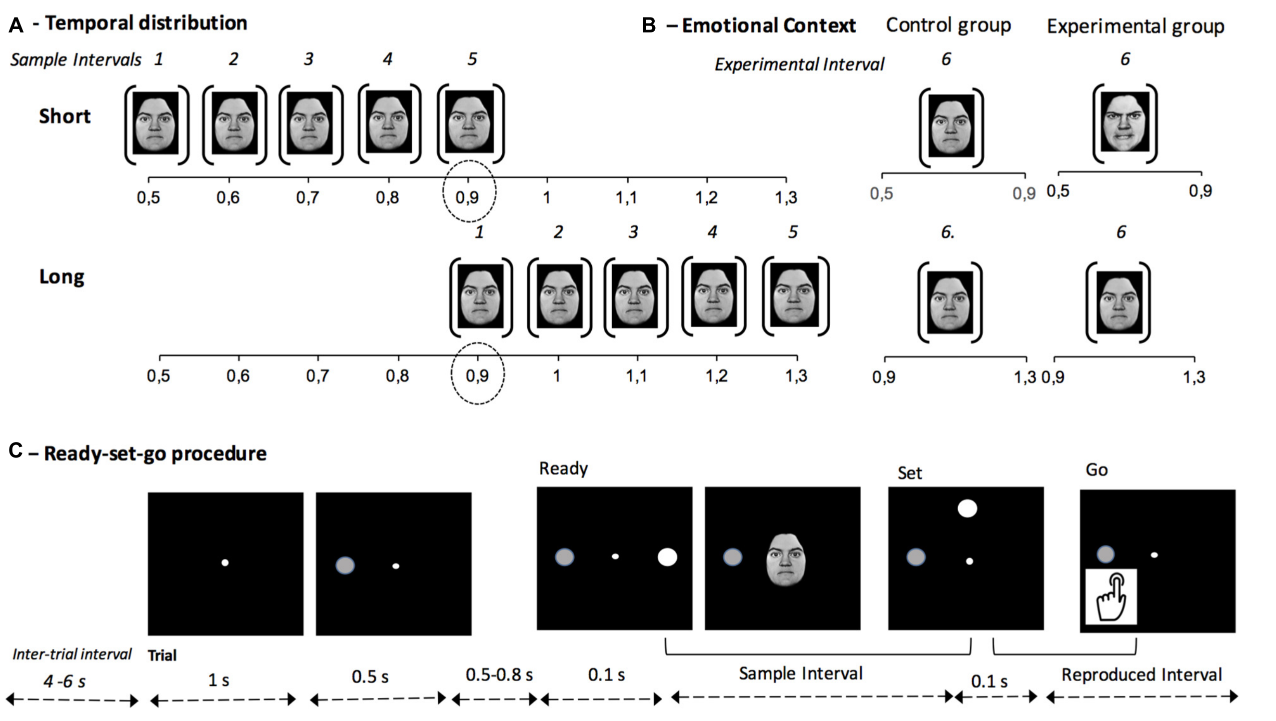

FIGURE 1 | Experimental design of the emotion-modified version of the ready-set-go procedure. **(A)** Temporal distribution description according to the Short vs. Long condition. The interval of 0.9 s is circle in dotted line because it is common to both temporal distributions. **(B)** Operationalized Emotional Context as a function of temporal distribution (Short vs. Long) and group condition [Control vs. Experimental (i.e., Emotion)]. **(C)** Detailed description of the ready-set-go general task, with a trial example.

faces were presented for the emotional intervals in both the Short and the Long task. For the emotion group, the angry faces were presented for the emotional intervals in the Short task but not in the Long task. Therefore, only the emotional context, i.e., presence of an angry or neutral face for the emotional intervals, changed between the groups in the Short ready-set-go task. The neutral face and the angry face were randomly taken from a set of three different faces.

RESULTS

Figure 2 shows the reproduced intervals for the different sample intervals (all with stimulus durations in the form of faces) in the emotion and the control group for the Short and the Long task. As observed in all reproduction tasks, the curve of reproduced intervals increased with the duration of the target intervals, and this in all conditions tested. More interestingly, in the control group, a kind of Vierordt-related effect was replicated with our new version of the ready-set-go procedure. The ANOVA conducted on the time estimates for the overlapping interval (0.9 s) with task (Short vs. Long) as within-subject factor and task-order as between-subjects factor showed a significant main effect of the task, $F(1,38) = 6.03$, $p = 0.01$, $\eta^2_p = 0.15$. The order effect and the order × task interaction were not significant ($p > 0.10$). Therefore, the same sample interval (0.9 s) was judged shorter when included in a temporal context with shorter ($M = 0.851$, SD = 0.30) rather than longer ($M = 0.933$, SD = 0.287) sample intervals.

By contrast, for the emotion group, the ANOVA showed a significant order × task interaction for the overlapping interval, $F(1,38) = 5.96$, $p = 0.02$, $\eta^2_p = 0.14$. When the Short task was performed first, there was no difference in the 0.90-s estimates between the Short ($M = 0.826$, SD = 0.304) and the Long task ($M = 0.820$, SD = 0.243), $t(20) = -0.64$, $p = 0.53$, Cohen's $d = -0.14$. However, when the Long task was performed first, the overlapping interval was judged longer, at a significant level, in the Short task ($M = 1114$, SD = 1188) than in the Long task ($M = 0.989$, SD = 0.872), $t(18) = 2.44$, $p = 0.025$, Cohen's $d = 0.56$. There was therefore a reversal of the time curves in this emotion condition, with the overlapping interval judged longer in the short task than in the long task.

To better understand this general bias in the judgment of short intervals in the emotion group, we calculated the slope and the intercept parameters of temporal curves from the linear regression performed on the averaged data (curves **Figure 2**). **Table 1** presents these parameters. It appears differences between the emotion and the control condition for the intercept values rather than for the slope-values in the Short task. This indicates a general overestimation of time estimates in the short intervals for the emotion group. The overestimation of the overlapping interval (0.9 s) in the emotion condition, despite being included in a short interval distribution, would therefore reflect a shift in the memory representation of this temporal distribution when samples were associated with emotional stimuli.

Further statistical analyses in the Short task for the emotion group were performed using a mixed linear model with the reproduced interval as dependent variable and the participants as random effect. A first analysis with the emotion as fixed factor confirmed that the emotional intervals were judged longer than the sample intervals, $E = 52.28$, ES = 24.35, 95% CI (4.52, 100.04), ddl = 2113.49, $t = 2.15$, $p = 0.03$. Obviously, the same analysis conducted for the control group showed no significant difference between these two intervals, $E = -24.47$, ES = 32.02, 95% CI (−87.26, 38.31), ddl = 2013, $t = -0.76$, $p = 0.45$. A second analysis was conducted to assess the weight of the estimate of the emotional interval on the current reproduction for the following sample intervals (current interval order: N + 1, N + 2, N + 3, N + 4, N + 5). This analysis showed a systematic effect of prior emotional interval for the different successive intervals, and even for the interval most remote from the "emotion prior" (e.g., N + 5). Indeed, our model with the current interval order and the value of the reproduced time for the immediate previous emotional interval as factors showed a significant main effect of the time estimate of emotional interval, $E = 0.13$, ES = 0.05, 95% CI (0.039, 0.2299), ddl = 1411.08, $t = 2.76$, $p = 0.006$, but no main effect of interval order (N + 1, N + 2, N + 3, N + 4, N + 5), $E = 12.26$, ES = 16.0, 95% CI (−19.27, 43.79), ddl = 1372.04, $t = 0.76$, $p = 0.45$, or of the emotion × interval-order interaction, $E = -0.145$, ES = 0.015, 95% CI (−0.044, 0,016), ddl = 1373,13, $t = -0.94$, $p = 0.35$. Therefore, the lengthening of time during the emotional interval led to a constant lengthening of time for the other sample intervals, even those far away from the prior emotional interval. This suggests that the weight (additive) of time reproduced for all sample intervals by the emotion prior did not decrease with the distance from this. For the control group, no effect of the time estimate for the prior emotional interval, $E = 0.059$, ES = 0.107, 95% CI (−0.15, 0.27), ddl = 1359.55, $t = 0.55$, $p = 0.58$, of interval order, $E = -16.61$, ES = 27.91, 95% CI (−71.38, 38.15), ddl = 1323.42, $t = -0.59$, $p = 0.55$, or of the interaction between these factors, $E = 0.009$, ES = 0.033, 95% CI (−0.056, 0.074), ddl = 1323.9, $t = 0.28$, $p = 0.79$, was found.

DISCUSSION

We tested a new emotion-based version of the ready-set-go procedure used by Jazayeri and Shadlen (2010) to examine the impact of emotional temporal context on current time measurement. With this new version, the results for the control group replicated the finding that the same interval duration is judged shorter when included in a short interval distribution than in a long interval distribution. Therefore, the presence of neutral faces during the sample intervals did not fundamentally change the results since "Vierordt's law" still held. The originality of our results was to find an overestimation of sample intervals despite there were included in a short interval distribution when a small proportion of intervals (0.16) were emotional (angry faces). For the emotion group, no difference in the judgment of the interval (0.9 s) that overlapped the two temporal distributions was observed when the Short task was performed before the Long task and a reversal effect was observed when the Long task was performed before the Short one, with the overlapping intervals being judged longer in the Short than in

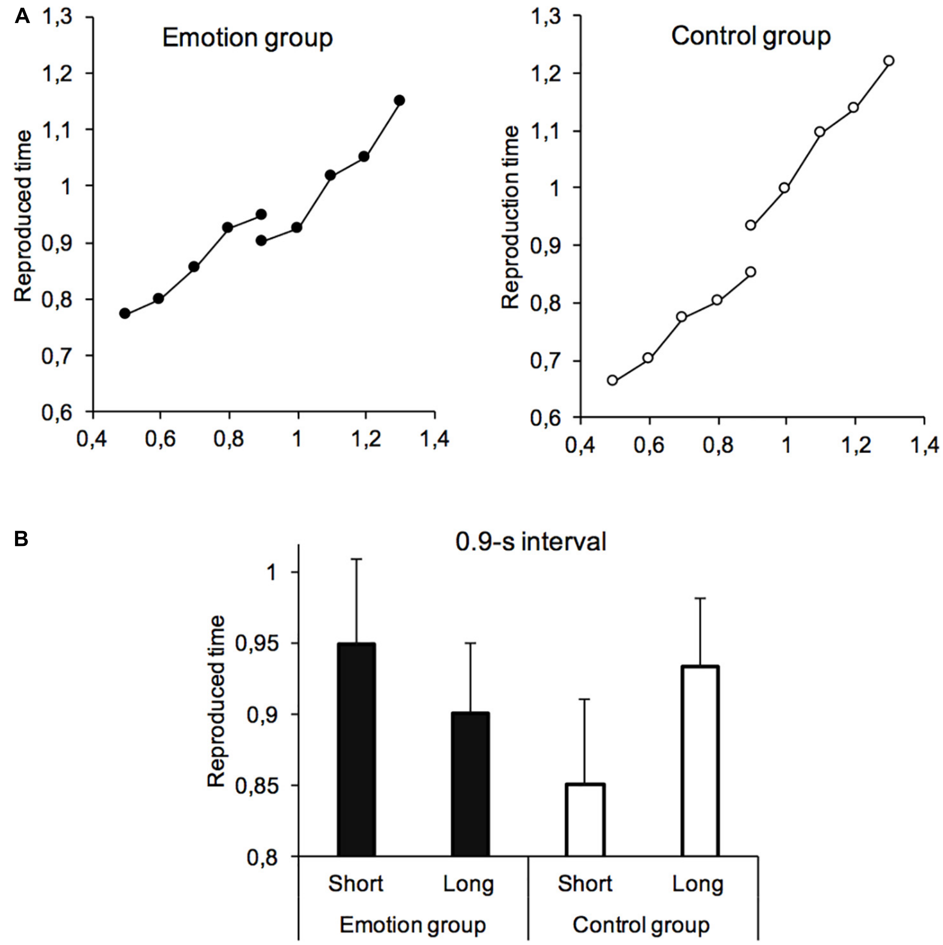

FIGURE 2 | Reproduced interval. **(A)** Reproduced time (seconds) plotted against the sample intervals for the temporal task with the distribution of short intervals (Short) and that with the distribution of long intervals (Long) for the control group and the emotion group. **(B)** Reproduced interval for the 0.9-s overlapping interval for the Short and the Long temporal task.

the Long task. This demonstrates that not only durations that have just been presented in the same task affect the current time judgment, but that those of another previously performed task also affect this judgment. Durations encountered in the past (and in particular those emotionally charged), therefore constitute reference durations in memory that influence temporal predictions in a new context. In other words, current time judgment is the product of not only the new temporal knowledge in memory but also of older knowledge.

The further analyses of time judgment in the emotion condition (Short task, emotion group) indicate that the intervals were judged longer with the angry face than with the neutral face. This is entirely consistent with the now well-established results on the time-lengthening effect produced by high-arousal negative emotional stimuli (e.g., Gil and Droit-Volet, 2012; Fayolle et al., 2015; Droit-Volet, 2019; Ogden et al., 2019; Piovesan et al., 2019). Nevertheless, the aim of our study was to test the effect of the prior emotional interval in memory on the present time judgment, but not the extension of the emotional reaction triggered in the emotional interval beyond this interval, i.e., on the encoding of subsequent sample intervals. Our results showed the significant impact of the prior time estimate for the emotional interval on the reproduced time for the subsequent sample intervals, regardless of their distance from the emotional interval. One assumption might be that this lengthening effect of estimates for the sample intervals is caused by the emotion induced during the emotional interval, which then persisted beyond this interval. This is, however, not credible because the sample intervals could occur a minute or more after the emotional interval depending on their location in the trial block (e.g., N + 5 with 5 inter-trial intervals). Besides, the time course of the emotional reaction to a picture of a face expressing anger presented on a computer is limited to a short period of time (Droit-Volet, 2019). This observation is consistent with the automatic processing of emotional signals, particularly in the case of emotional faces (Hsiao and Cottrell, 2008; Tracy and Robins, 2008). For instance, some studies have shown that the emotion-related temporal effect does not last long ($<$1–2 s) in the case of short emotional stimulus presentation on a computer (Angrilli et al., 1997; Noulhiane et al., 2007;

TABLE 1 | Slope and intercept obtained from the linear regression performed on the averaged data in each condition.

	Slope	Intercept[1]	Predicted value at the central time[2]	R^2	*p* value
Control group					
Short	0.478	422.98	757.46	0.99	*0.0007*
Long	0.716	289.4	1076.58	0.99	*0.0004*
Emotion group					
Short	0.476	526.6	860.03	0.98	*0.0015*
Long	0.626	320	1008.94	0.96	*0.0029*
Emotion group – Long first					
Short	0.502	651.26	1002.7	0.99	*0.001*
Long	0.796	232.86	1109.06	0.97	*0.007*
Emotion group – Short first					
Short	0.453	413.84	730.939	0.93	*0.02*
Long	0.472	398.75	918.356	0.98	*0.004*

[1]*Intercept in ms;* [2]*Predicted value for 700 ms (Short) or 1,100 ms (long).*

Ogden et al., 2019; Piovesan et al., 2019). Moreover, we took the further methodological precaution of incorporating an interval of 4–6 s between two successive trials. Furthermore, in this case, we should have observed a decrease in time estimates with increasing distance between the sample interval and the emotional interval. No such decrease was observed in our study. Another explanation would be that the participants' expectation of the forthcoming emotional stimulus produced an increase in their arousal level, thus resulting in a lengthening of the estimated duration of the sample intervals. However, this hypothesis is also not very credible, since no increase in time estimates was observed with increasing distance between the emotional interval and the sample interval. Indeed, the longer the time that elapsed, the greater the likelihood of seeing the next emotional stimulus.

Rather than these hypotheses related to an extension of the emotional state beyond the sample intervals, our data provide support for a memory-based hypothesis of the role of reference durations in memory in current time judgments. In line with this assumption, for the short sample intervals, our linear regression analyses indicated differences in the intercept rather than the slope of the time curves between the emotion and control groups. This suggests a general bias in temporal judgment related to a shift in the reference temporal distribution in memory due to the overestimation of sample intervals associated to emotional stimuli. Most models of timing, and even the internal clock models, describe the key role of reference time memory in the present judgment of time (e.g., Gibbon et al., 1984). This has been widely investigated, for example in studies using stimuli of different sensory modalities (auditory, visual) in the same task or in two successive tasks (Penney, 2003). It is therefore both simple and logical to assume that some longer sample durations, those associated with emotional events, were added to the distribution of sample intervals in memory. This would have shifted the mean of the temporal distribution toward a longer value. Consequently, the overlapping interval was judged longer in the short task by the emotion group than by the control group, and this in turn reduced the difference between the time estimates of the overlapping interval in the short and long task or even reversed the effect. Our data therefore provide additional evidence on the key role of previous experience (prior) on perceived intervals (likelihood). In other words, time judgment is not simply the result of an interval measured by an internal clock system, but also of participants' dispositions based on their knowledge, which is itself updated by experience of stimulus processing (Zhu et al., 2021).

However, it is well established in the literature that memories of threatening events are those that are remembered and recalled best (Ledoux, 1997; Reisberg and Heuer, 2004). Cocenas-Silva et al.'s (2013) study showed that emotional durations associated with threatening stimuli were those that were best recalled from long-term memory. It is therefore likely that durations associated with emotional events do not have the same weight in temporal memory as other durations associated with neutral events. This needs to be tested using our new emotional paradigm in further studies. However, the present study shows a limitation, such as a condition in which both duration ranges (Short and Long) are subject to the introduction of emotional stimuli, or a condition in which no modification of the basic paradigm is performed for direct comparison. Nevertheless, the originality of the present study lies in the development of an emotion-based version of Jazayeri and Shadlen's procedure and in showing that introducing longer time estimates produced by the perception of emotional events (angry face) in a temporal reproduction task modified the judgment of current intervals by changing the reference temporal distribution in memory. However, a new procedure also raises new questions that must be examined experimentally to better understand the role of emotional priors in the current time judgment. It is clear that this study offers a first step, a test of a new procedure that must be embraced by researchers for the future in the time-emotion domain.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the UCA Research Ethics Committee (IRB00011540-2019-32). The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SD-V and SG conceived and planned the design. SD-V conceived the implementation of the research, carried out the analyses of the results and carried out the first draft of the manuscript. SD-V and SG contributed to the final version of the manuscript. Both authors contributed to the article and approved the submitted version.

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The Intention to Conceal Does Not Always Affect Time Perception

Izumi Matsuda[1] and Hiroshi Nittono[2]*

[1] Department of Psychology, Aoyama Gakuin University, Shibuya, Japan, [2] Graduate School of Human Sciences, Osaka University, Suita, Japan

The display duration of stimuli is overestimated due to the increase in phasic arousal induced by the stimuli or high levels of background arousal. A previous study demonstrated that display duration of items (2 s) was overestimated when a participant attempted to conceal one of the items so as not to be detected in the concealed information test (CIT). As the time perception remained the same between the item to be concealed and the other items, the overestimation was thought to be due to the high level of background arousal under the conceal condition. Duration of 2 s may be too long to examine the phasic arousal effect induced by the concealed item. The present study conducted three online experiments with shorter durations, that is, each of three items was presented with duration of 1, 0.5, and 2 s in Experiments 1, 2, and 3, respectively. The participants were instructed to conceal one of the three items under the conceal condition and did not conceal any item in the innocent condition. The difference in time perception between the conceal and innocent conditions or between items under the conceal condition was observed in none of the three experiments. The result indicates that temporal overestimation does not occur when a participant is only concealing an object. Rather, temporal overestimation would occur only when the level of background arousal is amplified by the concealment.

Keywords: time perception, concealed information test, arousal, online experiment, physiological index

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****Correspondence:***
Izumi Matsuda
izumi@ephs.aoyama.ac.jp

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INTRODUCTION

The fact that arousal speeds up the pacemaker of an internal clock is well known (Treisman, 1963; Gibbon et al., 1984; Zakay and Block, 1997; Droit-Volet and Meck, 2007). The display durations of stimuli are generally overestimated when the level of background arousal is high under certain conditions (Wittmann and Paulus, 2008; Droit-Volet et al., 2011; Piovesan et al., 2019). The duration of a stimulus is also overestimated when it induces the increase of phasic arousal compared with non-arousing stimuli (Gil and Droit-Volet, 2012).

Arousal change occurs under various cognitive processes, one of which is concealment. Previous scholars have examined the psychological processes related to concealment using the paradigm of the concealed information test (CIT), which is a psychological tool for criminal investigations. The CIT presents one relevant item that the guilty person should be aware of and intend to conceal embedded among other irrelevant items. Previous studies on the CIT indicate that the relevant item elicits orienting responses that induce phasic arousal (e.g., increased skin conductance response) and responses related to cognitive control to inhibit the orienting responses (e.g., respiration suppression; Matsuda et al., 2013; klein Selle et al., 2016, 2018; Matsuda and Nittono, 2018). Due to the phasic arousal increase, the duration of the relevant item in the CIT is expected to be perceived as longer than those of irrelevant items.

Matsuda et al. (2020) investigated time perception during the CIT. In their experiment, the participants were instructed to steal an item and conceal it during the experiment. Each participant was presented with two conditions. The first includes pictures of three items, including the stolen one (i.e., conceal condition), whereas the second uses pictures of three items that were not stolen (i.e., innocent condition). The participants were instructed to determine the display duration of each picture as shorter than, equal to, or longer than a set duration of 2 s. The items were consistently presented for 2 s. However, the display duration of the items was perceived as longer under the conceal condition than that under the innocent condition. Matsuda et al. explained that this disposition was caused by an increased level of arousal when the participants were concealing an item, as evidenced by higher levels of skin conductance under the conceal condition than that under the innocent condition.

Contrary to the expectation, Matsuda et al. (2020) did not determine the difference in time perception between the relevant item to be concealed and the other irrelevant items under the conceal condition, despite the increased skin conductance response for the relevant item than the irrelevant items. Gil and Droit-Volet (2012) suggested that the effect of phasic arousal induced by a stimulus on time perception decreased when the stimulus duration exceeded 1 s. The authors argued that subjective time distortions with brief durations (i.e., less than 1 s) are a result of the action of a pure arousal mechanism. However, the interference between arousal and attention occurs with longer durations, which may reduce the time distortion phenomenon (Coull et al., 2004). The null finding of Matsuda et al. (2020) between items may be due to the longer stimulus duration of 2 s.

The present study aims to confirm whether the item to be concealed would be perceived as longer than the other items using shorter display durations than those used in Matsuda et al. (2020). Experiment 1 used a display duration of 1 s instead of 2 s to observe the stimulus-induced arousal effect (Gil and Droit-Volet, 2009). We then conducted Experiments 2 and 3, whose protocols were the same as those of Experiment 1 but with different durations. In Experiment 2, we used a shorter duration of 0.5 s given ERP studies that stated that cognitive control-related processes to inhibit arousal would occur at approximately 0.5 s after the onset of the item (Matsuda et al., 2013; Matsuda and Nittono, 2018). In Experiment 3, we used duration of 2 s to replicate Matsuda et al. (2020). The study presents the following hypotheses.

H1: The display duration of the items is perceived as longer in the conceal condition than in the innocent condition in all experiments.

H2: The display duration of the relevant item to be concealed is perceived as longer than that of the other irrelevant items in the conceal condition in Experiment 1 (item duration = 1 s) and 2 (item duration = 0.5 s) but not in Experiment 3 (item duration = 2 s).

The main experimental protocol of the present study was the same as that of Matsuda et al. (2020) except for the following points. First, although the previous study conducted experiment face-to-face, the present study conducted all experiments online. Thus, the participants did not meet the experimenter and undertook the CIT alone without the measurement of physiological indices. Several studies have shown that online CITs are feasible. They produced similar results to those obtained in traditional face-to-face CITs based on reaction times (Verschuere and Kleinberg, 2016; Lukács et al., 2017; Lukács and Ansorge, 2019). Second, although the participants memorized the object through a mock theft in the previous study, they memorized the object on the card they selected in the present study. A meta-analysis of the CIT (Ben-Shakhar and Elaad, 2003) showed that even when the participants memorized the relevant item without performing a mock crime, the relevant item elicited greater arousal responses than the irrelevant items. Therefore, the attempt to conduct the current experiments online with a method other than a mock crime is acceptable.

MATERIALS AND METHODS

Participants

The effect size of H1 in Matsuda et al. (2020) was $dz = 0.436$. To detect this effect with a power of 0.95 by a two-tailed t-test ($p < 0.05$), a sample size of 71 estimated by G*Power (ver. 3.1.9.2; Faul et al., 2007) was considered adequate. The study recruited participants through a crowdsourcing company (CrowdWorks, Japan) for each experiment. Those met the exclusion criteria (section "Exclusion Criteria") were excluded. The remaining participants were 72 [30 men and 42 women; $M = 38.85$, standard deviation (SD) = 7.85] for Experiment 1; 73 (39 men and 34 women; $M = 39.05$, $SD = 8.60$) for Experiment 2; and 71 (31 men and 40 women; $M = 41.66$, $SD = 9.14$) for Experiment 3. The Ethics Committee of Aoyama Gakuin University approved the study (approval number: AO20-16).

Stimuli

The stimuli were the same as those used in Matsuda et al. (2020). Two stimulus sets of real objects were prepared. The first consisted of three accessories (a ring, a necklace, and earrings), whereas the second consisted of three electronic products (a mobile phone, a digital camera, and a voice recorder). A photograph of each object was taken and presented in three angles (i.e., upright, left-rotated, and right-rotated) for a total of nine pictures per set (3 objects × 3 angles).

Procedure

The experiment was created using Inquisit 6 and the participants conducted it online via Inquisit Web Player 6.3.5 or 6.3.4.[1] The participants conducted the experiment using their PC and received 440 JPY as compensation (equivalent to approximately 4 USD) if they successfully reached the end of the experiment.

[1] https://www.millisecond.com

First, the participants memorized standard durations of 1, 0.5, and 2 s in Experiments 1, 2, and 3, respectively, by looking at pictures for nine times. These pictures were three stationaries and would not be used in the test session. The standard duration was not explicitly stated. Then, the training session began (see **Figure 1A**). In training trials, the same pictures were randomly presented for the standard duration and standard duration ± 0.2 s (i.e., 0.8, 1.0, or 1.2 s in Experiment 1; 0.3, 0.5, or 0.7 s in Experiment 2; and 1.8, 2.0, or 2.2 s in Experiment 3). After displaying the picture, buttons labeled as "short," "equal," or "long" appeared on the screen. The participants decided whether the duration was "short," "equal," or "long" compared with the memorized standard duration. To avoid confusion, the training session started with three trials by presenting a picture with a standard duration. If they responded correctly in two out of three trials, then the randomized training trials started. If not, then three more trials with the standard duration were repeated. The intertrial interval was 2–3 s, and the training session was completed when the correct response rate exceeded 80% in the last five randomized training trials.

The participants were then asked to memorize an object. They were instructed to select one of six cards on the screen.

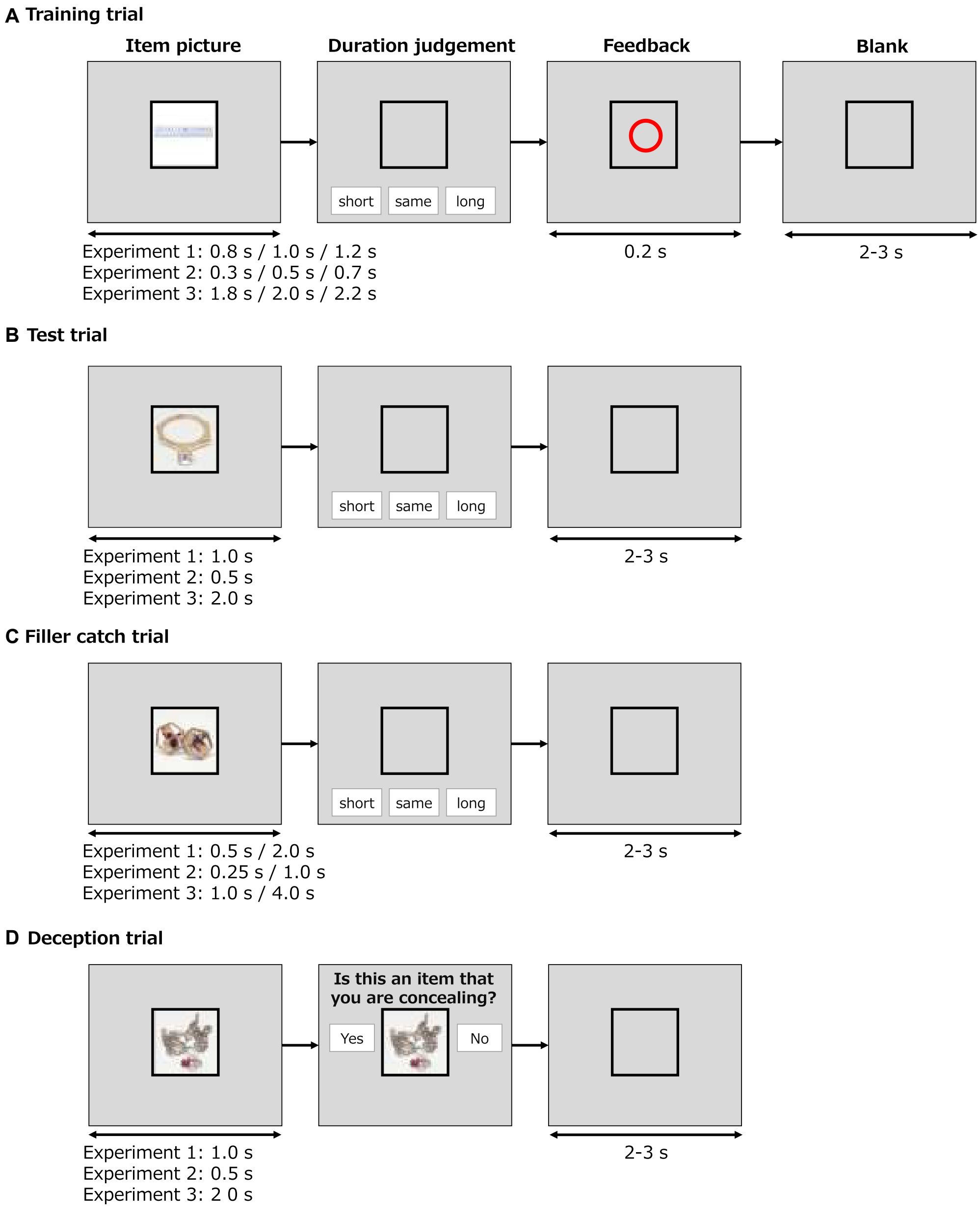

FIGURE 1 | Examples of a trial in the training session and a test trial, a filler catch trial, and a deception trial in the test session. **(A)** Training trial. **(B)** Test trial. **(C)** Filler catch trial. **(D)** Deception trial.

The selected card was turned over and a picture of an object (i.e., ring, necklace, earrings, mobile phone, digital camera, or voice recorder) was presented. The participants should remember and conceal the object until the end of the experiment. Unbeknownst to the participants, the object to be memorized was counterbalanced across participants.

In the test session, shown as a test trial in **Figure 1B**, each picture of a stimulus set was presented three times on the screen with a standard display duration (3 objects × 3 angles × 3 times = 27 trials in random order). **Figure 1C** presents a filler catch trial in which each of the three upright pictures was presented for half (0.5 s in Experiment 1; 0.25 s in Experiment 2; 1 s in Experiment 3) or twice (2 s in Experiment 1; 1 s in Experiment 2; 4 s in Experiment 3) of the standard duration (3 objects × 1 angle × 2 durations = 6 trials). Once a picture disappeared from the screen, "short," "equal," and "long" buttons appeared. The participants decided whether the display duration was "short," "equal," or "long" compared to the memorized standard duration. In addition to these trials, a deception trial (**Figure 1D**) was inserted infrequently in which the question "Is this an item that you are concealing?" was presented with "yes" and "no" buttons after the display of each of the three upright pictures (3 objects × 1 angles × 2 times = 6 trials) to remind the participants that they had to conceal the chosen object. The participants were expected to press the "no" button to all items. In total, 39 trials were conducted in random order with an intertrial interval of 2–3 s. No speeded response was required.

The abovementioned test session was repeated using the other stimulus set. The test session using a stimulus set that included an item to be concealed was defined as the conceal condition, whereas the other test session was defined as the innocent condition. The order of these conditions was counterbalanced across participants. The item to be concealed was defined as the relevant item in the conceal condition, whereas the sham "relevant" item in the innocent condition was counterbalanced across participants.

Lastly, the participants rated each of the six objects on two scales: stimulus valence (from 1 = *extremely unpleasant* to 7 = *extremely pleasant*) and motivational direction (from 1 = *extremely want to avoid* to 7 = *extremely want to approach*). They were then instructed to select the object they memorized at the beginning of the experiment from the pictures of the six objects. In addition, they rated how well they concealed the object during the experiment using a seven-point scale (from 1 = *not at all successful* to 7 = *extremely successful*).

Exclusion Criteria

The participants who met either of the following conditions were excluded from each of the three experiments.

1. Those who failed to recall the object they preselected at the end of the experiment.
2. Those who failed in more than two out of the six filler catch trials in either of the two conditions.
3. Those who failed in more than one out of the six deception trials in either of the two conditions.

Analysis

The frequencies of the "short," "equal," and "long" responses were counted separately for each item in each condition, and the mean index of time judgment was calculated as follows: (number of "long" responses − number of "short" responses)/total number of responses (Mella et al., 2011). The index ranges from −1 to + 1. A positive value indicates overestimation, whereas a negative value indicates underestimation of temporal duration. For the irrelevant items, the values for the two items were averaged.

The time judgment index and subjective ratings (stimulus valence and motivational direction) were subjected to a two-way analysis of variance (ANOVA) (Condition [conceal or innocent] × Item [relevant or irrelevant]) with repeated measures for each of the three experiments. The effect sizes were described as partial η^2 ($\eta_p{}^2$) for ANOVA and Cohen's *d* for *t*-tests. We focused on the main effect of condition and the interaction effect to verify H1 and H2, respectively. When testing for the difference between two means, Bayes factor is computed using JASP 0.14.1.[2] Lastly, a three-way ANOVA (Duration [1 s, 0.5 s, or 2 s] × Condition × Item) was conducted for confirmation, because the three experiments were very similar except for stimulus duration.

The abovementioned protocols were registered using duration of 1 s (i.e., Experiment 1). The preregistered protocol, stimulus materials, and obtained data are available at https://osf.io/m2zeg/.

RESULTS

To confirm whether the participants tried to conceal their knowledge, we first checked the subjective rating of how well they concealed the memorized object. The average ratings were 5.99 (*SD* = 1.26, range = 2–7), 6.06 (*SD* = 1.24, range = 3–7), and 5.94 (*SD* = 1.26, range = 2–7) for Experiments 1, 2, and 3, respectively. In other words, the majority of the participants felt that they could conceal the memorized object.

Time Judgment Index

Figure 2 presents the mean time judgment index for each condition and each item in Experiments 1, 2, and 3. **Table 1** shows the results of Condition × Item ANOVA related to H1 (main effect of condition) and H2 (interaction). In all experiments, neither of the main effects of condition or interactions was significant. **Table 1** also depicts the results of Duration × Condition × Item ANOVA, which indicated that neither of the main effect of condition or the Condition × Item interaction was significant. Other results for Duration × Condition × Item ANOVA indicate no significant effects of duration [main effect of duration: $F(2, 213) = 1.929$, $p = 0.148$, $\eta_p{}^2 = 0.018$; Duration × Condition interaction: $F(2, 213) = 1.942$, $p = 0.146$, $\eta_p{}^2 = 0.018$; Duration × Item interaction: $F(2, 213) = 0.521$, $p = 0.275$, $\eta_p{}^2 = 0.005$; Duration × Condition × Item interaction: $F(2, 213) = 0.103$, $p = 0.902$, $\eta_p{}^2 < 0.001$]. As an exploratory analysis, the same ANOVAs were conducted separately for

[2] https://jasp-stats.org/

TABLE 1 | Results of the Condition × Item ANOVA in each experiment and Duration × Condition × Item ANOVA across all experiments.

	Main effect of condition (H1)				Condition × Item (H2)			
	F	***p***	η_p^2	BF_{10}	***F***	***p***	η_p^2	BF_{10}
Time judgment index								
Experiment 1 [1 s, *df* = (1, 71)]	1.728	0.193	0.024	0.295	0.294	0.589	0.004	0.149
Experiment 2 [0.5 s, *df* = (1, 72)]	0.195	0.660	0.003	0.141	0.956	0.331	0.013	0.204
Experiment 3 [2 s, *df* = (1, 70)]	1.654	0.203	0.023	0.287	0.168	0.683	0.002	0.141
All experiments [*df* = (1, 213)]	0.282	0.596	0.001	0.087	1.257	0.263	0.006	0.143
Subjective stimulus valence								
Experiment 1 [1 s, *df* = (1, 71)]	3.323	0.073	0.045	0.621	1.117	0.294	0.015	0.221
Experiment 2 [0.5 s, *df* = (1, 72)]	5.506	0.022	0.071	1.668	11.232	0.001	0.135	19.977
Experiment 3 [2 s, *df* = (1, 70)]	3.644	0.060	0.049	0.724	2.526	0.116	0.035	0.432
All experiments [*df* = (1, 213)]	11.689	0.001	0.052	21.864	10.358	0.001	0.046	11.662
Subjective motivational direction								
Experiment 1 [1 s, *df* = (1, 71)]	0.831	0.365	0.012	0.193	0.038	0.846	0.001	0.132
Experiment 2 [0.5 s, *df* = (1, 72)]	1.841	0.179	0.025	0.309	2.929	0.091	0.039	0.515
Experiment 3 [2 s, *df* = (1, 70)]	3.834	0.054	0.052	0.789	2.130	0.149	0.030	0.359
All experiments [*df* = (1, 213)]	5.872	0.016	0.027	1.330	3.667	0.057	0.017	0.462

Results related to H1 and H2 are extracted.

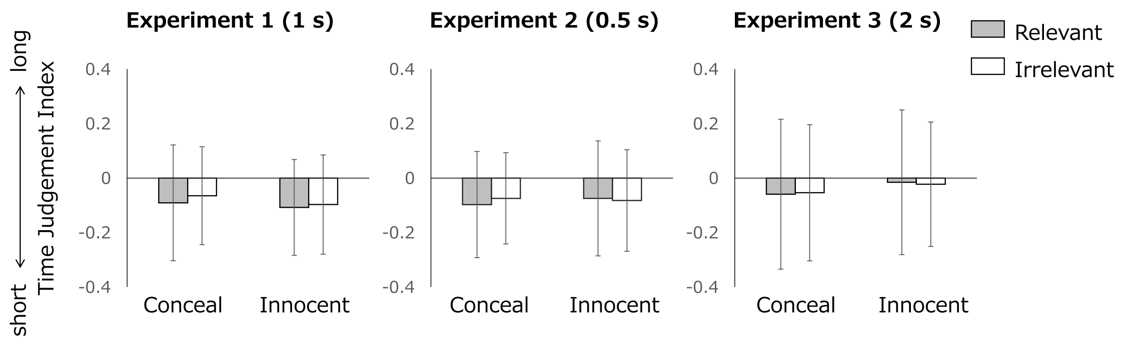

FIGURE 2 | The mean time judgment index for each condition and each item. Error bars denote standard deviations.

men and women. However, the results did not change and no significant differences in the time judgment index were found (see **Supplementary Material**).

Subjective Stimulus Valence

Figure 3 depicts the mean subjective rating of stimulus valence for each condition and each item in Experiments 1, 2, and 3. **Table 1** presents the results of Condition × Item ANOVA related to H1 (main effect of condition) and H2 (interaction). The main effect of condition was significant for Experiment 2, whereas it is marginally significant for Experiments 1 and 3. The Duration × Condition × Item ANOVA demonstrated that both of the main effect of condition and the Condition × Item interaction were significant. The items were evaluated as more pleasant in the conceal condition (M = 4.31) than in the innocent condition (M = 4.10). Moreover, the relevant item was evaluated as more pleasant than the irrelevant items in the conceal condition [$t(215) = 4.832$, $p < 0.001$, $d = 0.327$] but not in the innocent condition [$t(215) = 1.143$, $p = 0.254$, $d = 0.068$]. No significant effects of duration were observed [main effect of duration: $F(2, 213) = 1.264$, $p = 0.285$, $\eta_p^2 = 0.012$; Duration × Condition interaction: $F(2, 213) = 0.028$, $p = 0.972$, $\eta_p^2 < 0.001$; Duration × Item interaction: $F_{(2,213)} = 0.059$, $p = 0.943$, $\eta_p^2 < 0.001$; Duration × Condition × Item interaction: $F_{(2,213)} = 0.613$, $p = 0.543$, $\eta_p^2 = 0.006$].

Subjective Motivational Direction

Figure 4 shows the mean subjective rating of motivation direction for each condition and each item in Experiments 1, 2, and 3. **Table 1** shows the results of Condition × Item ANOVA related to H1 (main effect of condition) and H2 (interaction). In all experiments, neither of the main effects of condition or interactions was significant. The Duration × Condition × Item ANOVA indicated that the main effect of condition was significant. No significant effects of duration were observed [main effect of duration: $F(2, 213) = 0.223$, $p = 0.801$, $\eta_p^2 = 0.002$; Duration × Condition interaction: $F(2, 213) = 0.313$, $p = 0.732$, $\eta_p^2 = 0.003$; Duration × Item interaction: $F(2, 213) = 1.162$, $p = 0.315$, $\eta_p^2 = 0.011$; Duration × Condition × Item:[$F(2, 213) = 0.619$, $p = 0.539$, $\eta_p^2 = 0.006$].

FIGURE 3 | Subjective stimulus valence for each condition and each item. Error bars denote standard deviations (*SDs*).

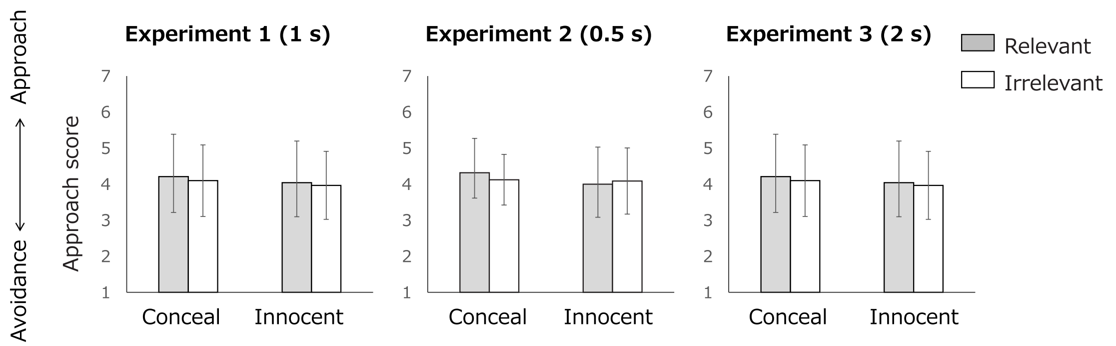

FIGURE 4 | Subjective motivation direction for each condition and each item. Error bars denote standard deviations.

Individual Data of Time Judgment Index

We computed differences in the mean of the time judgment index between the conceal and innocent conditions for each participant and categorized these differences in ascending order. **Figure 5** indicates the individual data of the differences in Experiments 1, 2, and 3 and Matsuda et al. (2020), respectively. The range and the variation of the differences between the conditions were similar for the previous and present studies except for Experiment 3. However, a larger number of participants showed a positive value in the previous study than in the present study: 66.67% of the participants exceeded zero in the previous study, whereas 56.94, 41.10, and 36.62% of the participants exceeded zero in Experiments 1, 2, and 3, respectively.

DISCUSSION

The present study examined the effect of concealment on time perception by revising a previous study (Matsuda et al., 2020). The previous study illustrated that the overall temporal overestimation would occur under the condition in which the participants were instructed to conceal an item. However, it did not determine the temporal overestimation for the item to be concealed compared with other items. The present study used shorter item durations of 1 and 0.5 s in addition to the 2 s used in the previous study with the expectation that the effect of the increase in phasic arousal elicited by the item to be concealed would be observed with shorter durations. Contrary to the expectation, the present study did not find any difference in time perception between conditions or between items. The variations of the differences in time perception between conditions were similar between the previous and present studies. However, the overestimation effect of concealment was observed in a larger number of participants in the previous study compared to the present study. The present study indicates that time perception may not always be distorted when participants are concealing an item.

There are several potential reasons that produced these differences. Although the main experiment protocol related to concealment was the same between the previous and present studies, the present study was conducted online, whereas the previous study was conducted face-to-face. In the previous study, the experimenter was observing the participant's responses throughout the test, of which the participant was aware. In contrast, in the present study, the participant conducted the test alone and did not meet with the experimenter. They were never aware of the existence of the experimenter or the observer during the test. Ogawa et al. (2007) proposed that the existence of the observer amplifies the skin conductance level, which reflects arousal level, during the CIT. Matsuda et al. (2020) also stated that the skin conductance level was higher in the conceal condition than in the innocent condition. In the present study, arousal level

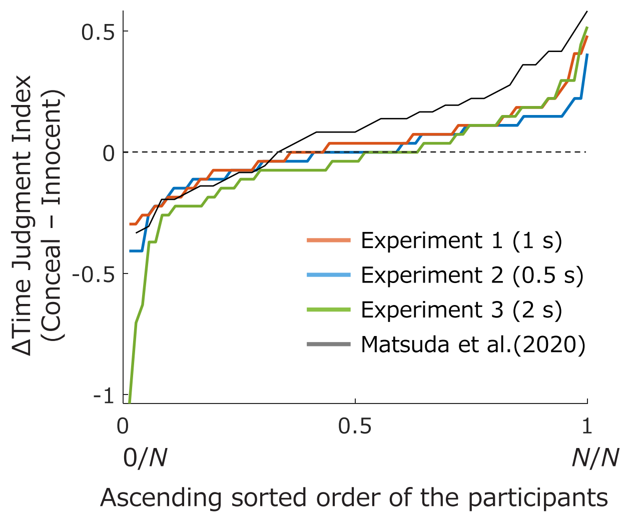

FIGURE 5 | Individual data of the difference in the time judgment index between conditions. The difference was computed between the mean of the Conceal condition and that of the Innocent condition for each participant, which was organized in ascending order. The horizontal axis indicates (ascending order of each participant)/(total number of the participants), whereas the vertical axis indicates the participant's difference in the mean between conditions. Data from Experiments 1 (blue), 2 (red), and 3 (green), and the previous study (gray) were plotted.

during the conceal condition may not be amplified due to the absence of the experimenter. This situation may negate temporal overestimation under the concealment. Although previous studies have shown that online CITs are feasible in that significant reaction-time differences between relevant and irrelevant items are observed (Verschuere and Kleinberg, 2016; Lukács et al., 2017; Lukács and Ansorge, 2019), online experiments may not be adequate to elevate arousal level as much as laboratory experiments.

Furthermore, in the previous study, the participant memorized the relevant item by stealing it as a mock crime, whereas the participant in the present study was only instructed to memorize the item displayed on the screen. The fact that the relevant item elicited greater physiological responses than the irrelevant items even when the participants were only asked to memorize the relevant item (i.e., without performing a mock crime) is well known (as a meta-analysis, see Ben-Shakhar and Elaad, 2003). In contrast, Elaad (2014) mentioned that the skin conductance level during the test was greater when the participants encountered the relevant item through a mock crime than when they only memorized the relevant item without performing a mock crime. In the present study, arousal level during the conceal condition would not increase due to the lack of a mock crime, which would decrease the difference in time perception between the conceal and innocent conditions.

Although we expected that the difference in time perception would be observed between the relevant and irrelevant items in the conceal condition using short display durations (i.e., 1 s and 0.5 s), no difference was found for any durations. Many previous studies have shown that the relevant item typically elicits greater skin conductance response than irrelevant items when the participants were asked to only memorize the relevant item (Ben-Shakhar and Elaad, 2003; Matsuda et al., 2006). Thus, the relevant item in the present study would also elicit increased phasic arousal than irrelevant items. The lack of difference in time perception between items may be explained by an unexpected result of subjective evaluation that the relevant item was evaluated as pleasant compared with the other items in the present study, contrary to the finding of Matsuda et al. (2020) where the relevant item was evaluated as unpleasant compared with the other items. In general, arousing negative stimuli can induce temporal overestimation, whereas arousing positive stimuli induce temporal underestimation (Gable and Poole, 2012) or no temporal distortion (Ogden et al., 2019). In the present study, the positive subjective evaluation of the relevant item may cancel the temporal overestimation elicited by the increase in item-induced arousal.

Why was the item to be concealed evaluated as pleasant in the present study? Generally, an owned object is valued higher than the same object that lacks an assigned ownership (Thaler, 1980; Kahneman et al., 1990; Morewedge and Giblin, 2015). This endowment effect is not confined to private goods, such that people value information they own more than information they do not own (Rafaeli and Raban, 2003). Thus, in the CIT, relevant information would be originally evaluated as valuable and pleasant compared with other information. In the face-to-face CIT, however, the participant is conscious of the experimenter or observer from whom the participant has to conceal knowledge. Only when the participant is aware of the other person that is observing his/her responses can the participant be motivated to avoid detection of the information owned. In this situation, information would become evaluated as unpleasant and should be avoided.

The limitation of the present study is that we did not measure physiological indices reflecting arousal, such as skin conductance level, because it was conducted online. Based on previous studies, we speculate that the present results were caused by the lack of increase in arousal level, which may be due to the absence of the observer and performance of a mock crime. However, we cannot provide a direct evidence of this notion because we did not measure any arousal indices. To examine the effect of an experimental manipulation that will influence time perception through an increase in arousal (e.g., concealment), we need to check whether the arousal is in fact amplified by measuring physiological indices such as skin conductance or at least by using a questionnaire (e.g., State-Trait Anxiety Inventory: STAI). Doing so can elucidate the discussion on the effect of experimental manipulation on time perception and can prevent mismatch of findings between studies.

CONCLUSION

Matsuda et al. (2020) demonstrated that a display duration of 2 s for each item is perceived as longer when the participants are concealing one of the items. In the present study, we conducted three online experiments with display durations of 1, 0.5, and

2 s for items in the conceal condition in which the item to be concealed was presented and in the innocent condition in which the item to be concealed was not presented. In all experiments, in contrast to the previous study, the duration of the items was not perceived as longer in the conceal condition than in the innocent condition. Furthermore, similar to the previous study, the display duration of the item to be concealed was not perceived as longer than that of the other items in the conceal condition. The present study indicates that temporal overestimation may not always occur when concealing objects but may occur only when the level of background arousal is amplified with the concealment. Arousal elicited by the concealment, instead of concealment itself, would influence time perception.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://osf.io/m2zeg/.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Aoyama Gakuin University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

IM and HN conceived the study and conducted the experiment. IM analyzed the data and drafted the manuscript. HN finalized the manuscript. Both authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.781685/full#supplementary-material

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How Facial Attractiveness Affects Time Perception: Increased Arousal Results in Temporal Dilation of Attractive Faces

*Sihong Zhou[1], Lingjing Li[1,2], Fuyun Wang[3] and Yu Tian[1]**

[1] Institute of Brain and Psychological Sciences, Sichuan Normal University, Chengdu, China, [2] Sichuan Conservatory of Music, Chengdu, China, [3] China Academy of Information and Communications Technology, Beijing, China

Time perception plays a fundamental role in people's daily life activities, and it is modulated by changes in environmental contexts. Recent studies have observed that attractive faces generally result in temporal dilation and have proposed increased arousal to account for such dilation. However, there is no direct empirical result to evidence such an account. The aim of the current study, therefore, was to clarify the relationship between arousal and the temporal dilation effect of facial attractiveness by introducing a rating of arousal to test the effect of arousal on temporal dilation (Experiment 1) and by regulating arousal *via* automatic expression suppression to explore the association between arousal and temporal dilation (Experiment 2). As a result, Experiment 1 found that increased arousal mediated the temporal dilation effect of attractive faces; Experiment 2 showed that the downregulation of arousal attenuated the temporal dilation of attractive faces. These results highlighted the role of increased arousal, which is a dominating mechanism of the temporal dilation effect of attractive faces.

Keywords: time perception, arousal, mediation analysis, automatic suppression, facial attractiveness

Edited by:
Huazhan Yin,
Hunan Normal University, China

Reviewed by:
Shengdong Chen,
Southwest University, China
Li Quan,
Qujing Normal University, China

Correspondence:
Yu Tian
tianyu@sicnu.edu.cn

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INTRODUCTION

The ability to perceive time is crucial to people's everyday life. It is not only fundamental to motor activities (e.g., walking, dancing, and driving) but also essential for social communications (such as word segmentation, speaking speed, and even language understanding). However, unlike the linear progression of physical time, human time perception is not always stable. It can be adaptively distorted by the changing environment rather than perceived veridically.

Recent empirical evidence has suggested that people's time perception varies with facial attractiveness. Specifically, Ogden (2013) asked participants to verbally estimate the duration of the attractive, average, and unattractive faces. She found that participants' estimations of the attractive and average faces were longer than those of unattractive faces. Arantes et al. (2013) adopted the temporal reproduction task and found that participants reproduced longer durations for attractive faces and neutral stimuli than unattractive faces. Using a similar temporal reproduction task, Tian et al. (2019) also found the time perception of attractive faces to be longer than that of unattractive faces, and such a temporal dilation effect was highlighted by opposite-sex faces. Tomas and Španić (2016) employed a temporal bisection task that required participants to distinguish whether the presentation time of faces (400–1,600 ms) was close to the short or long anchor (400 vs.

1,600 ms). They found that participants tended to distinguish angry expressions as "long" compared with neutral expressions, but this tendency was salient only under the attractive condition but not the unattractive condition. Taken together, although researchers used different tasks and their designs varied in details, the abovementioned empirical studies generally showed that facial attractiveness influences time perception, i.e., attractive faces tend to result in the dilation effect of time perception.

In the domain of time perception, the most dominant theoretical account in explaining such temporal distortion is the pacemaker-accumulator (PA) models, which posit three main components in generating time perception, involving the pacemaker component, the switch/gate component, and the accumulator component. During timing, the pacemaker emits pulses, which go through the switch/gate to be accumulated by the accumulator. The number of these accumulated pulses then represents people's time perception (Treisman, 1963; Church, 1984; Gibbon et al., 1984). Based on PA models, time perception can be distorted by two main mechanisms: the rate of the pacemaker and the state of the switch/gate. In a time perception study, pacemaker rate is conceptualized as arousal, with increasing arousal equivalent to an acceleration of the pacemaker (Mella et al., 2011; Lake et al., 2016; Piovesan et al., 2018; Vallet et al., 2019). When the arousal increases, the pacemaker runs faster, more pulses are emitted, thus time is perceived to last longer. Meanwhile, the functionality of the switch/gate is generally conceptualized as the allocation of attention, that is, pulses pass when attention is allocated toward timing, while the pulses are blocked when attention is distracted away from timing, thus the deficit of attention toward timing leads to temporal underestimation (Zakay and Block, 1996; Brown, 1997; Lejeune, 1998; Bar-Haim et al., 2010).

According to PA models, Ogden (2013) attributed the temporal dilation effect of facial attractiveness to attention. Ogden suggested that the time perception of unattractive faces was underestimated in comparison with the attractive and average faces because unattractive faces detracted attention from timing. Alternatively, other researchers suggested that the arousal mechanism should account for the temporal dilation effect of facial attractiveness. Specifically, Arantes et al. (2013) indicated that attractive faces (particularly opposite-gender faces) are biologically salient events that activate the appetitive motivational system, thereby increasing arousal, leading to an overestimation of time perception. Tomas and Španić (2016) proposed that the same-gender attractive faces may activate the defensive motivational system due to potential competition and also result in increased arousal, leading to temporal dilation. Although previous studies have found that attractive faces capture attention earlier than unattractive faces (Maner et al., 2003; Valuch et al., 2015), which may make the switch/gate work earlier and cause temporal dilation (Grommet et al., 2011; Liu et al., 2015), Tian et al. (2019) adopted the reproduction task and pointed out that the temporal dilation effect of attractive faces seems to be more closely associated with increased arousal, suggesting that the arousal mechanism may dominate the effect of facial attractiveness on time perception. They found that male and female participants showed different patterns in perceiving durations of opposite-/same-gender faces. For opposite-gender faces, male and female participants both perceived attractive faces to be longer than unattractive ones, but for same-gender faces, only female participants consistently showed this temporal dilation effect of facial attractiveness. These results have extended the appetitive motivation theory (Arantes et al., 2013), but not the defensive motivation theory (Tomas and Španić, 2016) of arousal mechanism to male participants, suggesting that male participants' temporal dilation effect of opposite-gender facial attractiveness can be more clearly explained by arousal unidirectionally.

So far, the generally used theoretical explanation of the arousal mechanism underlying the temporal dilation effect of facial attractiveness (Arantes et al., 2013; Tomas and Španić, 2016; Tian et al., 2019) still lacks direct empirical support. The goal of the current study, therefore, was to explore the relationship between arousal and the effect of facial attractiveness on time perception by (1) introducing a subjective rating of arousal and (2) regulating arousal by an emotion regulation paradigm.

Previous studies on time perception have tried to demonstrate the relationship between the increase in arousal and temporal dilation by testing the association between the measured arousal and time perception. Common ways to manipulate arousal include employing experimental materials in different arousal levels from a standardized emotional system and dividing arousing manipulations into corresponding categorizations. For example, Mella et al. (2011) employed neutral, low-arousal negative, and high-arousal negative sounds from the International Affective Digitalized Sounds System as stimuli and adopted the skin conductance response (SCR) as an indicator of arousal. They found that a higher level of arousal generates longer time perception (Mella et al., 2011). Fayolle et al. (2015) used electric shocks (shock vs. no-shock) to manipulate arousal and adopted self-report ratings and SCR to assess arousal. They observed that the temporal dilation effect of electric shocks increased with an increase in arousal (Fayolle et al., 2015). However, the relationship between facial attractiveness and arousal has been evidenced to be non-linear. Specifically, attractive faces are more arousing than the average and unattractive faces, but unattractive faces are also generally more arousing than average faces. As our goal was to explore the relationship between arousal and the temporal dilation effect of facial attractiveness, it seems difficult to achieve our goal by dividing experimental materials with arousal. Alternatively, we intended to employ faces with increasing facial attractiveness (ranging from unattractive to attractive) as experimental materials, measure the participants' time perception and arousal to these face stimuli, and use the mediating effect analysis to test the hypothesis that increasing arousal mediates the temporal dilation effect of facial attractiveness (**Hypothesis 1**).

With the second goal to regulate arousal, we chose to study time perception in the framework of emotion regulation. According to the process model of emotion regulation (Gross, 1998), five major emotion regulation strategies can be used at each of the many steps in the process through emotion-generation: situation selection, situation modification, attention allocation, cognitive reappraisal, and expression suppression. Among them, expression suppression is a strategy directed toward inhibiting behaviors associated with emotional responding (e.g., facial expressions, verbal utterances, and gestures), and has been proven to be effective for reducing arousal (Eippert et al., 2007; Goldin et al., 2008; Flynn et al., 2010; Yuan et al., 2015; Cai et al., 2016). Importantly, by requiring participants to deliberately suppress their expression, previous studies have successfully eliminated the emotional temporal dilation effect and attributed such elimination to the reduction of arousal (Effron et al., 2006; Tian et al., 2018). However, as deliberately suppressing expression is a costly strategy in terms of attentional resources (Gross, 1998; Ohira et al., 2006; Yuan et al., 2015), and might therefore lead to a temporal underestimation due to deficits in attention (Zakay, 1989; Zakay and Block, 1997), the use of deliberate suppression may mix the mechanisms of arousal and attention. Fortunately, some evidence has shown that expression suppression can be conducted automatically *via* a priming task that passively activates the goal of suppression and then realizes this goal without one's awareness (Bargh et al., 2001). Such automatic suppression has been shown to consume few attentional resources (Mauss et al., 2007a,b; Gallo et al., 2009), and to effectively reduce arousal (Mauss et al., 2007b; Chen et al., 2017a). Considering this, we intended to adopt automatic rather than deliberate expression suppression to regulate arousal and hypothesized that the temporal dilation effect of facial attractiveness would be attenuated by the manipulation of automatic expression suppression (**Hypothesis 2**).

Consequently, the current study has two aims: to explore the role of arousal in the effect of facial attractiveness on time perception by testing the mediating effect of arousal on temporal dilation (Experiment 1) and to regulate arousal by automatic expression suppression to explore the association between arousal and temporal dilation (Experiment 2). A temporal reproduction task would be employed to measure time perception. As previous studies have found that the arousal effect is most salient at 2,000 ms (Bar-Haim et al., 2010; Liu and Li, 2019), the current study adopted 2,000 ms as the target duration. Meanwhile, a self-reported 9-point scale was adopted to assess the facial attractiveness and arousal of each face. A sentence-unscrambling task that features suppression-related words (Mauss et al., 2007b; Yang et al., 2014; Yuan et al., 2020) was used to prime automatic expression suppression. As both physical and psychological gender have been found to have impacts on facial attractiveness (Samson and Janssen, 2014; Tian et al., 2019), all stimuli were female faces. Accordingly, heterosexual men were recruited as participants. All face stimuli were in neutral expressions to prevent a possible confounding effect of facial expressions.

EXPERIMENT 1

Method

Participant

An *a priori* power analysis was adopted using the G*Power software to determine the sample size (Faul et al., 2007). The effect size was set to a threshold of medium (i.e., 0.25) concerning previous studies using the duration reproduction task (Arantes et al., 2013; Tian et al., 2019), the alpha was set to 0.05, and power was set to 0.8. The results indicated that 28 participants are sufficient for Experiment 1.

Forty healthy men were recruited from a Chinese university. Their ages range from 18 to 24 ($M \pm SD = 20.63 \pm 1.81$) years. They had a normal or corrected-to-normal vision and were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). They were self-reported heterosexual, and none reported a history of neurological or psychiatric disorders. All participants received a moderate payment for their participation. The experiment was approved by the Ethical Committee of Human Research at Sichuan Normal University.

Stimuli

Twenty-four color images of female faces (four high-unattractive, four medium-unattractive, four low-unattractive, four low-attractive, four medium-attractive, and four high-attractive) were selected for Experiment 1. All the face stimuli displayed neutral expressions with full frontal views and were unified into a white background within 320 pixels × 400 pixels. The images were selected and categorized into each condition by the experimenters. To validate stimuli manipulations, these faces were rated by participants in attractiveness and arousal *via* a 9-point scale in the rating part of the experiment (see **Table 1**).

A repeated-measure ANOVA of attractiveness ratings with Attractiveness Polarity (two levels: attractive vs. unattractive) and Attractiveness Strength (three levels: high, medium, and low) showed a significant main effect of Attractiveness Polarity, $F(1,39) = 2{,}312.35$, $p < 0.001$, $\eta_p{}^2 = 0.98$, attractive faces were rated as systematically more attractive than unattractive faces. This main effect was modulated by Attractiveness Strength, as revealed by a significant interaction between these factors, $F(2,78) = 695.35$, $p < 0.001$, $\eta_p{}^2 = 0.95$. The simple effects analysis showed that in the attractive face session, the high-attractive faces were rated as more attractive than the medium- or low-attractive faces (ps < 0.001), the medium-attractive faces were also rated as more attractive than the low-attractive faces ($p < 0.001$); in the unattractive face session, the high-unattractive faces were rated as less attractive than the medium- or low-unattractive faces (ps < 0.001), the medium-unattractive faces were also rated as less attractive than the low-unattractive faces ($p < 0.001$).

A similar repeated-measure ANOVA of arousal ratings showed a significant main effect of Attractiveness Polarity, $F(1,39) = 184.18$, $p < 0.001$, $\eta_p{}^2 = 0.83$, attractive faces were rated as systematically more arousing than unattractive faces. This main effect was modulated by Attractiveness Strength, as revealed by a significant interaction between these factors, $F(2,78) = 43.41$, $p < 0.001$, $\eta_p{}^2 = 0.53$. The simple effects analysis showed that in the attractive face session, the high-attractive faces were rated as more arousing than the medium- or low-attractive faces (ps < 0.001), the medium-attractive faces were also rated as more arousing than the low-attractive faces ($p < 0.001$); in the unattractive face session, the high-unattractive faces were rated as more arousing than the medium- or low-unattractive faces (ps < 0.001), the medium-unattractive faces were also rated as more arousing than the low-unattractive faces ($p < 0.001$).

TABLE 1 | Mean (SD) of attractiveness and arousal for the faces in Experiment 1 (attractiveness: from 1 = "extremely unattractive" to 9 = "extremely attractive"; arousal: from 1 = "not excited at all" to 9 = "extremely excited").

	High-unattractive	Medium-unattractive	Low-unattractive	Low-attractive	Medium-attractive	High-attractive
Attractiveness rating	3.01 (0.29)	4.15 (0.33)	4.87 (0.35)	5.17 (0.31)	6.16 (0.46)	7.48 (0.36)
Arousal rating	4.92 (0.59)	3.91 (0.59)	3.01 (0.48)	3.07 (0.61)	5.18 (0.63)	6.43 (0.52)

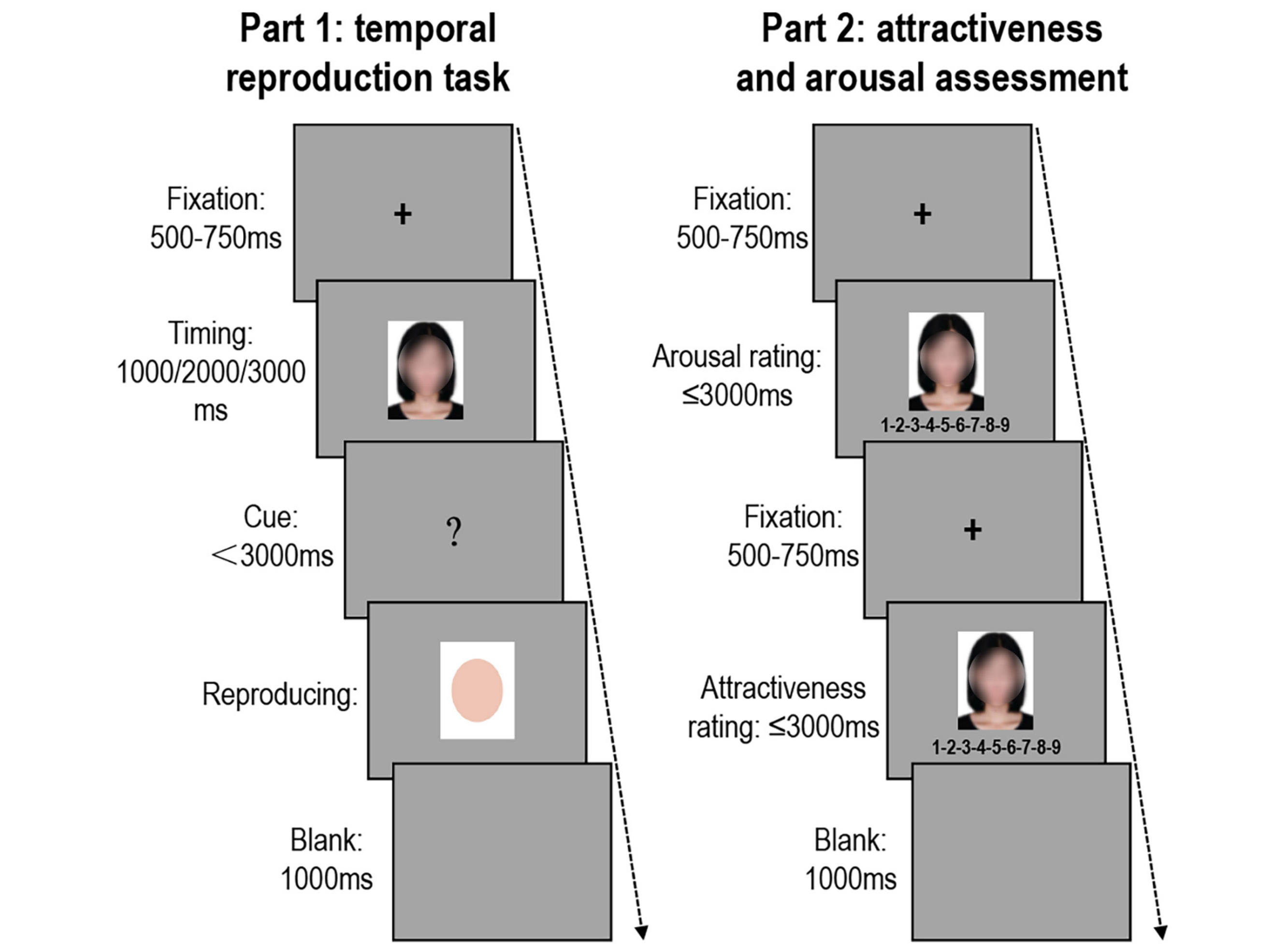

FIGURE 1 | The procedure of Experiment 1. Schematic illustration of the temporal reproduction task **(left panel)** and schematic illustration of the attractiveness and arousal assessment **(right panel)**. The faces were shown as blurred ones here for privacy.

Procedure

Participants were tested individually in a quiet and dimly lit room. They were required to seat approximately 60 cm from a 17″ LED screen (1,024 pixels × 768 pixels, 60 Hz) with horizontal and vertical visual angles of less than 16° and give their responses *via* a computer keyboard. The whole experiment involved two parts: the temporal reproduction task and the assessments of facial attractiveness and arousal. Two experimental parts were counterbalanced across participants.

In the part of the temporal reproduction task, each trial started with a fixation cross for 500–750 ms. It was immediately followed by a face, which was presented for 1,000, 2,000, or 3,000 ms. Subsequently, a question mark appeared on the screen cueing the participant to reproduce the time of face presentation. The question mark would remain on the screen either for 3,000 ms or until the participant responded by pressing the spacebar for a duration equivalent to the time the face was presented. An image of a pink oval with a white background appeared at the beginning of the key press and remained until the participant released the spacebar. Lastly, a 1,000 ms blank was presented. To ensure that the trials of target duration were about 80% (Li et al., 2017, 2019), each image was presented with eight repetitions at 2,000 ms, and only once at 1,000 and 3,000 ms, for a total of 240 trials. The trial order was randomized across participants.

In the rating part, participants were instructed to complete the assessments of attractiveness and arousal *via* a 9-point rating scale. Each trial started with a fixation cross for 500–750 ms. Then, a face was presented, in which participants were required to, respectively, rate its attractiveness and arousal within 3,000 ms, following a 1,000 ms blank (see **Figure 1**). Each face was assessed for attractiveness and arousal for once, which means a total of 24 trials. The trial order was randomized across participants, and the order of facial attractiveness and arousal assessments were counterbalanced across participants.

Results

The Effect of Facial Attractiveness on Time Perception

A repeated-measures ANOVA of reproduced duration with Attractiveness Polarity (two levels: attractive vs. unattractive) and Attractiveness Strength (three levels: high, medium, and low) revealed a significant main effect of Attractiveness Polarity, $F(1,39) = 156.60$, $p < 0.001$, $\eta_p^2 = 0.80$, attractive faces were reproduced as systematically longer than unattractive faces. This main effect was modulated by Attractiveness Strength, as revealed by a significant interaction between these factors, $F(2,78) = 68.80$, $p < 0.001$, $\eta_p^2 = 0.64$. The simple effects analysis showed that in the attractive face session, the high-attractive faces were reproduced as longer than the medium- or low-attractive faces (ps < 0.001), the medium-attractive faces were also reproduced as longer attractive than the low-attractive faces ($p < 0.001$); in the unattractive face session, the high-unattractive faces were reproduced as longer attractive than the medium- or low-unattractive faces (ps < 0.001), the medium-unattractive faces were also reproduced as longer attractive than the low-unattractive faces ($p < 0.001$). Further comparison found that for high and medium strength faces, the temporal dilation effects in the attractive face session was greater than those in the unattractive face session ($ps < 0.001$).

These results suggested that facial attractiveness could modulate time perception. Specifically, both increase and decrease of facial attractiveness led to the dilation of time perception, and attractive faces tended to result in salient temporal dilation (see **Figure 2**).

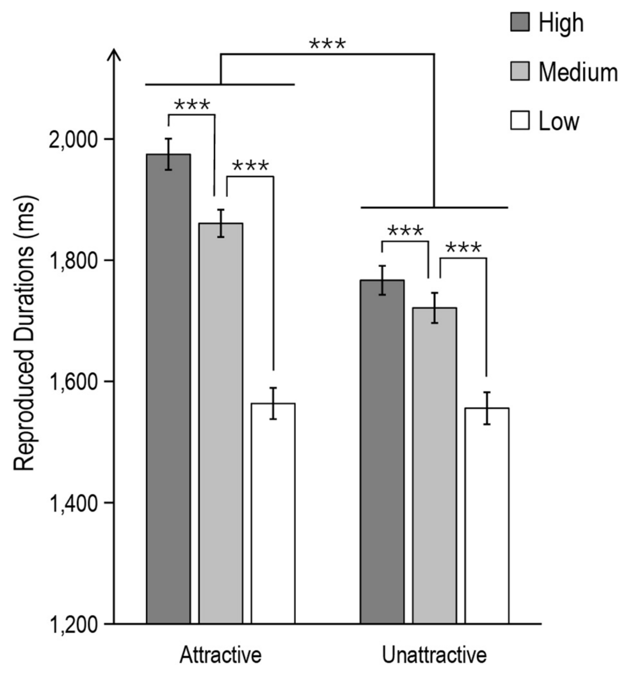

FIGURE 2 | Mean reproduced durations for each condition in Experiment 1. The error bar represents the SE (significance level ***$p < 0.001$).

The Mediating Effect of Arousal on Temporal Dilation

The *a priori* test revealed that the relationship between facial attractiveness and arousal fitted the U curve. Specifically, the closer the attractiveness rating was to the polarity (i.e., unattractive = 1 and attractive = 9), the higher the rating of arousal was. Therefore, we divided the polarity of attractiveness into attractive and unattractive sessions, and then performed mediation analyses to examine whether the relationship between facial attractiveness (X = attractiveness ratings) and time perception (Y = reproduced durations) was mediated by arousal (M = arousal ratings). The mediation analysis was performed with the PROCESS macro developed by Hayes (2013).

In the attractive session, the results showed that the 95% CI of an indirect effect of X on Y excluded 0, 95% CI: 63.12, 144.60, *Effect* = 103.08, *BootSE* = 20.31, the total effect of X on Y was significant, *Effect* = 148.91, SE = 10.60, $t = 14.05$, $p < 0.001$, 95% CI: 127.92, 169.89, and the direct effect of X on Y was significant, *Effect* = 45.83, SE = 20.69, $t = 2.22$, $p < 0.05$, 95% CI: 4.85, 86.79, thus indicating that arousal acted as a mediator between facial attractiveness and time perception in the attractive session; however, in the unattractive session, the results showed that the 95% CI of an indirect effect of X on Y included 0, 95% CI: −71.17, 15.08, suggesting that the mediating effect of arousal did not reach significance in the unattractive session (see **Figure 3**).

Discussion

In Experiment 1, we adopted subjective arousal ratings to test the hypothesis that increasing arousal mediates the temporal dilation effect of facial attractiveness (**Hypothesis 1**). The results showed that increasing arousal mediated the temporal dilation effect of attractive faces, suggesting that the increased arousal was the mechanism of the temporal dilation effect of attractive faces.

However, this underlying mechanism needs to be more directly tested. Therefore, in Experiment 2, we tried to regulate the arousal level and check whether this regulation can lead to changes in the temporal dilation effect. Again, we adopted the mediation analysis to illustrate the relationship between automatic expression suppression, arousal, and the temporal dilation effect.

EXPERIMENT 2

Method

Participants

The *a priori* power analysis was the same as the one used in Experiment 1. The results indicated that 28 participants are sufficient for Experiment 2.

FIGURE 3 | Mediation models in Experiment 1. Mediation model for the attractive session **(left panel)** and mediation model for the unattractive session **(right panel)**. The values represent the standardized regression coefficients (β) for the direct and indirect effects of Attractiveness on Reproduced Durations (significance level ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; $^{n.s.}p > 0.05$). Solid lines are used for significant effects, and dashed lines are used for insignificant effects.

A new cohort of 60 participants from the same Chinese university was recruited for Experiment 2. They were randomly assigned to one of the two groups: an experimental group (age: 18–23 years, $M \pm SD = 20.37 \pm 1.77$ years) and a control group (age: 18–24 years, $M \pm SD = 20.46 \pm 1.93$). All reported to have a normal or corrected-to-normal vision and were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). They were self-reported heterosexual, and none reported a history of neurological or psychiatric disorders. All participants received a moderate payment for their participation. The experiment was approved by the Ethical Committee of Human Research at Sichuan Normal University.

Stimuli

Twenty-four color images of female faces were used as stimuli, including eight attractive, eight average, and eight unattractive faces. All the faces displayed neutral expressions with full frontal views and were unified into a white background within 320 pixels × 400 pixels.

Images were tested using the results of a prior stimulus rating in which 30 additional male participants (age: 18–24 years, $M \pm SD = 20.23 \pm 1.99$) from the same Chinese university rated the attractiveness of 24 female faces *via* a 9-point rating scale (from 1 = "extremely unattractive" to 9 = "extremely attractive"). All raters reported to have a normal or corrected-to-normal vision and were right-handed. They were self-reported heterosexual, none reported a history of neurological or psychiatric disorders, and can be considered as homogeneous to participants in Experiments 1 and 2. These faces were rated by the rater group in attractiveness, arousal *via* a 9-point scale (see **Table 2**).

A repeated-measures ANOVA with Attractiveness (three levels: attractive, average, and unattractive) confirmed significant differences in the attractiveness ratings for the three conditions, $F(2,58) = 1{,}166.05$, $p < 0.001$, $\eta_p^2 = 0.98$. *Post hoc* tests (Bonferroni corrected) showed that attractive faces were rated as more attractive than the average or unattractive faces ($ps < 0.001$), and that average faces were also rated as more attractive than unattractive faces ($p < 0.001$).

TABLE 2 | Mean (SD) of attractiveness for the faces in Experiment 2 (attractiveness: from 1 = "extremely unattractive" to 9 = "extremely attractive").

	Unattractive face	Average face	Attractive face
Attractiveness rating	3.06 (0.29)	5.04 (0.35)	7.21 (0.39)

Procedure

The procedure for Experiment 2 involved three sequential parts: a sentence-unscrambling task, a temporal reproduction task, and an arousal assessment.

The sentence-unscrambling task was used to prime participants of suppression automatically. It was first adapted to manipulate the automatic emotion regulation by Mauss et al. (2007a,b). In this task, participants are required to construct grammatically correct, four-word sentences from five-word jumbles. For the experimental group, there were 20 sentences each included an "emotion suppression" term; for the control group, there were 20 sentences each included a "passively perceiving" term (see **Figure 4**). These terms were selected from a previous study (Yuan et al., 2020), and were effective in priming suppression and passively perceiving.

The time reproduction task and arousal assessment in Experiment 2 are similar to Experiment 1, except that different stimuli were used. In the time reproduction task, to ensure that the trials of target duration were about 80% (Li et al., 2017, 2019),

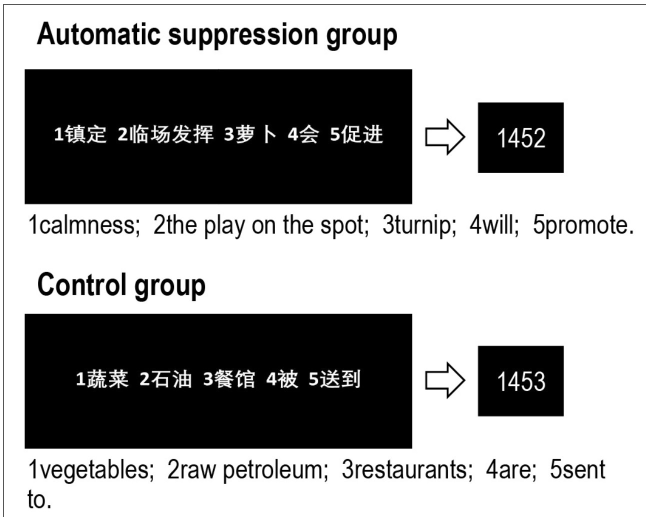

FIGURE 4 | Schematic illustration of the sentence-unscrambling task for the automatic suppression group **(top panel)** and control group **(bottom panel)**.

each image was presented with eight repetitions at 2,000 ms, and only once at 1,000 and 3,000 ms, for a total of 240 trials; in the arousal assessment, each face was assessed for arousal for once, which means a total of 24 trials. The trial order was randomized across participants.

At the end of Experiment 2, participants were required to complete a funneled debriefing procedure, which is similar to previous studies (Chartrand and Bargh, 1996; Bargh and Chartrand, 2000; Williams et al., 2009; Yuan et al., 2020). They were asked (1) whether they had ever seen or completed a sentence-unscrambling task for another experiment, (2) what they thought about the purpose of the sentence-unscrambling task, and (3) whether and what they thought that the sentence-unscrambling task and the temporal reproduction task had been related. This funneled debriefing procedure was used to check the validity of the automatic suppression manipulation. For the first question, nobody reported they had seen or completed a sentence-unscrambling task before. For the second question, most participants (n = 58) believed that the purpose of the sentence-unscrambling task was to test their grammatical abilities, and a few participants (n = 2) reported that they did not know. For the third question, more than a half of participants (n = 34) thought that the sentence-unscrambling task had nothing to do with the temporal reproduction task, and the remaining participants thought that the sentence-unscrambling task may have some relationship with the temporal reproduction task (n = 26), but nobody mentioned emotion or emotion regulation as the connection between the two tasks. Thus, no participants indicated suspicion of the experimental manipulation.

Result

Manipulation Check of Temporal Dilation

The control group data were used to check the temporal dilation effect of facial attractiveness. A repeated-measures ANOVA with Attractiveness (three levels: attractive, average, and unattractive) confirmed significant differences in the reproduced duration for the three conditions, $F(2,58) = 1{,}938.27$, $p < 0.001$, $\eta_p^2 = 0.99$. *Post hoc* tests (Bonferroni corrected) showed that attractive faces were reproduced as longer than the average or unattractive faces (ps < 0.001), unattractive faces were reproduced as longer than average faces ($p < 0.001$), suggesting that both attractive and unattractive faces led to the dilation of time perception, while attractive faces resulted in greater temporal dilation.

The Effect of Suppression on Arousal

A mixed-design ANOVA of arousal ratings with Attractiveness (three levels: attractive, average, and unattractive) as a within-subject factor and Group (two levels: control and experimental) as a between-subject factor revealed a significant main effect of Attractiveness, $F(2,116) = 899.69$, $p < 0.001$, $\eta_p^2 = 0.94$. *Post hoc* tests (Bonferroni corrected) showed that attractive faces were systematically rated as more arousing than average ($p < 0.001$), and unattractive faces were also systematically rated as more arousing than average ($p < 0.001$). The main effect of Group was also significant, showing that the experimental group systematically rated less arousal than the control group, $F(1,58) = 935.19$, $p < 0.001$, $\eta_p^2 = 0.94$. Importantly, the ANOVA found a significant interaction of Attractiveness by Group, $F(2,116) = 175.98$, $p < 0.001$, $\eta_p^2 = 0.75$. Further comparisons found that in the control group, the arousal effect of attractive faces is significantly greater than that of unattractive faces, $p < 0.001$; in contrast, in the experimental group, the arousal effect between attractive faces and unattractive faces was non-significant, $p > 0.05$.

These results indicated that the manipulation of automatic expression suppression attenuated the arousal rating for both attractive and unattractive faces, and the attenuation was salient for attractive faces.

The Effect of Suppression on Temporal Dilation

A mixed-design ANOVA of reproduced duration with Attractiveness (three levels: attractive, average, and unattractive) as a within-subject factor and Group (two levels: control and experimental) as a between-subject factor revealed a significant main effect of Attractiveness, $F(2,116) = 2{,}586.44$, $p < 0.001$, $\eta_p^2 = 0.98$. *Post hoc* tests (Bonferroni corrected) showed that attractive faces were systematically reproduced as longer than average faces ($p < 0.001$), and unattractive faces were also reproduced as longer than average faces ($p < 0.001$). The main effect of Group was also significant, showing that the experimental group systematically reproduced a shorter duration than the control group, $F(1,58) = 1{,}835.47$, $p < 0.001$, $\eta_p^2 = 0.97$. Importantly, the ANOVA found a significant interaction of Attractiveness by Group, $F(2,116) = 291.93$, $p < 0.001$, $\eta_p^2 = 0.83$. Further comparison found that the temporal dilation in the experimental group was generally smaller than that in the control groups, ps < 0.05 (see **Figure 5**).

These results indicated that the manipulation of automatic expression suppression attenuates the temporal dilation of both attractive and unattractive faces, and the attenuation is greater for attractive faces, suggesting that arousal plays an important role in the temporal dilation effect of attractive faces.

The Mediating Effect of Arousal on Temporal Dilation

In line with Experiment 1, we divided the polarity of attractiveness into attractive and unattractive conditions, then performed mediation analyses to explore the role of arousal in the temporal dilation of facial attractiveness. The Group was X (control group = 0, experimental group = 1), the Temporal Difference was Y (mean attractive/unattractive – mean average, for each participant), and Arousal Difference (mean attractive/unattractive – mean average, for each participant) was M.

In the attractive session, the results showed that the 95% CI of an indirect effect of X on Y excluded 0, 95% CI: −97.70, −7.6, *Effect* = −54.64, *BootSE* = 23.13, the total effect of X on Y was significant, *Effect* = −213.98, SE = 9.13, $t = -23.43$, $p < 0.001$, 95% CI: −232.26, −195.71, and a direct effect of X on Y was significant, *Effect* =−159.35, SE = 21.40, $t = -7.44$, $p < 0.001$, 95% CI: −202.20, −116.49, indicating that arousal acted as a mediator between automatic expression suppression and temporal dilation in the attractive session; however, in the unattractive session, the results showed that the 95% CI of an indirect effect of X on Y

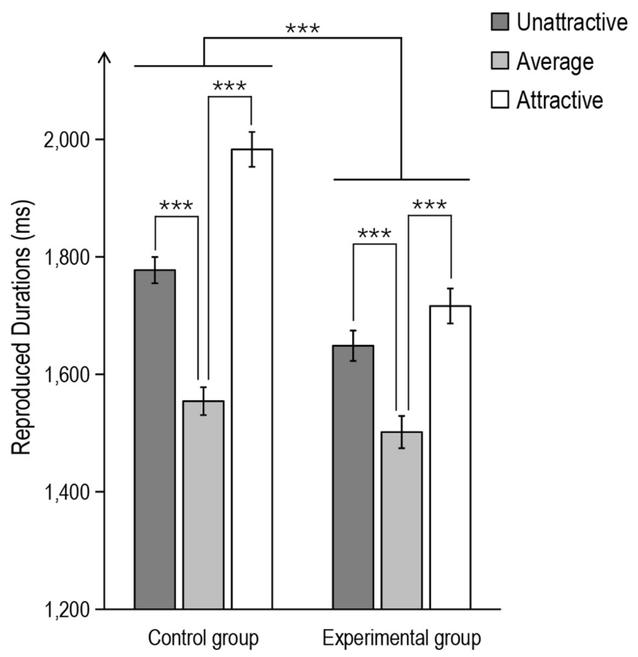

FIGURE 5 | Mean reproduced durations for each condition in Experiment 2. The error bar represents the SE. (significance level $^{***}p < 0.001$).

included 0, 95% CI: −41.46, 1.30, suggesting that the mediating effect of arousal did not reach significance in the unattractive session (see **Figure 6**).

These results highlighted that the decrease of arousal acted as a mediator between automatic expression suppression and temporal dilation in the attractive session, indicating that arousal is the mechanism of the temporal dilation effect of attractive faces.

Discussion

In Experiment 2, we used the manipulation of automatic expression suppression, i.e., the sentence-unscrambling task including "emotion suppression" terms, to test the hypothesis that the temporal dilation effect of facial attractiveness would be attenuated by the manipulation of automatic expression suppression (**Hypothesis 2**). The results showed that arousal mediated the effect of the automatic suppression manipulation on the temporal dilation of attractive faces (but of unattractive faces), adding direct empirical evidence to the arousal mechanism underlying the temporal dilation effect of facial attractiveness.

GENERAL DISCUSSION

Recent studies have shown that attractive faces generally result in temporal dilation (Arantes et al., 2013; Ogden, 2013; Tomas and Španić, 2016; Tian et al., 2019), and most researchers proposed that increased arousal evoked by attractive faces should account for the temporal dilation effect of facial attractiveness (Arantes et al., 2013; Tomas and Španić, 2016; Tian et al., 2019). The goal of the current study was therefore to verify such an account with two empirical experiments. Experiment 1 aimed at introducing a rating of arousal to test the mediating effect of arousal between facial attractiveness and temporal dilation. Experiment 2 focused on regulating arousal *via* automatic expression suppression to explore the association between arousal and temporal dilation.

In both Experiments 1 and 2, the current study convergently observed that facial attractiveness influences time perception. Specifically, the results of Experiment 1 showed that in both attractive and unattractive sessions, the closer the attractiveness rating was to attractiveness polarity (i.e., "extremely unattractive" and "extremely attractive") the longer time was perceived, while the attractive faces tended to result in salient temporal dilation. The results of the control group in Experiment 2 showed that both attractive and unattractive faces led to temporal dilation and the attractive faces resulted in greater temporal dilation. These results revealed that the current study replicated the findings of previous studies that the attractive face tended to result in the dilation effect of time perception (Arantes et al., 2013; Ogden, 2013; Tomas and Španić, 2016; Tian et al., 2019), suggesting that the effect of facial attractiveness on time perception was stable and reliable. Importantly, these results also provided a baseline for exploring the role of arousal in the effect of facial attractiveness on time perception.

Following **Hypothesis 1**, Experiment 1 found that arousal mediated the temporal dilation effect of attractive faces, that is, the increase in facial attractiveness increased the arousal and consequently led to the dilation effect of time perception. In the dominant theoretical accounts, PA models assumed that the time perception is determined according to the number of pulses generated by a pacemaker and counted by an accumulator

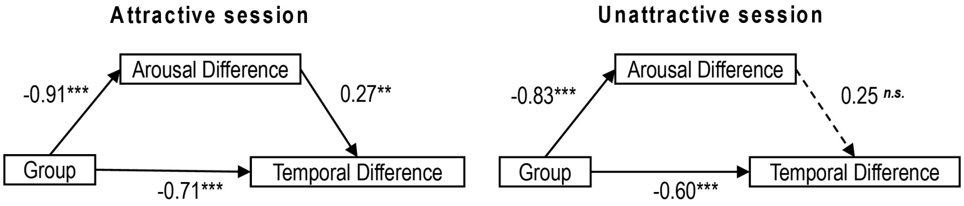

FIGURE 6 | Mediation models in Experiment 2. Mediation model for the attractive session **(left panel)** and mediation model for the unattractive session **(right panel)**. The values represent the standardized regression coefficients (β) for the direct and indirect effects of Attractiveness on Reproduced Durations (significance level $^{***}p < 0.001$; $^{**}p < 0.01$; $^{n.s.}p > 0.05$). Solid lines are used for significant effects, and dashed lines are used for insignificant effects.

through a switch/gate (Treisman, 1963; Church, 1984; Gibbon et al., 1984). Based on PA models, the pacemaker rate is usually conceptualized as arousal (Lake et al., 2016; Zhang et al., 2017; Li and Tian, 2020; Yuan et al., 2020), with an increase in arousal equivalent to an increase in the pacemaker rate. This increase in the pacemaker rate results in a greater number of pulses during the timing of a specific event and eventually led to temporal dilation. Anecdotal experience and empirical evidence both showed that attractive faces are arousing, and the more attractive the faces are rated, the more arousing they are (Maner et al., 2003; Nakamura and Kawabata, 2014; Lin et al., 2016). In consequence, previous researchers theoretically attributed the temporal dilation of attractive faces to arousal (Arantes et al., 2013; Tomas and Španić, 2016; Tian et al., 2019), and Experiment 1 directly evidenced such an inference by observing that increasing arousal mediated the dilation effect of time perception in attractive faces.

However, the observed association between increased arousal and temporal dilation only illustrated the role of arousal in time perception on a descriptive level. To further explore the relationship between arousal and the effect of facial attractiveness on time perception, Experiment 2 employed a sentence-unscrambling task that features suppression-related words to manipulate automatic expression suppression. Such manipulation was thought to be able to passively activate the goal of emotion suppression, thereby realizing the goal without the participant's awareness (Bargh and Chartrand, 2000; Bargh et al., 2001), and it is effective in reducing arousal and consuming little or no attentional resource (Gao et al., 2018). The results of arousal showed that the manipulation of suppression was effective in decreasing arousal, which was in line with previous studies (Mauss et al., 2007b; Chen et al., 2017b). The results of time perception revealed that the manipulation of suppression attenuated temporal dilation. Importantly, as hypothesized (**Hypothesis 2**), the results of mediating analysis of arousal on temporal dilation indicated that the decrease of arousal mediates the attenuation of temporal dilation in attractive faces, suggesting that the manipulation of automatic expression suppression decreases the arousal and consequently attenuates the temporal dilation of attractive faces. This finding is similar to previous investigation concerning emotional temporal dilation (Mella et al., 2011) or anxiety-related temporal dilation (Yuan et al., 2020), providing empirical evidence that the attenuation of temporal dilation was associated with the downregulation of arousal.

Taken together, the results of both Experiments 1 and 2 convergently highlighted the role of arousal in the temporal dilation effect of attractive faces. Specifically, the attractive faces generally induce an increase in arousal and consequently lead to the dilation of time perception; however, when the arousal of attractive faces was downregulated, the dilation of time perception would be correspondingly attenuated. These results suggested that an increase in arousal played a dominating mechanism in the temporal dilation effect of attractive faces. From the perspective of motivation (Peeters and Czapinski, 1990; Yuan et al., 2019), the increased arousal induced by attractive faces reflected the evolutionary activation of the approach motivation system (Rhodes, 2006). Accordingly, the temporal dilation effect of attractive faces could be interpreted as allowing individuals to prepare more for subsequent approaching behavior, rather than a byproduct of the increased arousal. On the other hand, the mediating effect of arousal on temporal dilation reflected the adaptation of time perception. The time perception could be dilated by the increased arousal, and the temporal dilation effect could be also attenuated by the manipulation of downregulating arousal. Such flexibility of time perception reflected the processes that allow individuals to adaptively respond to changes in the environment (Cicchini et al., 2012; Lake et al., 2016).

Several limitations of the current study should be addressed in future work. First, a self-reported 9-point scale was used to assess arousal. Some studies conceptualized the arousal of timing models as physiological measurement indicators (Angrilli et al., 1997; Mauss et al., 2004; Lake et al., 2016) due to its precision (Wilhelm et al., 2001; Edelmann and Baker, 2002). Although self-reporting and physiological results are somewhat consistent (McLeod et al., 1986; Gross, 1998; Kuo and Linehan, 2009), if future studies need to precisely assess arousal, physiological measurements should be used. Second, only male participants were employed. Although a previous study found that the temporal dilation effect of facial attractiveness was equally exhibited in both male and female (Tian et al., 2019), some empirical evidence showed that the emotional susceptibility of female was higher than that of male (Campanella et al., 2004; Yuan et al., 2009). Thus, the current results might underestimate the effect of arousal. Third, the efficacy of suppression is culture-specific: East Asians show better performance than Westerners (Butler et al., 2007; Murata et al., 2013), and suppression has been determined to produce beneficial emotion-regulation effects for Chinese at both behavioral and physiological levels (Yuan et al., 2015). However, all the participants of the current study were Chinese. This means that if future studies should employ Western participants, the arousal attenuation effect found in Experiment 2 may not be repeated.

CONCLUSION

The current study aimed to clarify the relationship between arousal and the temporal dilation effect of facial attractiveness. The results highlighted the role of arousal: (1) the increased arousal induced by attractive faces mediated the temporal dilation effect of facial attractiveness and (2) the downregulation of arousal attenuated the temporal dilation of attractive faces. These results indicated that increasing arousal is the dominating mechanism of the temporal dilation effect of attractive faces.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethical Committee of Human Research at Sichuan Normal University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

YT designed the experiment. YT and LL acquired and analyzed the data. All authors contributed to the interpretation of the data and approved the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.784099/full#supplementary-material

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Phrase Depicting Immoral Behavior Dilates Its Subjective Time Judgment

Lina Jia[1]*, *Bingjie Shao*[1], *Xiaocheng Wang*[1] and *Zhuanghua Shi*[2]

[1] Department of Education, School of Education, Jiangnan University, Wuxi, China, [2] Department of Psychology, Ludwig-Maximilians-Universität München, Munich, Germany

Intuitive moral emotions play a major role in forming our opinions and moral decisions. However, it is not yet known how we perceive the subjective time of moral-related information. In this study, we compared subjective durations of phrases depicting immoral, disgust, or neutral behaviors in a duration bisection task and found that phrases depicting immoral behavior were perceived as lasting longer than the neutral and disgusting phrases. By contrast, the subjective duration of the disgusting phrase, unlike the immoral phrase, was comparable to the neutral phrase. Moreover, the lengthening effect of the immoral phrase relative to the neutral phrase was significantly correlated to the anonymously prosocial tendency of the observer. Our findings suggest that immoral phrases induce embodied moral reaction, which alters emotional state and subsequently lengthens subjective time.

Keywords: time perception, emotion, immoral phrases, disgust phrases, embodied timing

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Southwest University, China

Correspondence:
Lina Jia
jialina@jiangnan.edu.cn

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INTRODUCTION

When reading newspaper headlines or browsing internet news, many of us are often captured by moral-related news as compared to other politics-related news, and our emotions follow the story. Such attentional capture and intuitive reaction seem to be very natural for us. Indeed, studies have shown that moral-related stimuli are often prioritized over nonmoral stimuli (Gantman and Van Bavel, 2014; Gantman et al., 2020). For example, moral words were easier discriminated than nonmoral words when they were presented very shortly (Gantman and Van Bavel, 2014; Gantman et al., 2020). Reading news about immoral behavior also causes us a negative emotion. However, it is not yet known if such negative emotion induced by an immoral stimulus would also lengthen its subjective time, given that it remains controversial regarding subjective time distorted by negative emotion (Droit-Volet et al., 2013; Lake, 2016; Droit-Volet, 2019). Some studies using high-arousing negative emotion have shown lengthening effect of subjective time (Angrilli et al., 1997; Noulhiane et al., 2007; Fayolle et al., 2015; Droit-Volet and Berthon, 2017), while others have argued that different types of negative emotions link to their distinct behavioral functions, which may yield differential subjective distortions (Gil and Droit-Volet, 2011; Shi et al., 2012; Grondin et al., 2014). Even worse, the connection to the subjective time of stimuli related to morality has not been formally investigated. On this ground, the aim of this study was therefore to investigate the relationship between morality and time perception. In the following, we first briefly review relations between time perception and emotion, and its connection to embodiment and morality. Then we hypothesize the relations between moral information and subjective time, and in the end, we propose the experimental design to verify our hypotheses.

Emotion and Time Perception

Emotion is often evoked and coupled by different types of moral behaviors (Tangney et al., 2007), while emotion can subsequently influence time judgment. Most studies investigating mechanisms underlying emotional time perception have applied simple affective stimuli (Droit-Volet and Gil, 2009; Droit-Volet et al., 2013) such as emotional images selected from International Affective Pictures System (Angrilli et al., 1997), emotional facial expressions (Effron et al., 2006), looming/receding movement stimuli (van Wassenhove et al., 2011; Jia et al., 2015), emotional clips of the film (Fayolle et al., 2014), and effective sounds (Noulhiane et al., 2007). Studies using explicit manipulation of arousal levels and saliency (Angrilli et al., 1997; Gil and Droit-Volet, 2012; Fayolle et al., 2015) often reveal that the high level of an arousing affective stimulus lengthens its subjective time. Many findings (Droit-Volet et al., 2013; Lake, 2016; Droit-Volet, 2019) have been interpreted through the classical framework of pacemaker-accumulator clock, respectively (Gibbon et al., 1984; Zakay and Block, 1996), which assumes three essential components in time processing: a pacemaker, a switch, and an accumulator. A pacemaker generates internal pulses, which pass to the accumulator *via* a switch control. The switch turns on and off following the on and off of the to-be-timed event. Affective stimuli are often assumed to elevate internal arousal states (Droit-Volet et al., 2013; Fayolle et al., 2015), which subsequently increases the rate of a pacemaker, generating more pulses per unit of time to the accumulator. In addition, high-arousal affective stimuli capture attention, and more temporal pulses were passed *via* the switch, resulting in duration lengthening (Tse et al., 2004; Lui et al., 2011; Droit-Volet et al., 2013).

It should be noted that arousal is not the main determinant factor in the subjective percept of affective stimuli, the meaning of social interaction could also impact time perception. For example, multiple studies have shown emotional facial expressions, as the social-interaction emotion, can differentially distort the subjective duration (Effron et al., 2006; Gil and Droit-Volet, 2011; Grondin et al., 2014, 2015). For instance, Gil and Droit-Volet (2011) compared subjective durations of six emotional facial expressions (anger, fear, sad, happy, shame, and disgust), and found that durations of the faces expressing anger, fear, sad, and happiness were judged longer relative to the neutral face. Furthermore, the subjective duration of anger and fear expressions were estimated longer than the sad and happy ones, even when their arousal levels were comparable. By contrast, the duration of a shame face was often underestimated while a disgusted face did not induce any duration distortion. The authors interpreted their findings of time distortion according to the urgency of readiness to act on a receiving stimulus: people tend to fight or flee when they see anger or a fearful face of another person, while they approach toward a happy or sad person. These different reactions lead to overestimation of anger and fear relative to the happy or sad expressions. The sight of a disgusted face, however, cannot motivate people to react, thus the subjective time is not modulated by its disgust emotion. Shame faces, on the other hand, elicit a feeling of shame, mirroring back to their own internal state, such that less attention is shared to the temporal processing, which subsequently causes its duration underestimated (Droit-Volet et al., 2013).

Embodiment, Morality, and Time Perception

There are several other recent studies that have also confirmed that implicit reaction caused by embodied affective states plays an important role in the perceived time (Droit-Volet et al., 2013; Grondin et al., 2014; Jia et al., 2015; Droit-Volet and Dambrun, 2019). For example, Jia et al. (2015) have shown that the subjective duration of a given tactile stimulus depends on whether participants can react to an external concurrent event (a moving ball) or not. When the ball is moving in the direction that participants can interact with, subjective time is lengthened as compared to the condition that the ball moving is irrelevant for reaction. In another recent study (Droit-Volet et al., 2020), participants saw an arm of a mannequin through virtual reality glasses. To produce out-body illusion, they were firstly stroked synchronous and asynchronous with the strokes to the mannequin and then were asked to judge the temporal interval between two touches to the body of the mannequin. Results showed that the subjective duration is perceived longer in the synchronous-stroking condition as compared to the asynchronous-stroking condition.

To be a social norm, individuals keep alert to their moral behaviors and react to moral events (Haidt, 2008; Haidt and Graham, 2009). Many of our moral judgments are closely linked to our embodied affective states (Haidt, 2001). For example, experimentally manipulated the heartrate of the observer seems to influence their moral judgments, with perceived faster heart rate leading to feelings of higher moral distress (Gu et al., 2013). Doing or seeing moral behaviors, on the other hand, can also influence affective states and perception. Behavioral and electrophysiologic studies have revealed that morality could enhance perception and awareness (Gantman and Van Bavel, 2014; Gantman et al., 2020). For instance, Gantman et al. (2020) recently reported that moral words are prioritized over nonmoral words in perceptual processing. Similarly, Anderson et al. (2011) have shown that enhanced perception for the neutral faces was previously paired with the description of negative social behavior. Notably, however, these studies mainly adopted target detection, identification, and lexical decision tasks. None of them has focused on time perception. Although the literature has shown the interplay of moral judgments and embodied affective states, little is known how the perception of a moral event, particularly with those immoral events, alters time judgment of the event.

On this ground, this study aimed to investigate whether time perception of moral events is coupled with moral perception. Given that perceiving immoral information often induces negative emotion and negative emotions differentially impact subjective time (e.g., the subjective time of the disgust emotion we reviewed above), we compared the subjective time of immoral information to both the neutral and negative disgust information. In addition, it should be noted that morality is an individual preference (Haidt, 2007; Saucier, 2018). Individual differences in moral preferences must be considered as an important factor mediating decision making and perception (Palmer et al., 2013; Yang et al., 2017). For example, Yang et al. (2017) investigated whether the individual difference in moral reference (measured by the Moral Foundation Questionnaire) influences the processing morality in a Rapid Stream Stimulation paradigm (Rudell, 1991). In their study, a recognizable word (depicting immoral behavior, disgust behavior, neutral behavior, or city/country name) was presented in a stream of nonrecognizable background stimuli. Each stimulus was shown for 250 ms without interstimulus intervals. Participants are usually required to respond as soon as they detect the name of a country or a city. Their results showed that the high-sensitivity group classified by the score of harm/care dimension showed the significant changes in recognition potentials between the moral and neutral conditions. In addition to the morality preference, prosocial behavior is an important form of reaction to moral events, which reflects the intention of the individual to help others (Eisenberg and Fabes, 1998; Malti et al., 2015; Turiel, 2015). Thus, specifically, in this study, we examined whether time perception of moral events relates to moral preference and prosocial tendency.

To this end, we designed two experiments using a temporal bisection task (Church and Deluty, 1977; Wearden, 1991; Nather et al., 2011; Fayolle et al., 2015; Jia et al., 2015). Participants first familiarized themselves with a short and a long standard duration, and then in the test they had to judge a given moral stimulus is close to the short or the long standard. Specifically, Experiment 1 conducted the temporal bisection task for the immoral and the neutral phrases, respectively. In addition, we measured the moral reference of individuals with the Moral Foundation Questionnaire (MFQ) (Graham et al., 2009, 2011) and tested their prosocial tendency with the prosocial tendency measure (PTM) (Carlo and Randall, 2002; Kou et al., 2007; Carlo et al., 2010). In Experiment 2, we introduced a further condition of disgust phrases, in addition to the immoral and neutral conditions, to distinguish the arousal account and embodiment account. According to the embodied time perception, the duration of immoral phrases can be lengthened relative to neutral and disgust phrases, if immoral phrases induce distinct embodied reactions. In addition, we expect that a strong moral preference and/or a strong prosocial tendency may enhance the difference of perceived duration between the immoral and neutral phrases. Alternatively, if immoral phrases only elicit negative emotion and elevate arousal similar to those disgust phrases, according to the arousal account, subjective durations of the immoral and disgust phrases should be comparable.

EXPERIMENT 1

Methods

Participants

A total of 26 university students (14 women; M = 20.96 years) from Jiangnan University were recruited for the experiment. The sample size was similar to the sample size (ranging from 18 to 25 participants) of previous studies on emotional modulation of time perception (Grondin et al., 2014; Droit-Volet and Berthon, 2017) and moral cognition (Yang et al., 2017). All the participants were native speakers of Chinese, with normal or corrected-to-normal vision. Before the experiment, each participant signed the form of informed consent. The study was approved by the Human Research Protections Program of Jiangnan University.

Stimuli and Apparatus

Word Phrases

Participants experimented individually in a quiet laboratory room, where they sat in front of a 24-inch LCD monitor (display resolution of 1,024 × 867 pixels and a refresh rate of 100 Hz) with a viewing distance of 57 cm. The target stimulus (subtended 3.9° × 1.5° visual angles) was a white phrase presented in the center of a black background. The left- and right-arrow keys on the keyboard were used as the response keys. The presentation of experimental stimuli and data records were generated through Matlab using the Psychophysics Toolbox (Brainard, 1997).

Two types of three-character Chinese phrases, with each of 20, were selected as the target stimuli: phrases depicting immoral behaviors (e.g., 杀老板, meaning “killing a boss”) and phrases indicating neutral behaviors (e.g., 擦桌子, meaning “wiping a table”).[1] For each type of phrases, the first character (verb) denotes an action, and the last two characters combined as a noun subject. Each type of phrase and the corresponding descriptions are listed in **Supplementary Table 1**.

Measure of Moral Foundations Questionnaire

The 30-item Moral Foundations Questionnaire (MFQ-30) was to measure the moral preferences of individuals across five dimensions: harm/care, fairness/reciprocity, ingroup/loyalty, authority/respect, and purity/sanctity. This questionnaire includes two subscales: moral relevance and moral judgment. In the subscale of moral relevance, participants were required to judge the relevance for each of 15 items on a 6-point scale ranging from 0 (not at all relevant) to 5 (extremely relevant). For the subscale of moral judgment, participants had to rate their agreement with each of 15 items on a 6-point scale from 0 (strongly disagree) to 5 (strongly agree).

The Measure of Prosocial Tendencies

The PTM here was used to evaluate the prosocial behavior of university students. The PTM consists of six dimensions:

[1] The three types of phrases in the experiment were adopted and modified from the phrases used by Yang et al. (2017). A total of 90 words, with each type of 30, were tested before the experiment by a separated group of participants (20 in total, 11 women, M = 19.25), who judged the subjective feeling of the depicted behaviors: immoral, disgust, or neutral. Phrases were selected for the formal experiment when the phrase was classified correctly above 75%. In addition, participants were asked to rate the arousal (from very calm to very exciting) and valence (from very unpleasant to very pleasant) for each phrase on a 9-point Likert scale of self-assessment-manikin (SAM) (Bradley and Lang, 1994). To ensure that both immoral- and disgust-behavior phrases had the same level of negative and high-arousal, we only selected those phrases that were rated as higher than 5 in arousal and lower than 5 in valence. In addition, we selected those neutral phrases that were evaluated in arousal lower than 5 and in valence between 4 and 6. Based on these criteria, 20 immoral, 20 disgust, and 20 neutral behavior phrases were selected as formal experimental stimuli (**Supplementary Table 1**). Both the immoral- and disgust-behavior phrases were evaluated as more arousing and negative than the neutral phrases (all $ps < 0.001$), while the immoral and disgust phrases were comparable in emotional arousal and valence ($ps > 0.1$). For the number of strokes, both the immoral- and the disgust-behavior phrases were matched with the neutral-behavioral phrases ($ps > 0.1$).

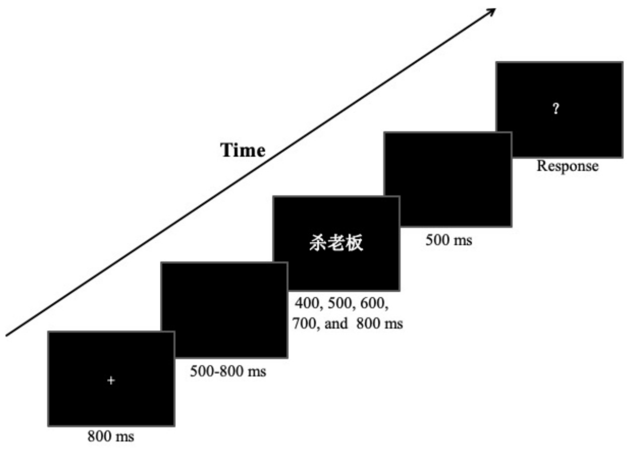

FIGURE 1 | Schematic illustration of a trial procedure used in the experiment.

public, anonymous, dire, emotional, compliant, and altruistic. Participants were asked to rate the extent to which the statements described themselves on a 5-point scale ranging from 1 (Does not describe me at all) to 5 (Describes me well). The average score for the 26 items was calculated, with a higher score indicating a higher level of prosocial behavior.

Procedure

Participants were first familiar with the short (400 ms) and long (800 ms) standard durations in a training session. A white rectangle (3.9° × 1.5° visual angles) was shown for either 400 or 800 ms, and participants had to identify the short ("S") and the long ("L") standard by pressing either the response keys labeled "short" or "long" on the keyboard. The training test consisted of 20 trials.

After participants got familiar with the short and long standards, a formal temporal bisection task started. Each trial started with a fixation cross ("+") presented in the center of a screen for 800 ms, followed by a random 500 to 800 ms blank screen. Then a target phrase, randomly selected from the phrases list, was displayed for a given duration, randomly sampled from 400, 500, 600, 700, and 800 ms. After a 500-ms interval blank, a question mark appeared, prompting participants to judge whether the probe duration was closer to the "S" or the "L" by pressing the corresponding keys. The intertrial interval (ITI) was 2,000 ms. A schematic illustration of the stimulus presentation is shown in **Figure 1**. The formal temporal bisection task included 11 blocks with each of 20 trials. The first block was treated as a practice block and discarded in further analysis. Each experimental condition was repeated 20 times, and the different conditions were tested randomly trial by trial. In addition, at the beginning of each block, both the S and L standard durations were separately presented five times to remind participants of the short and long standards.

After the temporal bisection task, participants were asked to complete the two questionnaires (MFQ-30 and PTM) at their own pace.

Results

Temporal Bisection

Figure 2A depicts the mean proportions of "long" responses as a function of the probe durations, separated for the immoral and neutral phrases with a fitted logistic psychometric curve for a representative participant. By visual inspection, the proportion of the "long" responses are generally higher for the immoral phrase relative to the neutral phrase. We then fitted individual psychometric curves and estimated the bisection point (BP) for each condition. The BP is the duration with which participants perceive neither closer to the short or the long [$p(\text{long}) = 0.50$, also known as the point of subjective equality, PSE]. The lower the BP is, the longer the duration is perceived. In addition, the just-noticeable difference (JND), an indicator of the temporal discrimination sensitivity, was estimated by calculating half of the difference limen between the 25 and 75% thresholds of the fitted curves.

The mean PSEs and JNDs for the immoral and neutral phrases are depicted in **Figures 2B,C**. A paired-sample t-test analysis revealed that the PSE was significantly lower for the immoral phrase (M = 588 ms) than for the neutral phrase (M = 599 ms), t (25) = –3.09, $p < 0.01$, Cohen's $d = 0.62$, which indicates that the perceived duration of the immoral phrase was overestimated relative to the same duration of the neutral phrase. However, there was no significant JND difference in the temporal discrimination between two types of phrases, t (25) = 0.96, $p = 0.35$, Cohen's $d = 0.19$, suggesting the discrimination sensitivity remained comparable across two conditions.

Relation Between the Scores on Moral Foundation Questionaire, Prosocial Tendency Measure, and the Point of Subjective Equality

To examine the correlation between the moral preference and/or prosocial tendency and the shift of subjective time, we first used the neutral condition as a baseline and measure the shift by the difference of PSEs (i.e., $\Delta PSE = PSE_{immoral} – PSE_{neutral}$). We then correlated this with the scores from MFQ[2] and PTM. We failed to find any significant correlation between the MFQ score and the ΔPSE, $r = 0.08$, $p = 0.70$. The correlation between the total score of PTM and the ΔPSE was also nonsignificant, $r = 0.14$, $p = 0.51$. Interestingly, though, the score on the anonymous dimension of PTM was positively correlated with the shift of the PSE, $r = 0.43$, $p = 0.03$ (see **Figure 3**). In other words, the higher the anonymous prosocial tendency was, the larger the positive shift of PSE in the immoral phrase condition. Note, the positive shift in the PSE means that the overestimation of the immoral phrase is reduced. The anonymous score reflects the tendency that participants give anonymous help to others. In this study, its positive relationship with the ΔPSE might imply that participants who have a higher anonymous prosocial tendency pay more attention to the meaning of the immoral phrase (nontemporal processing) rather than the time processing of the stimulus, thus reducing the overestimation.

[2]One participant was excluded for this correlation analysis, because the score of MFQ was beyond 2.5 SDs of the average score ($M = 91.82$, $SD = 18.14$).

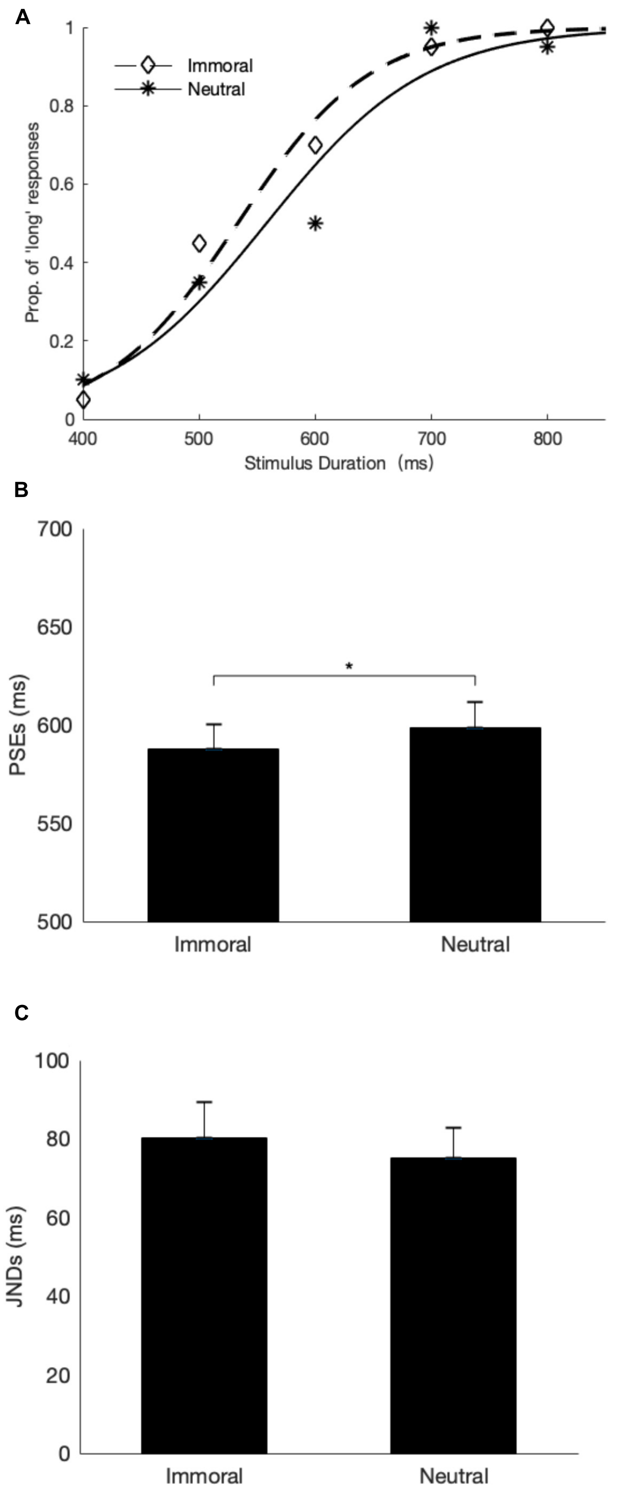

FIGURE 2 | Temporal judgment results of Experiment 1. **(A)** Mean proportions of "long" responses (diamonds: the immoral phrase, stars: the neutral phrase) for a representative subject are plotted as a function of the probe durations, together with fitted psychometric curves (dashed: the immoral phrase, solid: the neutral phrase). **(B)** The mean PSEs and their respective one-standard errors for the two conditions. **(C)** The mean JNDs and their corresponding one-standard errors for the two conditions. *denotes $p \leq 0.05$.

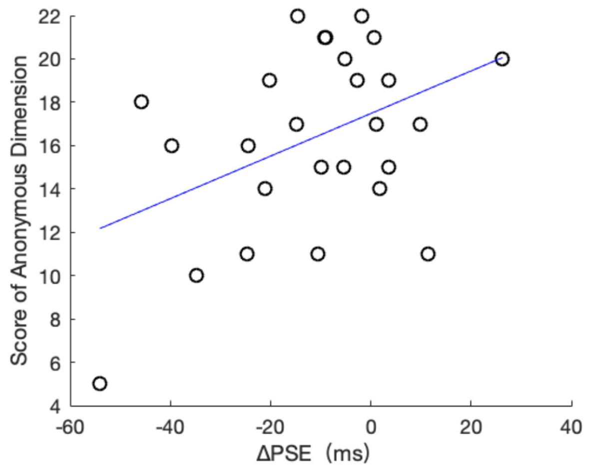

FIGURE 3 | The scatter diagram between the ΔPSE and the score of anonymous dimensions from PTM.

EXPERIMENT 2

Methods

Participants

A total of 24 university students from Jiangnan University 24 (12 females; M = 21 years) volunteered to take part in the experiment. All participants were native speakers of Chinese, with normal or corrected-to-normal vision. Each participant gave written informed consent before the experiment. The study was approved by the Human Research Protections Program of Jiangnan University.

Stimuli and Apparatus

The experimental design, stimuli presentation, and apparatus were the same as those in Experiment 1, except that Experiment 2 included a third type of phrase, describing disgusting behaviors (e.g., 吃鼻屎, meaning "eating booger").[1] In other words, the experiment involved three types of phrases: phrases depicting immoral behaviors, phrases describing disgusting behaviors, and phrases indicating neutral behaviors. The three types of phrases and the corresponding descriptions were listed in **Supplementary Table 1**.

Procedure

The structure of the procedure was the same as that used in Experiment 1, except for introducing the condition of disgusting-behavior phrases. Thus, the experiment consisted of 30 practice trials and ten blocks with each of 30 trials. The different types of phrases were tested randomly trial by trial.

Results

Figure 4A shows the average psychometric curves for a representative participant. **Figures 4B,C** depict the mean PSEs and JNDs, respectively, for the three experimental conditions and all the participants. By visual inspection, the results were consistent with the findings of Experiment 1.

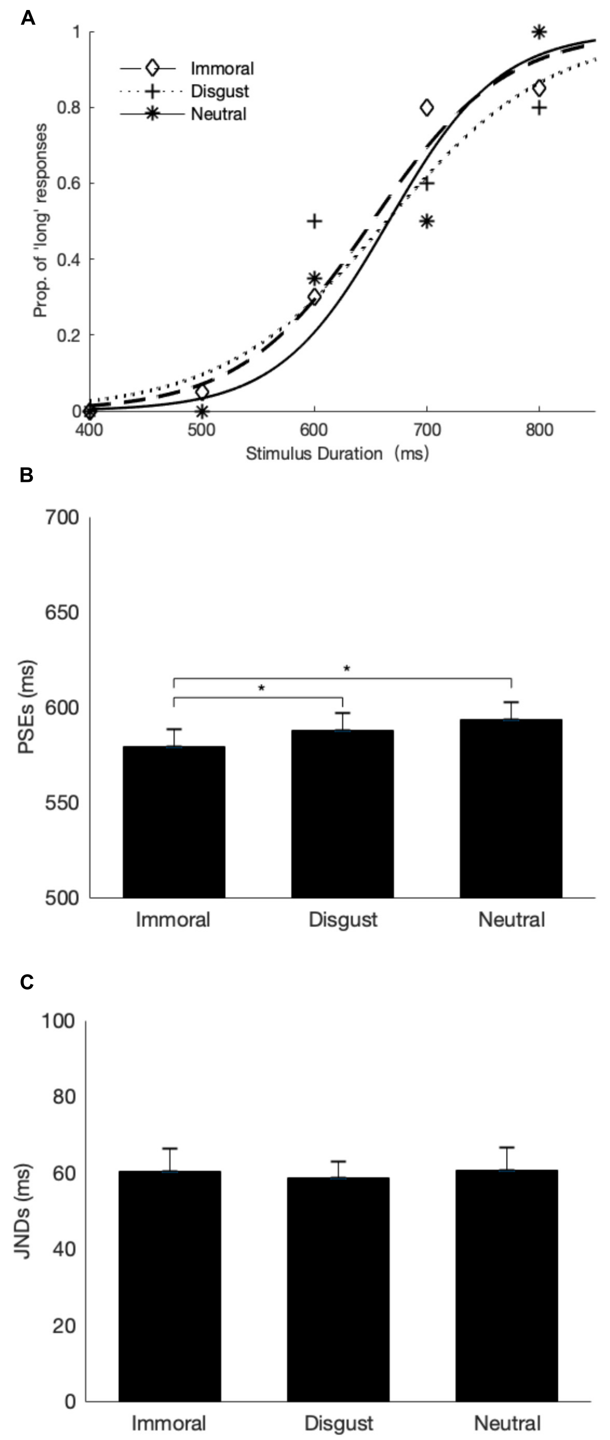

FIGURE 4 | Temporal bisection results of Experiment 2. **(A)** The mean proportions of "long" responses from a representative subject are plotted (diamonds: the immoral phrase; crosses: the disgust phrase; and stars: the neutral phrase) against the probe durations, together with the fitted psychometric curves (dashed: the immoral phrase, dotted: the disgust phrase, and solid: the neutral phrase). **(B)** The mean PSEs and their respective one-standard errors are shown for the three conditions. **(C)** The mean JNDs and their respective one-standard errors are displayed for the three conditions. * denotes $p \leq 0.05$.

A repeated-measures ANOVA with the factor of phrase type revealed a significant main effect, F (2, 46) = 5.23, $p < 0.01$, $\eta_p^2 = 0.19$. A follow-up *post-hoc* comparison with Holm–Bonferroni correction revealed that the mean PSE was significantly lower for the immoral phrase (M = 579 ms) relative to the neutral phrase (M = 594 ms, corrected p = 0.01), and just reached significant level in comparison with the disgust phrase (M = 588 ms, corrected p = .05). Importantly, there was no significant difference between the disgust and the neutral phrases (corrected p = 0.27). Similar to Experiment 1, temporal discrimination sensitivities revealed in JNDs were comparable across three types of phrases, F (2, 46) = 0.24, p = 0.79, and $\eta_p^2 = 0.01$.

DISCUSSION

This study aimed to examine the influence of morality on time perception. We compared duration judgments of three types of phrases depicting immoral, disgust, and neutral behaviors. The results showed the immoral phrase was perceived longer in duration than the neutral and disgust phrases with the same physical duration, while the latter two did not differ from each other in duration judgments. In addition, we found a positive moderate correlation between the anonymous prosocial tendency and the difference in PSEs between the immoral and neutral phrases. The positive correlation indicates that the higher the anonymous prosocial tendency is, the less the overestimation would be for the immoral phrase.

The effect of social emotion on time perception has been mainly investigated with emotional facial expressions (Effron et al., 2006; Gil and Droit-Volet, 2011; Grondin et al., 2015). This study provides new evidence of social emotion on time perception with the moral-related stimuli. Immoral-related stimuli can also lengthen subjective time. One might argue that the finding is trivial, given that immoral stimuli are likely coupled with negative emotion and high arousal, which could be interpreted by the arousal account (Treisman et al., 1990; Penton-Voak et al., 1996). However, the arousal account could not fully explain the difference we observed between the immoral and disgust phrases, given that the disgust phrases had similar valence and arousal ratings as the immoral phrases. Rather, our findings can be better explained by discrete emotion theory (Izard and Ackerman, 2000; Mikels et al., 2005) and embodied time perception (Wittmann, 2014). According to discrete emotion theory (Izard and Ackerman, 2000), different types of behavioral functions link to different types of emotions, and vice versa. For example, both thread and disgust are categorized as high-arousal negative-valence emotions, but they activate different processes: threat activates our defense system, while disgust may merely activate avoidance. Similarly, seeing or doing different moral behaviors may link to different social reactions. Phrases depicting immoral behaviors (e.g., 踢老人, meaning "kicking an old person") likely evoke people to blame this behavior or/and even be ready to rescue the victim. As a result, the intuitive social reaction lengthens the subjective time of the phrase. By contrast, phrases describing disgust behavior (e.g., 吃鸡屎, meaning "eating chicken shit") may not invoke any social reaction, rather just feel the behavior is unacceptable.

Admittedly, previous studies have shown inconsistent results for the impact of disgust emotion on time perception. For example, the disgust-inducing pictures (e.g., mutilated body) were judged longer than the neutral and disgust faces (Grondin et al., 2014), whereas it has also been found no difference in duration to the neutral expressions (Gil and Droit-Volet, 2011) or even opposite, the presentation of disgust food shortened its subjective duration (Gil et al., 2009). Droit-Volet et al. (2013) have suggested that time perception of a disgust stimulus depends on whether the stimulus is perceived as relevant or not. Participants seem to regard the observation of disgusting expression of another person as irrelevant, whereas the disgusting scenes probably prompt participants to react as quickly as to avoid possible harm. Disgust food, however, might activate participants to protect their health, which requires more attention toward this kind of food and thus less attention is given to temporal processing. In short, specific meanings of disgust stimuli and the correspondent reactions determine the perceived time. Compared with disgusting scenes and disgust food, semantic level of disgust expression, such as disgust phrases we used in this study, may not be strong enough to induce implicit reaction (As shown in **Figure 4B**, there was a numerical reduction, but not significant, for the disgusting phrase relative to the baseline neutral phrase).

Another interesting finding of this study is that the shift of PSE of the immoral phrase relative to the neutral phrase was correlated with the score of the anonymous dimension of PTM. The anonymous dimension is defined as the willingness to help without others' knowing (Carlo et al., 2010). When an observer has a higher relative to a lower level of anonymously prosocial trait, they are likely captured more by the nontemporal semantic processing of the immoral phrase (i.e., interpretation of its meaning and consequence) relative to the temporal processing (i.e., monitoring the passage of time) (Zakay and Block, 1996). As a consequence, those observers with high anonymously prosocial traits had less overestimation with the immoral phrase as compared to those with the low anonymously prosocial trait. Interestingly, though, the overestimation did not correlate with the moral reference. The possible reason is that the moral reference mainly relates to the later decision-related processing (Palmer et al., 2013; Zhang et al., 2016), but might not have a direct linkage with the moral-induced temporary internal states (e.g., high arousing, potential embodiment), the latter determining timing process.

Recall the review in the introduction, the duration lengthening effect in recent studies is usually attributed to the arousal or/and the attention mechanism under the framework of the pacemaker-accumulator clock (Gibbon and Church, 1990), and the implicit reaction mediated by the relevance to our body (Wittmann and van Wassenhove, 2009; Droit-Volet et al., 2013; Wittmann, 2014). Our findings distinguish the role of implicit reaction induced by moral-related information from that of arousal in perceived duration. Both the immoral- and disgust-behavioral phrases were categorized as the negative and high-arousal stimuli, but only the immoral-behavioral words lengthened the subjective duration relative to the neural-behavioral words. The absence of duration distortion for disgust-behavioral words further supports that the embodied reaction is a key factor influencing duration perception (Gil and Droit-Volet, 2011; Shi et al., 2012; Jia et al., 2015; Droit-Volet, 2019).

Still, one might wonder whether the number of experimental conditions would affect the duration judgment as contextual bias. It has been shown that the experimental context could affect the temporal judgment by mediating participants' prior knowledge and prediction of the forthcoming stimulus (Shi et al., 2013; Ulrich and Bausenhart, 2019; Glasauer and Shi, 2021a,b; Zhu et al., 2021). For example, the frequency of the probe durations can cause a shift of the bisection point toward the ensemble mean of the sample durations (Zhu et al., 2021). However, this is unlikely here given that all conditions were tested in the same range with a same number of trials. Introducing the third category disgust phrases in Experiment 2, however, might increase the variability of the test stimuli as compared to Experiment 1. This might introduce more working memory resources to represent different categories in Experiment 2 relative to Experiment 1, which could potentially cause a contrast effect in working memory. In other words, observers might bias temporal judgments of different categories into separate temporal ranges (e.g., one was biased toward the short and the other toward the long) to maintain the discriminability among the categories. However, this is also unlikely given that the difference between the PSEs of the two extremes (the immoral and neutral phrases) was comparable in Experiment 1 and 2 (11 and 15 ms, respectively).

In summary, this study showed that the immoral phrase lengthens its subjective duration, while the disgust-behavioral words did not. The findings favor the important role of moral-induced intuitive reaction on temporal processing, which is distinct from the arousal-based lengthening effect.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Human Research Protections Program of Jiangnan University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

LJ, ZS, and XW developed the design of the study and contributed to writing and drafting the manuscript. BS collected data. LJ, BS, and ZS performed the data analyses. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.784752/full#supplementary-material

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The Influence of Emotional Awareness on Time Perception: Evidence From Event-Related Potentials

Jia Ma, Jiamei Lu and Xu Li**

Department of Psychology, Shanghai Normal University, Shanghai, China

Prior studies found that participants overestimated both negative and positive emotional stimuli, compared with neutral emotion. This phenomenon can be explained by the "arousal mechanism." Participants demonstrated individual differences in emotion perception. In other words, high emotional awareness resulted in high emotional arousal, and vice versa. This study extended existing findings by exploring the influence of emotional awareness on time perception in a temporal generalization task, while recording electroencephalographic (EEG) signals. The findings revealed that in the positive emotion condition, the high emotional awareness group made more overestimations, compared with the low emotional awareness group. However, no difference was observed in the neutral or negative emotion conditions. Moreover, the event-related potential (ERP) results showed that in the positive emotion condition, the high awareness group elicited larger vertex positive potential (VPP) amplitudes, compared with that of the low awareness group. However, no such differences were observed in the neutral and negative emotion conditions. Moreover, the contingent negative variation (CNV) (200–300, 300–490 ms) component showed that in the positive emotion, the amplitudes of the high awareness group were larger than that of the low awareness group; however, they did not show differences in the neutral condition. The findings of this study suggest that high emotional awareness produces higher physiological arousal; moreover, when participants were required to estimate the time duration of emotional pictures, they tended to make higher time overestimation. Thus, our results support the relationship between emotional awareness and time perception.

Keywords: overestimated, emotional stimulus, arousal mechanism, emotional awareness, time perception

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Lina Jia,
Jiangnan University, China

****Correspondence:***
Jiamei Lu
lujiamei_vip@163.com
Xu Li
lxuthus@shnu.edu.cn

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INTRODUCTION

Time perception differs from the accuracy of the clock, and it is a subjective temporal experience, which is influenced by emotion. A number of studies showed that emotional arousal is an important influencing factor of time perception (e.g., Droit-Volet et al., 2013; Fayolle et al., 2015). For example, participants in (Gil and Droit-Volet, 2012) study verbally estimated the duration of emotional pictures (i.e., neutral, disgust, and sadness). The same discrete emotion varied in arousal level (high/low arousal). The results of their study showed a lengthening effect on the time perception of the emotional picture, thus indicating that this effect increased with the arousal level. Studies using different emotional materials or experimental paradigms reached the same conclusion. That is, within the time perception of 2 s, the participants made a higher time overestimation when in high emotional arousal (Droit-Volet and Meck, 2007; Gan et al., 2009a; Jia et al., 2015). Furthermore, the emotion-based time overestimation was caused by the arousal-based mechanism, which involves the activation of an internal clock system. The internal clock modes hold that perceived duration is based on the number of pulses collected in the pacemaker; thus, the more pulses accumulated, the longer the perceived duration (Treisman, 1963; Schwarz et al., 2013; Droit-Volet and Gil, 2016; Cui et al., 2018). Emotional arousal increases the speed of the pacemaker; thus, emotional events are overestimated, compared with their neutral events.

Previous studies have proved the impact of emotional stimulus' arousal on time perception (Smith et al., 2011; Van and Balsam, 2014; Wang et al., 2016). Moreover, individual physiological differences have been found for the same type of emotional arousal (Zhang and Lu, 2013; Zhang et al., 2016). Thus, individual differences in physiological arousal may influence time perception.

Prior studies have found that individuals with high emotional awareness are more likely to produce high physiological arousal, whereas those with low emotional awareness produce low arousal (Zhang and Lu, 2013; Wang et al., 2015; Zhang et al., 2016). Emotional awareness refers to the ability to recognize and describe one's own and also others' emotions (Lane and Schwartz, 1987; Zhang and Lu, 2013; Wang et al., 2015); moreover, it is closely related to physiological arousal. Zhang et al. (2016) used blood volume pulse (BVP) and resistance from skin conductance (SCR) as emotional arousal indexes to explore the relationship between emotional awareness and emotional arousal. Their results confirmed that in the emotion conditions (positive and negative), the rate of physiological change (i.e., BVP, SCR) in the high emotional awareness group was higher, compared with that of the low emotional awareness group. Thus, their results revealed that high awareness resulted in higher emotional arousal. Their study also used path analysis to explore the mechanism from stimuli awareness to emotional arousal: when the emotional expression was presented to participants, their awareness of emotion led to unconscious imitation of the expressions. Moreover, the unconscious imitation often occurred with physiological arousal, which caused them to produce the corresponding emotion (Zhang and Lu, 2013; Zhang et al., 2016). Therefore, in the same discrete emotional stimulus, high awareness resulted in high mimicry with high emotional arousal; however, the opposite was true for low emotional awareness.

This study aimed to explore the effects of emotional awareness on time perception. In particular, we aimed to examine the neural mechanisms underlying the effects of emotional awareness on time perception using the event-related potential (ERP) technique. The neural mechanisms were primarily analyzed by the vertex positive potential (VPP) and contingent negative variation (CNV) components.

Vertex positive potential is differently modulated by emotional and neutral faces; it is a positive deflection detected at the frontocentral electrode, with peak latency between 140 and 200 ms (Williams et al., 2006; Luo et al., 2010; Zhang et al., 2013). VPP is sensitive to facial expressions in the rapid serial visual presentation paradigm (Luo et al., 2010; Zhang et al., 2013; Wang et al., 2015). Its amplitude is influenced by emotion valence, with the amplitude of the emotional stimuli which is larger than that of neutral stimuli (Luo et al., 2010). Differences in awareness levels are mainly reflected in the recognition and judgment of emotional stimuli. Prior studies have found that participants with high emotional awareness responded faster and more accurately to emotional expressions, compared with those with low awareness (Wang et al., 2015; Zhang et al., 2016). Therefore, we chose VPP components to explore the difference between high and low emotional awareness groups.

The CNV component has been suggested to reflect the accumulation process (Macar and Vidal, 2009) in pacemaker–accumulator models of interval timing [e.g., Treisman, 1963; Gibbon et al., 1984; Meck, 1996; Wearden, 1999; Meck and Benson, 2002; Taatgen et al., 2007]. It covers the median frontocentral area (FCz) and initiates ~250 ms poststimulus (Pfeuty et al., 2005, 2008; Zhang et al., 2006; Pouthas et al., 2015). According to Birbaumer et al. (1990), slow potential changes of negative polarity recorded over the scalp reflect neuronal activation in the underlying cortical layers. An increase in CNV amplitude indicates increased neuronal activation. In accumulator-based models of timing, when one target interval is to be processed, increased neuronal activation in the structures that subtend temporal encoding should be associated with longer estimates of the interval. It reflects an increase in the number of units that accumulate during the interval. Research has suggested that CNV amplitude may represent an index of temporal encoding as achieved by an accumulator mechanism: larger CNV amplitudes correspond to overestimation of time (Macar and Vidal, 2004; Olofsson et al., 2008). Thus, we used the CNV to explore the difference between the effects of high and low emotional awareness on time perception.

This study hypothesized that the high awareness group would make more time overestimation of emotional condition (positive/negative), compared with the low awareness group; however, no differences would be observed in the neutral condition. Furthermore, we generated the following hypotheses related to the ERP result are as follows: (1) for the VPP component, the emotional (positive/negative) amplitude of the high awareness group would be significantly larger than that of the low awareness group; (2) for the CNV component, the emotional amplitude of the high awareness group would be significantly larger than that of the low awareness group. Moreover, for both VPP and CNV, there would be no differences between the high and low awareness groups in the neutral condition.

METHODS

Participants

First, we estimated our sample size with the effect size of 0.25 and power of 0.8 (see Cohen, 1988) using G*power (Faul et al., 2007). We aimed for a sample size of a minimum 18 participants. Then, we chose the high and low emotional awareness group

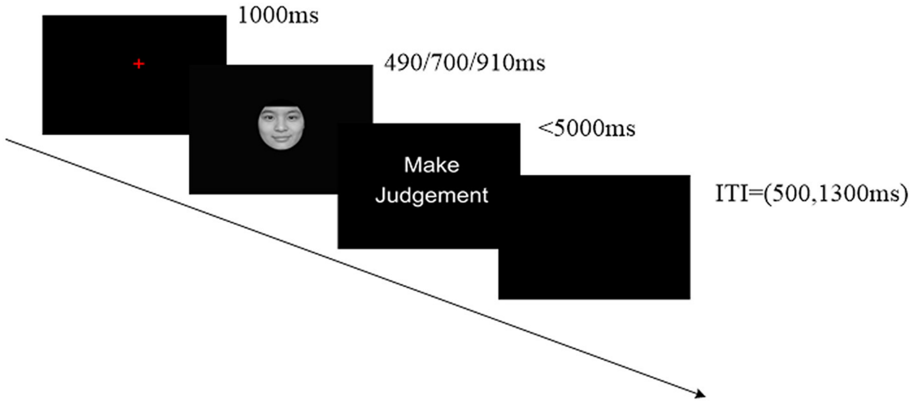

FIGURE 1 | Example of one trial in the test phase. Participants were asked to focus on the crosshairs for 1,000 ms before being presented with a stimulus for 490, 700, or 910 ms; they were then asked to make a judgment within 5,000 ms. Individual trials were separated by a 500 or 1,300 ms intertrial interval (ITI). We recorded EEG data for the emotional stimulus presentation during the test phase. Human images reproduced from Chinese Facial Affective Picture System (CFAPS) with permission.

participants using the Levels of Emotional Awareness Scale (LEAS; Lane and Schwartz, 1987; Lane, 2000; Wang et al., 2015). Eighty college students were selected through random sampling from the Shanghai Normal University, who then completed the LEAS. Participants who scored in the first 27% and last 27% were ranked as the high awareness group and low awareness group, respectively (Wang et al., 2015; Zhang et al., 2016). Hence, 45 right-handed volunteers were selected to enroll in the ERP experiment. Then, we excluded three participants whose electroencephalographic (EEG) signal showed excessive artifacts. The final sample include 42 participants, aged 22–24 years [mean (M) = 22.24, standard deviation (SD) = 0.69], with 21 participants each in the high (10 men, 11 women) and low awareness groups (11 men, 10 women). The LEAS score of the high awareness group (M = 2.88, SD = 0.17, n = 21) was significantly higher than that of the low awareness group (M =1.94, SD = 0.44, n = 21) [$t_{(38)} = 9.06$, $p < 0.001$, $D = 0.71$]. All of them had normal or corrected-to-normal vision and also no neurological or psychiatric disorders.

The study protocol was approved by the Ethical Committee of the School of Psychology at Shanghai Normal University. Written informed consent was obtained prior to the experiment onset, and all participants received monetary compensation after completing the experiment.

Stimuli

The stimuli used for the representation of standard duration were a gray oval. The emotional stimuli were three types of facial pictures (neutral, negative, and positive), selected from the standard Chinese Facial Affective Picture System (CFAPS; Bai et al., 2005). A total of 90 pictures were selected: 30 neutral, 30 negative (10 sad, 10 angry, and 10 fear), and 30 positive (happy). Each discrete emotional expression was equally represented by typically male and female faces. Each picture was previously assessed for valence and arousal using a nine-point scale with a large sample of Chinese participants in a previous survey (valence: positive = 6.53, negative = 2.19, neutral = 4.11; arousal: positive = 5.95, negative = 5.88, neutral = 3.28).

Stimuli did not show hairs, with merely their interior characteristics being retained. Each picture was cropped into an elliptical shape using Adobe Photoshop 8.0. All stimuli were matched in terms of luminance and size (visual angle: 6.57 × 6.861°), and the screen resolution was 72 pixels per inch. All stimuli were displayed at the center of the screen (17-inch).

Experimental Procedure

The experiment was administrated in a quiet chamber. Further, the participants were at a distance of ∼50 cm from the computer monitor. We recorded the participants' responses using the E-Prime software (Psychology Software Tools Inc., Pittsburgh, USA). Participants performed a temporal generalization task (Gan et al., 2009b), which was composed of two successive phases, including learning and testing. In the learning phase, participants were shown the "standard" stimulus duration (700 ms) 10 times, which was represented by the gray oval. In the testing phase, the participants were required to judge whether the face was presented in shorter, longer, or equal durations compared with the "standard" stimulus by pressing the "F," "SPACE," or "J" key on the keyboard correspondingly, within 5,000 ms. The left–right response position was counterbalanced across participants. Every participant performed 360 trials, and each discrete emotion was tested 40 times at every duration (i.e., 490, 700, and 910 ms) in a random order. There was a blank interval between stimuli in each trial (randomly chosen between 500 and 1,300 ms). After every 90 trials, the participants were given a break and the "standard" duration was presented 10 times once again to prevent the participants from forgetting it. A trial in the testing phase is displayed in **Figure 1**.

Behavioral Recordings and Data Analysis

In this study, the "overestimation response ratio" and "underestimation response ratio" were the dependent variables in the behavioral analysis (Gan et al., 2009a;

TABLE 1 | Means and standard error of overestimation and underestimation response ratio for the high and low awareness groups.

	Underestimation ($M \pm SE$)		Overestimation ($M \pm SE$)	
	Low awareness group	**High awareness group**	**Low awareness group**	**High awareness group**
Neutral facial expression	0.156 ± 0.01	0.131 ± 0.01	0.166 ± 0.01	0.166 ± 0.01
Positive facial expression	0.150 ± 0.01	0.133 ± 0.01	0.166 ± 0.01	0.202 ± 0.01
Negative facial expression	0.145 ± 0.01	0.125 ± 0.01	0.190 ± 0.01	0.190 ± 0.01

Mella et al., 2011). Emotional awareness and emotion valence acted as independent variables in a mixed repeated measures analysis of variance (rmANOVA) with the between-factor awareness group (2: high/low) and the within-factor emotion valence (3: neutral/positive/negative). Participants' key response was used to record their time estimation (correct/overestimation/underestimation). The behavior results are divided into correct response, time underestimation, and time overestimation; the time underestimation and time overestimation are actually a wrong response. If a participant judged the duration of 490 ms to be equal to or longer than the "standard" stimulus duration (700 ms), it was considered an overestimation of time. However, if they judged it as shorter, it was considered the correct response. If the participants judged the 910 ms duration to be equal to or shorter than 700 ms, it was considered an underestimation, whereas if they judged it as "longer," it was considered a correct response. For the 700 ms condition, "shorter" was considered an underestimation, "equal" was considered a correct response, and "longer" was considered an overestimation of time.

The "overestimation respond ratio" refers to the ratio of overestimation response trials to the total trials. For example, the positive emotion in the 490 ms condition had 40 trials; if a participant's time overestimation was 20 trials, their overestimation response ratio would be 0.5 (20/40). The statistical method of "underestimation respond ratio" is the same.

ERP Recordings and Data Analysis

The EEG was recorded from 64 scalp sites using Ag/AgCI mounted in an elastic cap (NeuroScan Inc., EI Paso, Texas, USA). The EEG and electrooculography were amplified using a direct current (0.05 Hz) with ∼100 Hz bandpass and continuously sampled at 500 Hz/channel. All interelectrode impedance was maintained below 5 kΩ. ERP averages were computed offline; trials with artifacts were rejected with a criterion of ± 80 μV. ERP waveforms were time locked to the onset of the stimulus, and the average epoch was 1,000 ms, including a 200 ms prestimulus baseline. Recording electrodes were referenced to the left mastoid and recalculated offline to an average mastoids reference. The vertical electrooculogram signal was measured both above and below the left eye, whereas horizontal electrooculogram signal was measured on both sides at the external canthi. Eye-blink artifacts were rejected automatically using vertical ocular correction. All channels were filtered at 0.1–30 Hz offline. Incorrect response trials were removed.

Similar to previous studies (Macar and Vidal, 2004; Pfeuty et al., 2005, 2008; Luo et al., 2010; Wang et al., 2015), the amplitudes of the early components of VPP and the middle-late stage of CNV components were computed. VPP (150–200 ms) average amplitudes were measured in the time window of the frontocentral sites (F1, FZ, F2; Luo et al., 2010; Wang et al., 2015). For CNV components (200–300, 300–490 ms), FCz was used for statistical analysis (Macar and Vidal, 2004; Pfeuty et al., 2005, 2008; Zhang et al., 2006). Average amplitudes for each component were measured by a mixed rmANOVA, with emotional awareness (high/low) as the between-subjects factor and emotional valence (neutral/positive/negative) and electrodes (VPP: F1, FZ, F2; CNV: FCz) as within-subject factors. The Greenhouse–Geisser epsilon correction was applied to adjust the degrees of freedom of the F ratios, and multiple comparisons were conducted using the Bonferroni method.

RESULTS

Behavioral Results

For the overestimation response ratio as dependent variable, a mixed rmANOVA with the between-factor awareness group (2: high/low) and the within-factor emotion valence (3: neutral/positive/negative) revealed a main effect of emotion valence, $F_{(2,80)} = 13.16$, $p < 0.001$, $\eta^2 = 0.25$. *Post hoc* analysis with Bonferroni correction showed that time overestimation of the positive condition (0.184 ± 0.01) was greater than the neutral condition (0.166 ± 0.01), $p = 0.002$, whereas that of the negative emotion condition (0.190 ± 0.01) was greater than the neutral condition, $p < 0.001$. There were no significant differences between the positive and negative emotion conditions ($p = 0.51$). The interaction between emotion valence and awareness group was significant, $F_{(2,80)} = 8.58$, $p < 0.001$, $\eta^2 = 0.18$. Simple-effect analysis showed that in the positive emotion condition, the high awareness group overestimated time more than the low awareness group, $F_{(1,40)} = 4.86$, $p = 0.03$, $\eta^2 = 0.11$. There were no significant differences between high and low awareness groups in the neutral or negative emotion conditions ($ps \geq 0.98$); emotional awareness had no main effect ($p = 0.41$).

For the underestimation response ratio as the dependent variable, a mixed rmANOVA with the between-factor awareness group (2: high/low) and the within-factor emotion valence (3: neutral/positive/negative) did not reveal either significant main effect (ps ≥ 0.36) or interactive effects ($p = 0.99$).

Means and *SE* of overestimation and underestimation response ratios for the two groups are displayed in **Table 1**. Behavior results of the time underestimation and time overestimation between the two groups are displayed in **Figure 2**.

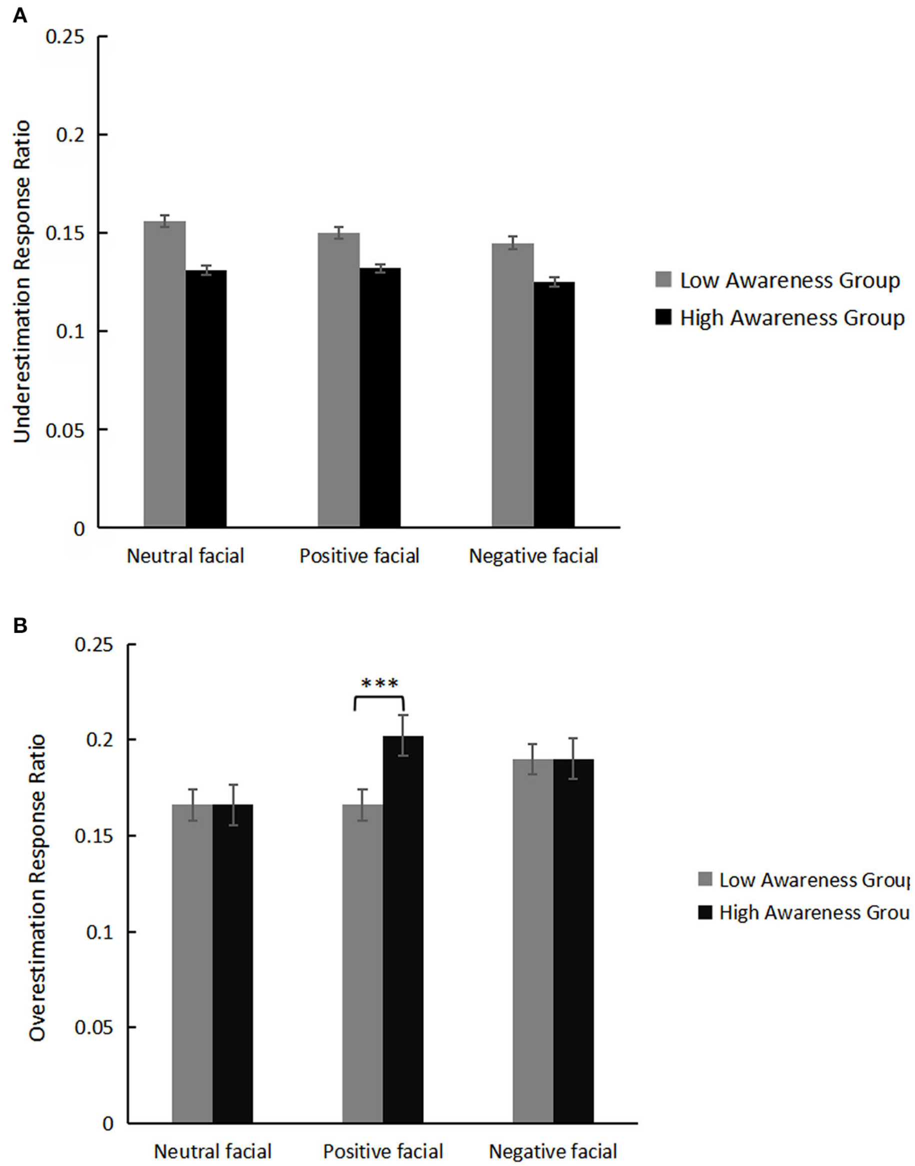

FIGURE 2 | Means and standard error of underestimation response ration **(A)** and overestimation response ratio **(B)** for the high and low awareness groups. "***" represents the $p < 0.001$.

ERP Results

VPP

The mixed rmANOVA with the between-factor awareness group (2: high/low) and the within-factor emotion valence (3: neutral, positive, and negative) and electrodes (3: F1, FZ, and F2) revealed a main effect of emotion valence, $F_{(2,80)} = 26.51$, $p < 0.001$, $\eta^2 = 0.40$. Bonferroni *post hoc* test showed that the amplitudes of the negative emotion (7.21 ± 0.50 μV) were larger than that of the positive emotion condition (6.42 ± 0.47 μV), $p = 0.01$, and that of the positive emotion condition was larger than that of the neutral condition (5.80 ± 0.52 μV), $p = 0.01$. The electrode factor also resulted significant, $F_{(2,80)} = 12.72$, $p < 0.001$, $\eta^2 = 0.24$; VPP amplitudes at Fz (6.68 ± 0.51 μV) were larger than F1 (6.39 ± 0.47 μV) and F2 (6.37 ± 0.47 μV; *ps* < 0.001), whereas F1 and F2 showed no significant difference (p =1.00). The interaction between emotional awareness and emotion valence was significant, $F_{(2,80)} = 5.50$, $p = 0.008$, η^2 =0.12. Simple-effect analysis showed that in the positive emotion condition, VPP amplitudes in the high awareness group (7.24 ± 0.66 μV) were larger than in the low group (5.60 ± 0.66 μV), $F_{(1,40)} = 3.06$, $p = 0.048$, $\eta^2 = 0.07$. There were no significant differences between the high and low awareness groups in the neutral or negative emotion conditions (*ps* ≥ 0.12). The interaction between emotional awareness and electrodes was significant, $F_{(2,80)} = 6.81$, $p = 0.003$, $\eta^2 = 0.15$. Simple-effect analysis showed that for the low group, VPP amplitudes at Fz (5.98 ± 0.71 μV) were larger than at F2 (5.68 ± 0.67 μV), $p = 0.002$; however, no other significance differences were observed. For the high awareness group, VPP amplitudes at Fz (7.38 ± 0.71 μV) were larger than F1 (6.86 ± 0.67 μV), $p < 0.001$; VPP amplitudes at Fz were larger than F2 (7.05 ± 0.67 μV), $p = 0.001$. No other significant main or interactive effects were observed (*p*s ≥ 0.09). As shown in **Figure 3A**, we selected Fz as the example diagram to show the groups' difference (in positive emotion) of VPP components, a: for the topographic map.

CNV

Average amplitudes of CNV components (FCz; 200–300 ms), measured by a mixed rmANOVA with the between-factor awareness group (2: high/low) and the within-factor emotion valence (3: neutral, positive, and negative), revealed a main effect of emotion valence, $F_{(2,80)} = 30.98$, $p < 0.001$, $\eta^2 = 0.44$. *Post hoc* analyses using Bonferroni correction showed that the CNV amplitudes for negative emotion (1.88 ± 0.59 μV) were larger than in the positive emotion condition (1.07 ± 0.58 μV), $p = 0.001$, whereas the CNV amplitudes (200–300 ms) in the positive emotion condition were larger than in the neutral condition (0.26 ± 0.53 μV), $p < 0.001$. The interaction between emotion valence and awareness group was significant, $F_{(2,80)} = 11.25$, $p < 0.001$, $\eta^2 = 0.22$. Simple-effect analysis showed that in the positive emotion condition, the high awareness group (2.33 ± 0.82 μV) elicited larger CNV amplitudes (200–300 ms), compared with the low awareness group (−0.19 ± 0.82 μV), F (1, 40) = 11.25, $p = 0.035$, $\eta^2 = 0.11$. The high and low awareness groups showed no differences in the neutral or negative emotion conditions (*p*s ≥ 0.34); moreover, no main effects of awareness group were observed ($p = 0.21$). As shown in **Figure 3B**, we selected FCz to show the groups' difference (in positive emotion) of CNV components (200–300 ms), a: for the topographic map.

A mixed rmANOVA with the between-factor awareness group (2: high/low) and the within-factor emotion valence (3: neutral, positive, negative) and CNV components (FCz; 300–490 ms) revealed a main effect of emotion valence, $F_{(2,80)} = 90.05$, $p < 0.001$, $\eta^2 = 0.69$. *Post hoc* analyses showed that CNV amplitudes (300–490 ms) in the negative emotion condition (0.66 ± 0.49 μV) were larger than in the positive (−0.32 ± 0.48 μV) or neutral conditions (−0.26 ± 0.49 μV), *ps* < 0.001. The interaction between emotion valence and awareness groups was significant, $F_{(2,80)} = 14.61$, $p < 0.001$, $\eta^2 = 0.27$. Simple-effect analysis showed that in the positive emotion condition, CNV amplitudes (300–490 ms) of the high awareness group (−1.23 ± 0.68 μV) were larger than that of the low awareness group (0.51 ± 0.68 μV), $F_{(1,40)} = 2.87$, $p = 0.038$, $\eta^2 = 0.07$. In the negative emotion condition, the high awareness group (1.19 ± 0.66 μV) elicited larger CNV amplitudes (300–490 ms), compared with the low awareness group (0.13 ± 0.66 μV), $F_{(1,40)} = 11.87$, $p = 0.049$, $\eta^2 = 0.06$. In addition, the high and low awareness groups showed no difference in the neutral emotion condition (*ps* = 0.93), and the awareness group had no main effect (*ps* = 0.33). As shown in **Figure 3C**, we selected FCz to show the groups' differences (in positive/negative emotion) of CNV components (300–490 ms), a, b: for the topographic map in positive emotion and negative emotion, respectively.

DISCUSSION

This study used a temporal generalization paradigm to explore the relationship between emotional awareness and time perception, through behavior and ERP components. The behavior results revealed that the time overestimation of the high and low awareness groups had no difference in the neutral and negative emotion conditions, but showed significant difference in the positive emotion condition. The ERP results showed that in the positive emotion condition, the high awareness group elicited larger VPP amplitudes, compared with that of the low awareness group. The high and low awareness groups had no difference in the neutral and negative emotion conditions. The CNV (200–300, 300–490 ms) results showed that in the positive emotion condition, the high awareness group elicited larger amplitudes, compared with that of the low awareness group. However, for the negative emotion condition, the high awareness group elicited larger CNV (300–490 ms) amplitudes, compared with that of the low awareness group. Whereas, the high and low reported no significant differences in the neutral emotion condition of the CNV components, our results indicated that the high and low awareness groups had a time overestimation difference on emotional pictures.

Behavioral Performance

Our behavioral results show a time overestimation difference in the emotion (mainly positive emotion) conditions between the high and low awareness groups. These findings are consistent with our hypothesis and can be explained by the arousal-based time perception hypothesis. Arousal and attention are the main factors affecting time perception (Angrilli et al., 1997; Droit-Volet et al., 2013; Schwarz et al., 2013; Van and Balsam, 2014; Fayolle et al., 2015); arousal-based time perception causes time overestimation, whereas attention-based time perception leads to underestimation. These time distortions can be attributed to the internal clock models (Chambon et al., 2005; Tipples, 2008; Droit-Volet et al., 2010, 2013). Arousal-based time perception has revealed that higher emotional arousal increases the speed of the pacemaker quickly, accumulating more pulses, resulting in the overestimation of time duration (Treisman, 1963; Schwarz et al., 2013; Droit-Volet and Gil, 2016; Cui et al., 2018). Moreover, the attention-based time distortion results showed that online accumulation of temporal pulses during the timed stimulus is compromised when we pay less attention to time, resulting in the underestimation of time duration (Lejeune, 1998; Macar, 2002; Coull et al., 2004; Droit-Volet and Meck, 2007). The time overestimation results showed differences between the high and low awareness groups in the emotion condition, whereas the underestimation results showed no difference between the groups. The results are consistent with previous findings suggesting that, within 2 s, emotional arousal played the main role in time perception (Angrilli et al., 1997; Gan et al., 2009a; Lake et al., 2016). In the positive emotion condition, the high emotional awareness group showed higher physiological arousal, compared with the low awareness group (Zhang et al., 2016). This study extended prior findings by examining the relationship

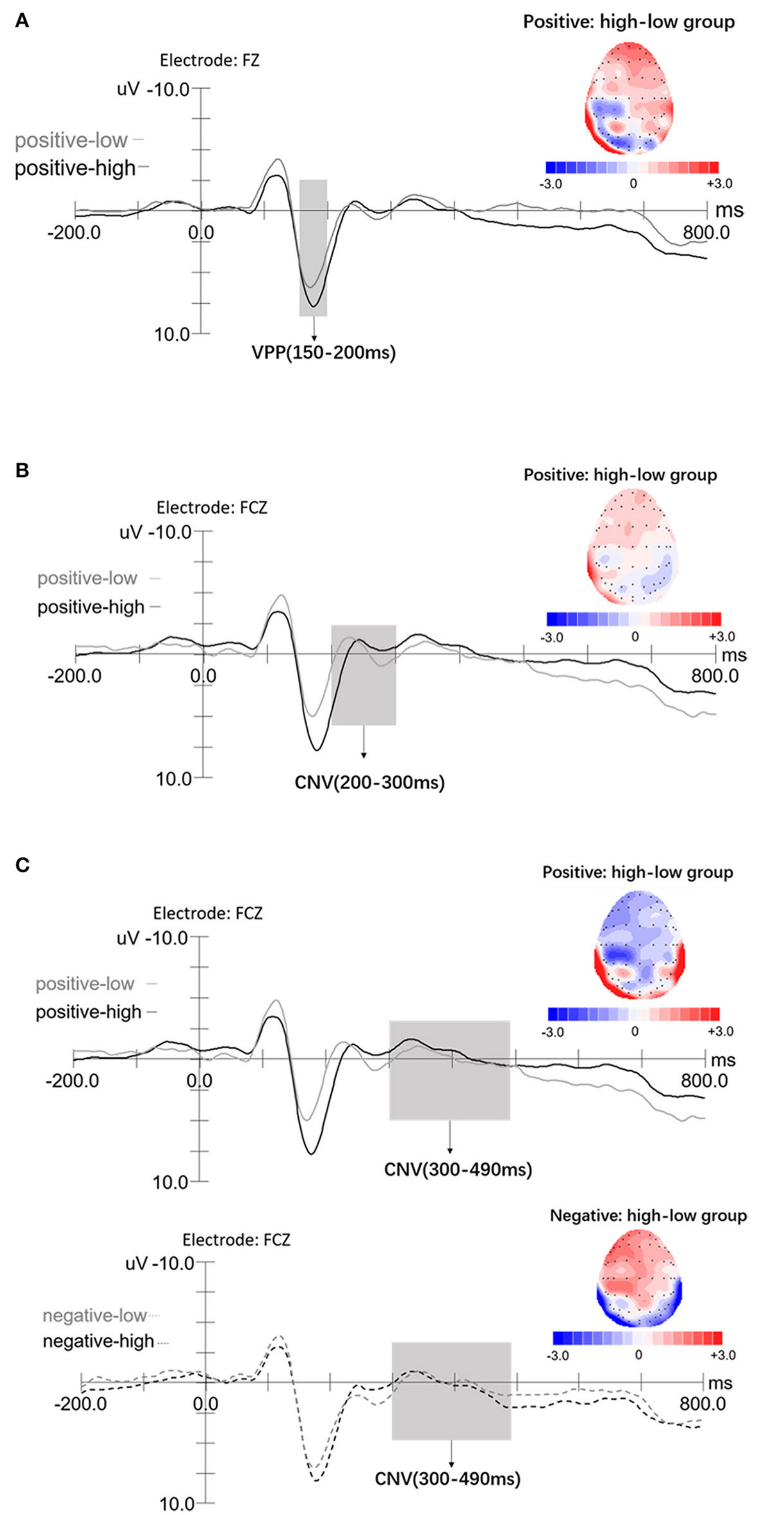

FIGURE 3 | ERPs elicited by the high emotional awareness (black lines) and low awareness (gray lines) displayed for VPP (150–200 ms) and CNV (200–300, 300–490 ms) components, with −200 to 800 ms time span. The *x*-axis represents time (ms) and the *y*-axis represents amplitude (μV). **(A)** Grand-average ERP of the VPP component at the onset of the emotion pictures at Fz for an example diagram; a: topographic maps of difference waves in the positive emotion condition (high awareness group minus low awareness group). **(B)** Grand-average ERP of CNV (200–300 ms) component at the onset of the emotion pictures at frontocentral area (FCz); a: topographic maps of difference waves in the positive emotion condition (high awareness group minus low awareness group). **(C)** Grand-average ERP of CNV (300–490 ms) component at the onset of the emotion pictures at frontocentral area (FCz); a, b: topographic maps of difference waves in the positive emotion and negative emotion (high awareness group minus low awareness group), respectively.

between arousal and time perception from the perspective of individual differences.

ERP

In accordance with our expectations, the VPP amplitude of the high awareness group was significantly larger than that of the low awareness group in the emotion (mainly positive emotion) condition. The VPP component is an index for distinguishing emotional and neutral expression; the amplitude of the emotional stimuli is larger than that of neutral stimuli (Vogel et al., 1998; Luo et al., 2010; Wang et al., 2015). The VPP results may suggest that the high awareness group (compared with the low awareness group) has an advantage in differentiating between positive expression and neutral expression. This is supported by prior findings where the high awareness group easily recognized positive emotion, whereas the low awareness group reported some difficulties (Wang et al., 2015). Therefore, the VPP results may provide electrophysiological evidence for the relationship between emotional awareness and time perception. High emotional awareness has been found to result in higher emotional arousal (Zhang et al., 2016), and that participants with high arousal tended toward larger time overestimation (Effron et al., 2006; Chambon et al., 2008; Droit-Volet et al., 2010).

Consistent with our hypotheses, the results of CNV components (200–300, 300–400 ms) showed that in the emotion (mainly positive) condition, the amplitudes of the high awareness group were larger than that of the low awareness group. This may suggest that CNV amplitude was not only an index of emotional arousal, but also of the accumulation mechanism and time overestimation, especially at the FCz electrode site (Olofsson et al., 2008; Klorman and Ryan, 2010; Mella et al., 2011; Pouthas et al., 2015). The CNV results suggest that the high awareness group may have a higher physiological arousal and timing accumulation, compared with the low awareness group in the positive emotion condition. This is partially consistent with previous findings that the high awareness group had a higher physiological arousal in the emotion condition, compared with the low awareness group (Zhang et al., 2016), and that higher arousal led to more time overestimation (Chambon et al., 2008; Droit-Volet et al., 2010). The CNV results extend existing evidence using electrophysiological techniques.

It should be noted that both behavioral and ERP results showed the influencing effects of emotional awareness on time perception in the positive emotion condition. However, in the negative emotional condition, we found almost no such effects. One possible reason may be that the negative emotional material combines images of fear, anger, and sadness. The complexity of negative emotional materials may confound the effect of emotional awareness on time perception. This is supported by research demonstrating that, at the same emotional arousal level, fear images are more likely to induce an overestimation of time than sad images (Droit-Volet and Gil, 2016). Future studies should consider using purer experimental materials to investigate this effect.

CONCLUSION

This study aimed to explore the neural mechanism of the influence of high and low emotional awareness on time perception. This study provides evidence that in the positive emotion condition, participants with high emotional awareness tend toward larger time overestimations, compared with those with low emotional awareness.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical Committee of the School of Psychology at Shanghai Normal University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JM contributed to conceptualization, acquisition, collection, analysis, interpretation, and drafting. XL contributed to conceptualization, interpretation, and revision of the work. JL contributed to supervision and validation. All authors contributed to the article and approved the submitted version.

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The Variability of Mental Timeline in Vertical Dimension

Jiaoyan He, Cuihua Bi, Hao Jiang and Jianan Meng*

Faculty of Psychology, Sichuan Normal University, Chengdu, China

People often use concrete spatial terms to represent abstract time. Previous studies have shown that mental timeline (MTL) is represented along a horizontal axis. Studies of the mental timeline have demonstrated that compared with English speakers, Mandarin speakers are more likely to think about time vertically (up-down) than horizontally (left-right /front-back). Prior studies have suggested that MTL in the up and down dimensions originated from temporal-spatial metaphors in language. However, there are still a large number of perceptual experiences in the up and down dimensions, such as visual and sensorimotor experience. Then does the visual experience in daily life affect the MTL in the vertical dimension? This study is aimed to investigate whether visual experience can promote or activate the opposite direction of MTL from implicit and explicit levels. The results showed that when the time information in the task was not prominent, the direction of vertical MTL cannot be affected by ascending or descending perceptual experience. While when the time information was prominent, whether the task was implicit or explicit, compared with the control group, watching the top-down scene significantly increased the top-down direction selection, while in the implicit task, watching the bottom-up scene made the top-down MTL disappear. To the best of our knowledge, our study provides the first evidence that the flexibility of space–time associations in vertical dimension extends beyond explicit and embraces even implicit levels. This study shows that the vertical MTL is activated in certain conditions and could be affected by the visual experience.

Keywords: vertical dimension, mental timeline, visual experience, variability, implicit and explicit

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Huazhan Yin,
Hunan Normal University, China

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Xiangyong Yuan,
Institute of Psychology, Chinese Academy of Sciences (CAS), China
Baolin Li,
Shaanxi Normal University, China

****Correspondence:***
Cuihua Bi
cuihuabi1215@163.com

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INTRODUCTION

The concept of time and space are indispensable for our thinking. The connection between time and space not only exists in language expression but also in the cognitive processing of information. A large number of studies have shown that time is represented by means of space (Santiago et al., 2007; Weger and Pratt, 2008). The connection between time and space is manifested in length, distance, direction, and other aspects. In terms of direction, people tend to imagine time from past to future as a line extending along a certain spatial direction, namely the mental timeline (MTL). The spatial representation of time is multi-directional: in the left and right dimensions, past/short time/early stimuli are represented on the left side of the timeline, while future/long time/late stimuli are represented on the right side of the timeline (Vallesi et al., 2011; Eikmeier et al., 2015). In the front and back dimensions, people tend to put the future time in front and the past time behind. In the up and down dimensions, "up" is associated with past temporal stimuli, and "down" is associated with future temporal stimuli (de la Fuente et al., 2014; von Sobbe et al., 2019).

The MTL has been confirmed by many studies in the left-right and front-back axis. Santiago et al. (2007) presented some words referring either to the past or to the future, and asked the subjects to press the left and right keys to classify them. The results showed that the subjects responded faster when they used the left key to react to the past words and the right key to react to the future words. By using different stimulating materials, such as pictures (Fuhrman and Boroditsky, 2010), video (Santiago et al., 2010), duration (Casasanto and Boroditsky, 2008; Ishihara et al., 2008; Coull et al., 2018; Isham et al., 2018), past or future time words or events (Santiago et al., 2007; Ouellet et al., 2010; Ding et al., 2015), actor names (Weger and Pratt, 2008) and auditory stimulus (Kong and You, 2012), they found that the left hand reacted more quickly to "past/short time/early events" and the right hand reacted more quickly to "future/long time/late events." Using eye movement as an indicator, subjects' eyes shifted to the left when thinking about the past and to the right when thinking about the future (Anelli et al., 2018; He et al., 2018).

The existing studies have done a lot of research on the left-right and front-back dimensions, but there are still many disputes about the MTL in the vertical direction. Boroditsky (2001) required the subjects to answer two spatial priming questions and then asked them to answer a time-related question. The spatial priming questions described the horizontal or vertical spatial relationship such as "the black bug crawling before the white bug (left)" and "the black ball is above the white ball." The results showed that the Mandarin subjects had a shorter reaction time to complete the time–related task after the vertical space was activated. Subsequently, the researchers directly manipulated these stimuli, they selected images containing the time range from only a few seconds to decades of years. And then asked the subjects to judge the second picture was earlier or later than the first picture by pressing the left and right keys in the horizontal direction or the up and down keys in the vertical direction. The result showed that there was early-up and late-down temporal-spatial correlation in the vertical dimension. Compared with native English speakers, Mandarin speakers talk more about MTL in the vertical dimension. Especially when the subjects were really good at Chinese and the experimental material was in Chinese, they were more inclined to represent time in the vertical dimension (Boroditsky et al., 2011). These studies have shown that the experience of spatial metaphor has a long-term impact on the representation of time. For Mandarin Chinese speakers, vertical spatial metaphors are often used to express temporal information. For example, people often say "last week," "next month," "second half of the year," "ancient era," etc. Vertical temporal-spatial metaphors are occasionally used in English, they are not as systematic or frequent as in Mandarin where earlier events are called as "Shang" (means up) and later events are called as "Xia" (means down).

Although most studies have supported that time moves from early to late in a top-down direction, some research still found different results that more downward eye movements were detected when recalling the past, and more upward eye movements were detected when imagining the future (Hartmann et al., 2014). Meanwhile, when processing future events, the subject's eye movement was higher than processing past events (Stocker et al., 2016). Other studies have also pointed out that, whether in the explicit time arrangement task or the implicit spatio-temporal correlation task, the early-up, late-down spatio-temporal mapping was not observed (Yang and Sun, 2018).

Taken together, the direction of vertical MTL is unstable. The instability of the MTL is related to reading and writing habits. Previous studies have found that subjects showed a "right-past, left-future" spatio-temporal mapping after reading the text which was rotated clockwise and counterclockwise (Casasanto and Bottini, 2014; Román et al., 2015). Mandarin people have both left-right and top-down reading and writing habits, as a result, their MTL is multi-directional. Besides, people have a lot of visual experience in their lives. For example, in ancient China, people could know the time by judging the burning height of the incense column (there were fixed intervals on an incense stick, the distance of each interval corresponded to a specific length of time), so the early and late time were characterized in the top-down direction. However, in certain situations, individuals often observe a great number of "rising" scenes, such as balloons flying to the sky and the rocket launching from bottom to top, which means the early time is at the bottom and the late time is on the top. This raises the question of whether vertical representation of time is the result of experience with writing and reading vertically or of visual perception of the physical world. In recent years, the core role of visual experience has been proved by some studies. For example, Bottini et al. (2016) found that sighted and late blind people consistently organize working memory items in space (with early items in the list mapped onto leftward location and later items onto rightward location), however, early blind do not show such consistent spatial mapping, which demonstrated that spatio-temporal mapping was due to visual experience.

According to the embodied cognition theory, time perception is closely related to personal physical activities (Holyoak and Thagard, 1995; Gentner et al., 2002; Barsalou and Wiemer-Hastings, 2005; Gibbs, 2006; Barsalou, 2008). In daily life, everyone will accumulate a variety of perceptual movement experience which is the foundation and key of the connection of time and space (Anelli et al., 2018). Therefore, visual experience might affect people's concept of mental timeline. To the best of our knowledge, there is no direct experimental evidence to support the role of the visual experience in the vertical dimension of MTL. Meanwhile, we still don't know whether the vertical MTL is flexible. In this study, life scenarios were used as priming materials of visual experience in order to directly examine the impact of visual experience on the vertical MTL. In experiment 1 and experiment 2, words and events were used as experimental stimuli, and then the subjects were required to complete implicit and explicit time-related judgment task. We assume the direction of vertical MTL will be enhanced in the top-down priming condition and will be weakened or disappear under the bottom-up priming condition.

EXPERIMENT 1

Method

Participants

In this experiment, we estimated the required sample size by using $f = 0.25$ as effect size input in G-Power 3.1.9

($\alpha = 0.05$) to detect a medium-sized effect on the main outcomes. The calculation outcome suggested a required sample size of seventy-two in this study. We randomly recruited eighty-five undergraduates and postgraduates, aged from 18 to 24 years old, and they were randomly divided into three groups: twenty-seven subjects were assigned to the "descending group" (15 females, 12 males, mean age = 20.15 ± 1.79), twenty-seven subjects were assigned to the "ascending group" (16 females, 11 males, mean age = 19.74 ± 1.26), and thirty-one people served as the control group (17 females, 14 males, mean age = 20.46 ± 1.30). All participants were right-handed and had a normal or corrected-to-normal vision. No subject quitted during the experiment and everyone was given an appropriate remuneration after the experiment. All participants provided written informed consent before the study, and this study was approved by The Ethics Committee of Sichuan Normal University.

Materials

The stimulus was presented on a 17-inch monitor screen with a resolution of 1024 × 768 and a refresh rate of 85 Hz. The image scene was presented in a white rectangle with a side length of 8 cm × 11 cm, which involved two black and white animations of a little man who was ascending and descending a wooden ladder. In each animation, there was a wooden ladder in the vertical direction which had a total height of 9.7 cm and 11 horizontal steps, and each horizontal step was 0.15 cm wide with a 0.7 cm distance between every two steps. The subject's eyes were about 60 cm away from the screen and kept the same level as the center of the screen during the experiment.

A total of 46 four-character vocabulary related to the "morning and evening" of a day (24 words about the morning and 22 words about the evening) were selected. We asked thirty-eight students to evaluate the familiarity and meaning of these words. According to the scores, a total of 24 words were selected to be used in the formal experiment. There was no significant difference between the morning words (familiarity 4.33 ± 0.19, image degree 3.96 ± 0.23) and the evening words (familiarity 4.38 ± 0.28, image degree 4.00 ± 0.08) [familiarity $t(22) = -0.54$, $p = 0.60$; image degree $t(22) = -0.41$, $p = 0.69$].

Procedures

We conducted a mixed design of 2 (time type: early and late) × 2 (response position: above and below) × 3 (priming condition: descending group, ascending group, and control group), with priming condition as a between-subject variable and time type and response position as within-subject variables. The dependent variables are the average response time and accuracy of the vocabulary judgment.

E-prime 2.0 was used to design the program and collect data. In the experiment, the participants in the ascending and descending wooden ladder groups watched the animation first. They could clearly see a person climbing down from the top to bottom or climbing up from the bottom to top, respectively. The animation of descending or ascending the wooden ladder was repeated three times in each group, lasting 3000 ms for each time with an interval of 3000 ms between each time. When the animation finished, the subjects were required to verbally describe it and make sure they had kept the scene in their mind (no less than 1 min). Once subjects make sure that they could keep the scene smoothly, they pressed any key to enter the judgment task. In each trial, a "+" appeared in the middle of the screen for 500 ms, and then a blank screen appeared for 500 ms. When a word appeared, participants were required to distinguish whether the word represent morning or evening by pressing the up or down key within 4000 ms. They pressed the "↑" key if they thought it was earlier than noon and pressed the "↓" key if they thought it was later than noon. There was an interval of 1000 ms between each trial. If the subject did not respond within 4000 ms, the next trial was automatically entered. The control group did not watch the animation and completed the judgment task directly.

Each subject had a certain amount of practice until the correct response rate was over 80 %. Each subject performed a total of 240 trials divided into four blocks. The sequence of keys was balanced among the subjects. Some participants were required to press the "early-up key, late-down key" to respond to the first two blocks, and press the "early-down key, late-up key" to respond to the last two blocks. For other participants, the key sequence was reversed. Participants could take a short break between blocks.

Results

After the experiment, all of the subjects reported that they were not clear about the purpose of the experiment. We deleted five subjects' trials (including three in the descending wooden ladder group and two in the ascending wooden ladder group) because their accuracy rate was below 75 % in a single block. For each participant, the trials with error response and response time within 400 ms and beyond 3500 ms were deleted. The percentage of deleted data was 10.65 %.

The accuracy was analyzed by repeated measures ANOVA. The main effect of time type was significant, $F(1,77) = 11.53$, $p = 0.001$, $\eta_p^2 = 0.13$, and the correct rate of response to late words was significantly higher than that to early words. The main effect of priming condition was not significant, $F(2,77) = 1.91$, $p = 0.15$, $\eta_p^2 = 0.05$. The interaction effect between time type and response position was significant, $F(1,75) = 6.49$, $p = 0.013$, $\eta_p^2 = 0.08$. Importantly, the interaction effect among time type, response position, and priming condition was approximately significant, $F(2,77) = 3.08$, $p = 0.052$, $\eta_p^2 = 0.07$. Simple effect analysis showed that in the ascending group, the accuracy of pressing the "up" key was significantly higher than that of pressing the "down" key when responding to early words (0.96 ± 0.01 vs. 0.93 ± 0.01), $F(1,77) = 6.89$, $p = 0.01$, $\eta_p^2 = 0.08$, and the accuracy of pressing the "down" key was significantly higher than that of pressing the "up" key when responding to late words, (0.97 ± 0.01 vs. 0.94 ± 0.01), $F(1,77) = 6.63$, $p = 0.012$, $\eta_p^2 = 0.08$. In the descending group and the control group, the interaction was not significant ($p > 0.05$).

The reaction times were analyzed by repeated measures ANOVA. The main effect of time type was significant, $F(1,77) = 13.02$, $p = 0.001$, $\eta_p^2 = 0.15$, that the responses to late words were significantly faster than those to early words, (1025.44 ± 19.12 ms vs. 1065.94 ± 21.28 ms). The main effect of priming condition was significant, $F(2,77) = 3.20$, $p = 0.046$,

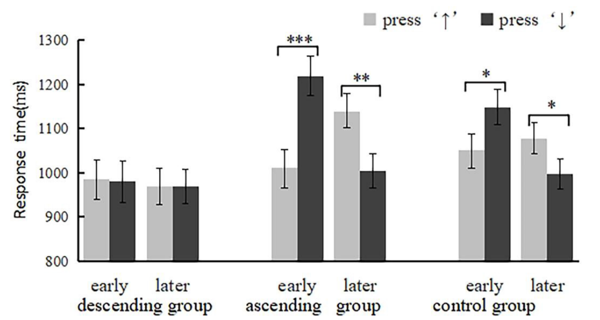

FIGURE 1 | Results from Experiment 1: mean response time as a function of priming condition (ascending group, descending group and the control group) and time type (early and later) in pressing "↑"(gray bars) or "↓"(black bars) conditions. The Error bars represent the standard errors for each condition. $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

$\eta_p^2 = 0.08$. The *post hoc* analysis showed that the descending group responded significantly faster than the ascending group (975.35 ± 35.26 ms vs.1093.33 ± 34.55 ms) and than the control group (975.35 ± 35.26 ms vs. 1068.39 ± 31.02 ms). The interaction effect between time type and response position was significant, $F(1,77) = 14.34$, $p < 0.001$, $\eta_p^2 = 0.16$. The interaction among word type, response position, and task type was significant, $F(2,77) = 4.69$, $p = 0.012$, $\eta_p^2 = 0.11$. Simple effect analysis to the control group found that subjects responded faster when pressing the "up" key to early words [$F(1,77) = 6.30$, $p = 0.014$, $\eta_p^2 = 0.08$] and pressing the "down" key to late words [$F(1,77) = 4.53$, $p = 0.036$, $\eta_p^2 = 0.06$], which indicated that the direction of the MTL was from top to down. In the ascending group, subjects responded faster when pressing the "up" key to early words [$F(1,77) = 23.02$, $p < 0.001$, $\eta_p^2 = 0.23$] and pressing the "down" key to late words [$F(1,77) = 10.66$, $p = 0.002$, $\eta_p^2 = 0.12$], which showed that the ascending group did not show an expected opposite MTL. While in the descending group, the interaction effect between word type and response position was not significant, demonstrating the up-down mental timeline disappeared (see **Figure 1**).

Experiment 1 showed that participants' response to late stimuli was significantly faster than that to early stimuli. The time range in Experiment 1 was limited to one day. According to the general life rhythm, in the morning, people are usually busy at work and school, and in the evening and night, they have more leisure time to observe and experience the surrounding environment. Therefore, people respond more quickly to late words as a result of having more experience of sunset and night.

Reaction time revealed that the control group showed an "early-up, late-down" spatio-temporal mapping, which was in line with our expectation. However, contrary to the expectation, when we asked subjects to watch up-down or down-up scenes, we did not observe an opposite MTL. But in the study of Chen (2018), after joining the virtual sensation movement of up and down of the elevator, the top-down MTL did not appear. The different results may be due to "safety" reasons. Ascending wood ladder situation may cause subjects' safety anxiety, which made them want to be closer to the land, inhibiting the emergence of spatio-temporal association. While in the descending wooden ladder situation, the task itself was more in line with the subjects' safety needs and did not consume too many cognitive resources, which lead to faster response. In experiment 1, we used implied time information that did not directly express time, which might cause the expected results did not to appear. In Experiment 2, we used materials that represent time directly to further investigate the role of visual experience under implicit and explicit conditions.

EXPERIMENT 2

Method

Participants

In this experiment, we estimated the required sample size by using $f = 0.25$ as effect size input in G-Power 3.1.9 ($\alpha = 0.05$) to detect a medium-sized effect on the main outcomes. The calculation outcome suggested a required sample size of seventy-two for the experiment. A total of eighty-seven undergraduates and postgraduates were randomly divided into three groups. The first group contained a total of thirty participants (17 females and 13 males, mean age = 19.17 ± 1.23). The second and control group were composed of twenty-eight participants (17 females and 11 males mean age = 19.79 ± 1.91) and twenty-nine participants (20 females and 9 males, mean age = 19.62 ± 1.76). All participants were right-handed and had a normal or corrected-to-normal vision. No subject quitted during the experiment and everyone was given an appropriate remuneration after the experiment. All participants provided written informed consent before the study, and this study was approved by The Ethics Committee of Sichuan Normal University.

Materials

(1) Video: There were a total of 10 videos with 5 descending videos (e.g., apple falling) and 5 ascending videos (e.g., balloon flying away). The videos were presented on a 17-inch monitor screen with a 1024 × 768 screen resolution and a refresh rate of 85 Hz.
(2) Cards: There were 15 sets of cards in sequence of events and each set of cards included 3 cards (12 cm × 12 cm) which represented the early, middle and late states of the event (see **Supplementary Figure 1**).
(3) Filling board: There was a character in the middle of the first board with empty squares above and below the character (see **Figure 2A**). The mid-term picture of the occurrence of the event was presented in the middle of the second board with two empty squares above and below the mid-term picture (see **Figure 2B**).
(4) Voice material: The recording software (version 2.2.0 of the mobile APP "Recording Expert") was used to record. The material itself did not contain any direction, but there were 30 Chinese items such as "Xiao Ming visited the zoo yesterday and will visit the botanical garden tomorrow."

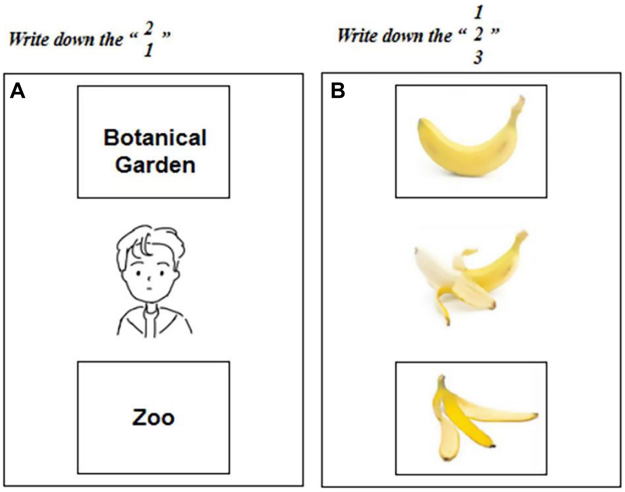

FIGURE 2 | Order diagram of event occurrence **(A,B)**.There is a character in the middle of the first board with empty squares above and below the character **(A)**. The mid-term picture of the occurrence of the event is presented in the middle of the second board with two empty squares above and below the mid-term picture **(B)**.

Procedures

A two-factor mixed design of 3 (priming direction: downward, upward and none priming group) × 2 (task type: implicit and explicit) was adopted, in which priming direction was taken as the between-subject variable and task type as within-subject variable.

Each participant first watched 5 downward or upward videos in sequence, and tried to use one sentence to briefly describe what they had just seen after each video. And then they completed the time chart task and card sorting task. In the time chart task, the subjects first listened to a sentence, such as "Xiao Ming visited the zoo yesterday and will visit the botanical garden tomorrow" which was repeated twice, then they orally repeated the main content of the sentence to make sure they had heard it clearly. Finally the subjects wrote the words "zoo" and "botanical garden" into the box within 15s, and those positions written by the participants were recorded by the examiner (see **Supplementary Table 2** record 1). The subjects were not allowed to modify their answers once they finished the task. Subsequently, each subject received a set of cards which represent early and late states of the event, and placed it into the upper and lower boxes in the second board according to the sequence of events. The examiner recorded the position of the cards placed by the participant (see **Supplementary Tables 1**, **2** record 2). The specific recording method is as follows:

Record 1: Audio material "Xiao Ming visited the zoo yesterday, and will visit the botanical garden tomorrow":

The zoo was on the top and the botanical garden was on the bottom (the early words associate with up and the late words associate with down) were marked as "$\substack{1\\2}$";

The botanical garden was on the top and the zoo was on the bottom (the early words associate with down and the late words associate with up) were marked as "$\substack{2\\1}$."

Record 2: Top-down was marked as $\substack{1\\2\\3}$; bottom-up was marked as $\substack{3\\2\\1}$.

Data Analysis

According to records 1 and 2, respectively, the percentage of participants who wrote the names of the early things or put the early pictures in the "up" position was calculated and the ratio of the "bottom-up" direction = 1-the ratio of the "top-down" direction.

Results

We took the percentage of top-down arrangement as the dependent variable, and conduct ANOVA of repeated measure with 2 (task type: implicit and explicit) × 3 (priming direction: downward, upward, and none priming condition). The main effect of task type was significant, $F(1, 84) = 8.24$, $p = 0.005$, $\eta_p^2 = 0.09$. The implicit group had a lower average selection ratio than the explicit group (0.76 ± 0.02 vs. 0.84 ± 0.03). The main effect of priming direction was significant, $F(2, 84) = 35.87$, $p < 0.001$, $\eta_p^2 = 0.46$. The interaction effect was significant, $F(2, 84) = 3.21$, $p = 0.045$, $\eta_p^2 = 0.07$ (see **Figure 3**). Simple effect analysis showed that in the implicit task, the selection ratio of downward priming group was higher than that of upward priming group (0.98 ± 0.04 vs. 0.50 ± 0.04), $p < 0.001$; the selection ratio of downward priming group was higher than that of the control group (0.98 ± 0.04 vs. 0.79 ± 0.04), $p < 0.001$; the selection ratio of the control group was higher than that of upward priming group(0.79 ± 0.04 vs. 0.50 ± 0.04), $p < 0.001$. In the explicit task, the results were similar. The selection ratio of downward priming group was higher than that of the upward priming group (0.96 ± 0.05 vs. 0.65 ± 0.05), $p < 0.001$; the selection ratio of the control group was higher than that of the upward priming group (0.90 ± 0.05 vs. 0.65 ± 0.05), $p < 0.001$. But the difference between the downward priming group and the control group was not significant (0.96 ± 0.05 vs. 0.90 ± 0.05, $p > 0.05$).

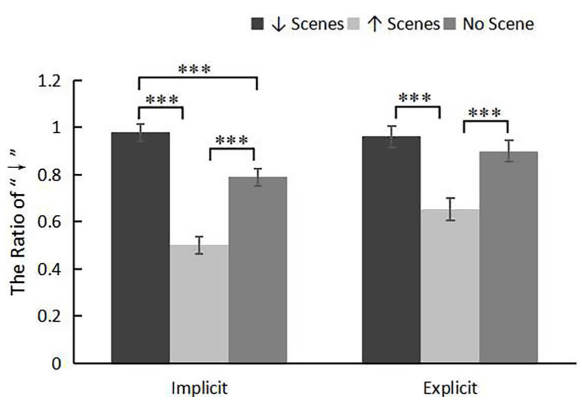

FIGURE 3 | Results from Experiment 2: mean ration of "↓" as a function of task type in downward priming (black bars), upward priming (light gray bars) and none priming conditions (dark gray bars).The Error bars represent the standard errors for each condition. ***$p < 0.001$.

In the implicit and explicit tasks, the ratio of participants' choice of top-down and bottom-up directions was tested by single sample T-test, and the compared value was 0.5. The results showed that in the downward priming group, the participants tended to choose the top-down direction in both implicit ($t = 60.69$, $df = 29$, $p < 0.001$, $d = 22.54$) and explicit tasks ($t = 21.31$, $df = 29$, $p < 0.001$, $d = 7.91$). In the upward priming group, the participants in the implicit task had no orientation tendency, $t = 0.001$, $df = 27$, $p > 0.05$; while in the explicit task, the participants tended to choose the top-down direction, $t = 2.07$, $df = 27$, $p = 0.049$, $d = 0.79$. In the control group, participants tended to choose the top-down direction in both implicit ($t = 9.29$, $df = 28$, $p < 0.001$, $d = 3.51$) and explicit tasks ($t = 13.66$, $df = 28$, $p < 0.001$, $d = 5.16$).

In Experiment 2, compared with the control condition, the downward priming enhanced the top-down MTL at the implicit and explicit level, and the upward priming weakened the top-down MTL at the implicit level. It showed that when the experimental stimulus was directly related to time, the vertical MTL was affected by the experience of perceptual movement. Existing studies have also found that after reading sentences containing top-down or forward-to-backward metaphors, subjects were more inclined to construct time representation that adopt the corresponding trend (Lai and Boroditsky, 2013; Hendricks and Boroditsky, 2017). But one study found that visual experience had no effect on the vertical MTL (Chen, 2018). The reason may be that the subject's own movement was opposed to the motion scene they watched. In our study, participants' visual experience was separated from their own motion, and the results found that visual experience in different directions had a significant impact on the MTL.

GENERAL DISCUSSION

In alphabetic languages such as English, mental timeline are exclusively in a horizontal manner, whereas Mandarin can be either horizontally or vertically. It was suggested that Mandarin speakers' vertical conceptualization of time may be the result of the experience of writing and reading vertically (Chan and Bergen, 2005; Bergen and Chan, 2012; Chen and O'Seaghdha, 2013). Fuhrman et al. (2011) and Miles et al. (2011) also reported a strong vertical pattern in Mandarin speakers with more experience in writing and reading vertical texts, suggesting that vertical spatio-temporal metaphors used in the language should have a stronger influence on the conceptualization of time.

Researchers have found the spatio-temporal mapping of "past-up, future-down" by using different reaction methods such as manual buttons pressing, eye movement position, free placement task in three-dimensional space and so on (Boroditsky et al., 2011; Gu et al., 2017). However, these studies have thus far focused only on vertical representations of time, which has not much exploration about whether the mental timeline is stable in the vertical direction and the role of visual experience other than writing and reading. The MTL in the vertical direction is very unstable, as this study shows that when task stimuli directly express time information, perceptual experience can significantly change the MTL.

THE ROLE OF VISUAL EXPERIENCE

Visual experience is an important factor affecting the MTL. In Experiment 2, subjects' visual experience of watching other things moving was separated from their own sensory movement, and the results found that visual experience in different directions had a significant impact on the vertical MTL. From the perspective of embodied theory, perceptual experience plays an important role in the formation of MTL. Since people recognize the surrounding environment through observing and playing in their early stage, they accumulate a large number of spatio-temporal related scenes in vision and motor perception, which form the relationship between the concept of time and the concept of space. Multiple situational stimuli make this relationship repeatedly strengthened and eventually form the spatial representation of time.

However, the priming effect of perceptual experience is related to the task. When the time task is not relevant, some studies have not found the automatic activation of the MTL (Ulrich and Maienborn, 2010; Ulrich et al., 2012; Maienborn et al., 2015; von Sobbe et al., 2019). The activation of the MTL depends on the level of temporal complexity (Scheifele et al., 2018). When time has high complexity and has nothing to do with the task, the spatio-temporal mapping might disappear. In Experiment 1, the stimuli were words with high complexity which contain implicit time information, thus subjects may concentrate on processing and understanding the time information of the material without using spatial information. At this time, the degree of spatial activation was low, so the results showed that ascending and descending the wooden ladder had no impact on the direction of the vertical MTL.

THE DIFFERENCE BETWEEN IMPLICIT AND EXPLICIT SPATIO-TEMPORAL MAPPING

This study also investigated the implicit and explicit spatio-temporal mapping. The results of the control group showed that the subjects had a significant advantage in the top-down direction regardless of the implicit or explicit levels, supporting the previous view that subjects had a top-down mental timeline (Boroditsky, 2001; Boroditsky et al., 2011; Fuhrman et al., 2011; Miles et al., 2011). Existing studies have found the implicit spatio-temporal mapping mainly in the front and back dimensions. de la Fuente et al. (2014) used the method of cognitive training to randomly assign Spanish speakers to the "past focus" and "future focus" groups, and found that in the time chart task, the frequency of answering "the past is in front and the future behind" increased when participants received past focus training, and the frequency of answering "the future is in front and the past behind" increased when participants received future focus training. Although the two groups of subjects had the same linguistic and cultural background, their implicit spatio-temporal mapping directions were also different due to the different time focus of their attention. Other researchers also found that subjects did not show obvious preferences in the front and back dimensions by carrying out the time chart task; while the implicit spatio-temporal mapping of Qiang subjects was "past-before, future-after" (Li and Cao, 2018). In this study, when the MTL was activated by upward perceptual experience, the original "early-up, late-down" spatio-temporal mapping was weakened at both implicit and explicit levels, and the weakening effect was even more significant at the implicit level. Together with previous studies, this study shows that human implicit space-time mapping has greater flexibility and plasticity which could be changed with people's perceptual experience.

CONCLUSION

In this paper, we provided an investigation of the influence of visual experience on the vertical MTL. The results showed that the MTL on the vertical axis was not activated automatically when the temporal information was not prominent. And the MTL on the vertical axis could be changed in both explicit and implicit tasks, and the changes were more obvious under implicit conditions. To date, none of studies have considered visual experience as a variable when investigating vertical mental timeline. It is therefore expected that our research will attract more attention of researchers to investigate the vertical MTL.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Sichuan Normal University and all the procedures involved were in line with the sixth revision of the Helsinki Declaration. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

CB contributed to conception. JH and CB designed the experiment and wrote the manuscript. JH carried out the experiment and analyzed the data. HJ and JM modified the manuscript and refined the language. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.782975/full#supplementary-material

Supplementary Figure 1 | Order diagram of event occurrence. Each set of cards included 3 cards (12 cm × 12 cm) which represented the early, middle and late states of the event.

Supplementary Table 1 | Results Record Table of Card sorting task (Section). First record the judgment of the two small cards as "start" or "last", correctly call "√" under "R" and "√" under "W"; then call "√" in the corresponding position in the table in the direction represented by the display itself.

Supplementary Table 2 | Record table of implicit and explicit task results (section). According to the placement results of the subject, play "√" in the corresponding position in the table according to the direction of the placement representative.

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The Effect of Electrical Stimulation–Induced Pain on Time Perception and Relationships to Pain-Related Emotional and Cognitive Factors: A Temporal Bisection Task and Questionnaire–Based Study

Chun-Chun Weng[1,2], *Ning Wang*[1,2]*, *Yu-Han Zhang*[1,2], *Jin-Yan Wang*[1,2] *and Fei Luo*[1,2]

[1] *CAS Key Laboratory of Mental Health, Institute of Psychology, Chinese Academy of Sciences, Beijing, China,* [2] *Department of Psychology, University of Chinese Academy of Sciences, Beijing, China*

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***Correspondence:**
Ning Wang
wangn@psych.ac.cn

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Pain has not only sensory, but also emotional and cognitive, components. Some studies have explored the effect of pain on time perception, but the results remain controversial. Whether individual pain-related emotional and cognitive factors play roles in this process should also be explored. In this study, we investigated the effect of electrical stimulation–induced pain on interval timing using a temporal bisection task. During each task session, subjects received one of five types of stimulation randomly: no stimulus and 100 and 300 ms of non-painful and painful stimulation. Pain-related emotional and cognitive factors were measured using a series of questionnaires. The proportion of "long" judgments of a 1,200-ms visual stimulus duration was significantly smaller with 300 ms painful stimulation than with no stimulus ($P < 0.0001$) and 100 ms ($P < 0.0001$) and 300 ms ($P = 0.021$) non-painful stimulation. The point of subjective equality (PSE) did not differ among sessions, but the average Weber fraction (WF) was higher for painful sessions than for no-stimulus session ($P = 0.022$). The pain fear score correlated positively with the PSE under 100 ms non-painful ($P = 0.031$) and painful ($P = 0.002$) and 300 ms painful ($P = 0.006$) stimulation. Pain catastrophizing and pain anxiety scores correlated significantly with the WF under no stimulus ($P = 0.005$) and 100 ms non-painful stimulation ($P = 0.027$), respectively. These results suggest that electrical stimulation–induced pain affects temporal sensitivity, and that pain-related emotional and cognitive factors are associated with the processing of time perception.

Keywords: time perception, interval timing, pain, electrical stimulation, emotion, cognition

INTRODUCTION

Pain is defined by the International Association for the Study of Pain as "an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage" (Raja et al., 2020). It has sensory and emotional components (Loeser and Treede, 2008), including pain-related fear, anxiety, and depression (Price, 2000). Some researchers have suggested that pain also has cognitive and social dimensions (Williams and Craig, 2016), inducing changes in attention, memory, and empathy (Eccleston and Crombez, 1999; Smith et al., 2021). The cognitive dimension of pain determines how individuals express and deal with pain (Williams et al., 2012). For example, some individuals facing pain tend to focus on and amplify its threat, engaging in pain-related catastrophic thinking (Sullivan et al., 1995), which can enhance the sensation of pain and is related closely to negative emotions such as fear and anxiety (Martel et al., 2016; Sugiura and Sugiura, 2016). The multidimensional nature of pain makes its impact on cognitive psychological processes, such as time perception, complex.

Patients with chronic pain commonly perceive the prolongation of time (Bilting et al., 1983; Zhang et al., 2012). In laboratory studies conducted with human subjects, cold pressor, thermal, and electrical forms of stimulation are used to explore the effect of pain on interval timing (Thorn and Hansell, 1993; Hellstrom and Carlsson, 1997; Khoshnejad et al., 2014; Ogden et al., 2015; Rey et al., 2017). However, the results obtained have been inconsistent. Some studies have shown that pain leads to the underestimation of temporal durations (Hellstrom and Carlsson, 1997; Khoshnejad et al., 2014), whereas others have shown that it leads to overestimation (Ogden et al., 2015; Rey et al., 2017). This inconsistency may be due to the diversity of time perception task paradigms, and/or to the multidimensional and complex nature of pain. Thus, exploration of the impact of pain on time perception should involve consideration not only of its sensory dimension, but also related emotional and cognitive factors.

Few studies have examined the effect of electrical stimulation–induced pain on time perception. Using a verbal estimation task, Piovesan et al. (2019) found that subjects significantly overestimated the duration of pain caused by high-intensity electrical stimulation. Compared with pain induced in the laboratory by other common means (e.g., thermal and cold stimuli), that induced by electrical stimulation may produce more cognitive and emotional changes affecting time perception. Sarigiannidis et al. (2017, 2020) noted the need to pay attention to the effects of electrical stimulation–related emotions in experiments conducted with this stimulus type. They found that anxiety, but not fear, induced by electrical stimulation caused the underestimation of time intervals (Sarigiannidis et al., 2017, 2020). Thus, the use of other research paradigms is needed to clarify the impact of electrical stimulation–induced pain on time perception and the roles of individual pain-related emotional and cognitive factors.

The purpose of this study was to explore whether pain caused by electrical stimulation affects individuals' perception of the duration of neutral visual stimuli, and whether individual pain-related emotional and cognitive traits are related to this time perception. A temporal bisection task and a questionnaire-based survey, respectively, were used to investigate these research questions.

MATERIALS AND METHODS

Subjects

In total, 30 students (10 males and 20 females, mean age 22.1 ± 0.4 years) recruited from universities near our institute participated in this study. Eligible subjects had normal or corrected-to-normal vision, no history of mental illness or chronic pain, no drug or alcohol abuse, no recent use of painkillers, and no recent injury affecting limb pain perception (e.g., leg injury). The volunteer participants were informed of the experimental procedure and provided written informed consent. After completing the experiment, they received a reward of 60 RMB. This study was approved by the Institutional Review Board of the Institute of Psychology, Chinese Academy of Sciences (no. H16036).

Experimental Procedure

The subjects completed the whole experimental process in an independent laboratory in a single visit. They completed an electronic questionnaire, rated the intensity of painful and non-painful electrical stimuli, and performed a temporal bisection task with electrical stimulation (**Figure 1A**).

Questionnaire

The electronic questionnaire-based survey included the Pain Catastrophizing Scale (PCS), Chinese Pain Anxiety Symptoms Scale (CHPASS), and Fear of Pain Questionnaire (FPQ) III. The PCS is used to assess the negative cognition affecting actual or expected pain, including redundant thinking, amplification, and helplessness, thereby reflecting individuals' strategies for coping with pain (Sullivan et al., 1995; Darnall et al., 2017); it has 13 items rated on a 0–4 scale (total range, 0–52) (Yap et al., 2008). The CHPASS is used to measure pain-related anxiety; it has 20 items rated on a 0–5 scale (total range, 0–100) (McCracken and Dhingra, 2002; Wong et al., 2012). The FPQ is used to measure individuals' fear of pain; it has 30 items rated on a 1–5 scale (total range, 30–150) (Osman et al., 2002). The Cronbach alpha values for the PCS, CHPASS, and FPQ in this study were 0.928, 0.915, and 0.940, respectively.

Pain Rating

Electrical stimulation was applied to the subjects using a DS7A instrument (Digitimer Ltd., Glenwyn Garden City, United Kingdom). A pair of Ag/AgCl electrodes was attached 5 cm above the subject's lateral malleolus. Each electrical stimulation pulse was an asymmetrical square wave applied for 2 ms; a 6-ms interstimulus interval was used (Van Ryckeghem et al., 2012) for the delivery of a total of 12 (100-ms session) or 36 (300-ms session) pulses.

The subjects rated the stimulation on a 0–10 scale (0 = no feeling; 1 = slight stimulation; 2 = obvious stimulation; 3 = very obvious stimulation, but no pain; 4 = slight pain; 5 = relatively painful; 6 = very painful; 7 = can't bear more pain; 8 = extreme pain; 9 = feeling injured; 10 = unimaginable pain). Scores of 1–3

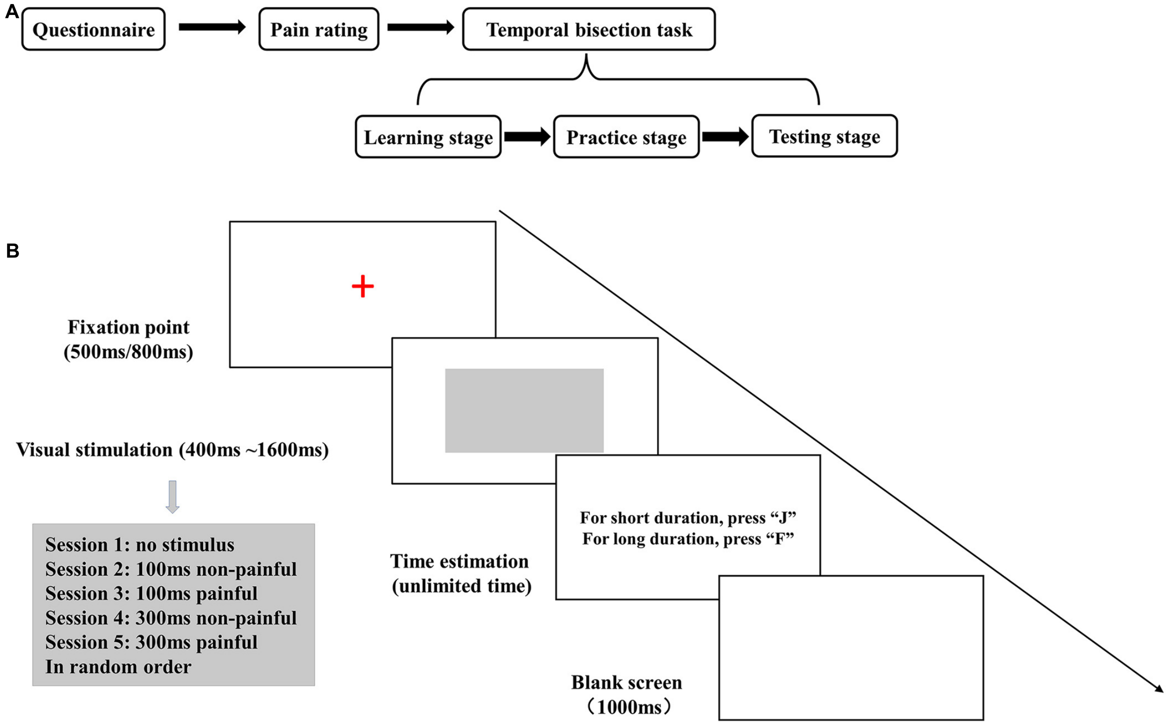

FIGURE 1 | (A) Diagram of the study flow. **(B)** The experimental stage of the temporal bisection task. The gray rectangle was presented for 400, 600, 800, 1,000, 1,200, 1,400, or 1,600 ms. Electrical stimulation was applied during the last 100 or 300 ms of the visual stimulus presentation.

points were taken to indicate non-painful stimuli, scores of 4–7 points were considered to reflect tolerable pain under laboratory conditions, and scores of 8–10 points were taken to indicate intolerable pain (Gong et al., 2020).

The subjects first underwent 300 ms electrical stimulation at an initial current intensity of 0.5 mA, which was increased by 0.1 mA until the participant reported a score of 6 or was unwilling to receive a more intense stimulus. The current intensities at scores of 2, 4, 5, and 6 were recorded. The maximum intensity of those generating multiple reports of the same pain score was taken as the current intensity for that score. When a subject reported pain at the initial current intensity of 0.5 mA, this intensity was adjusted to 0.1 mA and then increased in 0.02- or 0.01-mA increments. Then, we took the current intensity generating a pain score of 2 or 5 with 300 ms electrical stimulation as the initial intensity for 100 ms electrical stimulation, and adjusted it slightly according to the actual situation to ensure that the score was also 2 or 5 at 100 ms electrical stimulation.

Temporal Bisection Task

The E-Prime 1.2 software (Psychology Software Tools, Pittsburg, PA, United States) was used for programming and data acquisition for the temporal bisection task. The task was performed with a 12.1-inch color monitor with a resolution of 1,280 × 800 pixels, a refresh rate of 60 Hz, and a white display background. In each trial, an initial fix-point (a red "+") was presented for 500- or 800-ms (randomly selected), and then a gray rectangle was displayed in the center of the screen as the neutral visual stimulus. The subjects rated the neutral stimulus presentation as "long" or "short" by pressing the "F" or "J" key (balanced between subjects). After rating, a blank screen was displayed as a buffer for 1,000 ms, and then the next trial began (**Figure 1B**).

The temporal bisection task was adopted from previous studies (Fayolle and Droit-Volet, 2014; Huang et al., 2018) and performed in three stages. In the learning stage, the gray rectangle was displayed five times each for 400 ms (standard short duration) and 1,600 ms (standard long duration), in random order. The subjects were asked to remember these two durations, and no timing strategy was used (Matthews and Meck, 2016).

In the practice stage, the two standard durations were presented three times each in random order, the subjects rated them, and feedback on the correctness of their responses was displayed on the screen. Then, standard- and intermediate-duration (600-, 800-, 1, 200-, and 1,400-ms) stimuli were presented twice each in random order, and the subjects rated whether the stimulus durations were closer to "long" or "short." Instead of feedback after each rating, the total accuracy was presented after the completion of the exercise. Subjects repeated the learning and practice stages until they attained >70% accuracy, upon which they proceeded to the testing stage.

In the testing stage, seven standard- and intermediate-duration (400-, 600-, 800-, 1, 000-, 1, 200-, 1, 400-, and 1,600-ms) gray rectangle stimuli were presented 10 times each in random order per session. The subjects rated stimulus duration without feedback. The experiment consisted of five sessions conducted with no electrical stimulation (no stimulus) and with electrical stimulation at the pain scores of 2 (non-painful) and 5 (painful) during the last 100 and 300 ms of visual stimulation, respectively. The five sessions were administered in random order while avoiding two consecutive painful sessions.

Statistical Analysis

Prism 8 (GraphPad Software, Inc., La Jolla, CA, United States) was used for the statistical analysis. Following previous studies (Ward and Odum, 2007; Deane et al., 2017), the proportion of "long" responses (P_L) for each visual stimulus duration was recorded to analyze time perception using a fitting curve:

$$F(t) = a + \frac{b}{\sigma\sqrt{2\pi}} \int_{-\infty}^{t} [\exp -(\frac{(t-\mu)^2}{2\sigma^2})]dt$$

In this function, $F(t)$ is the P_L at t duration. The point of subjective equality (PSE) is the mean (μ) of this function, and the Weber fraction (WF) is equal to the standard deviation (σ) divided by the PSE. The PSE represents the subjectively perceived length of time, and an increase in the WF reflects a decrease in temporal sensitivity. The results are presented as means ± standard errors of the mean. Student's t test and one- and two-way repeated-measures analyses of variance (RM ANOVAs) were used to compare the current intensities, P_Ls for each duration, PSEs, and WFs among sessions. Bonferroni analysis was used for *post-hoc* testing. Pearson's correlations were used to assess relationships among questionnaire results, stimulus intensity, and temporal bisection task performance. Multivariate linear regression was also performed to assess factors associated with time perception (see **Supplementary Table 1** for details). $P < 0.05$ was set as the significance level.

RESULTS

Electrical Stimulation Intensities and Questionnaire Scores

The mean current intensity for the 100- and 300-ms non-painful sessions was 0.77 ± 0.07 mA. The mean intensities for 100- and 300-ms painful sessions were 2.07 ± 0.20 and 1.94 ± 0.18 mA, respectively. The average current intensity for all painful sessions (2.01 ± 0.18 mA) was significantly higher than that for non-painful sessions [$t_{(29)}$ = 8.390, $P < 0.0001$]. The average PCS, CHPASS, and FPQ scores were 20.80 ± 1.77, 44.77 ± 2.88, and 100.40 ± 3.03, respectively.

Temporal Bisection Task Performance

In the P_L analysis, the main effect of the duration was significant [$F_{(6,174)}$ = 514.8, $P < 0.0001$, η_p^2 = 0.947], indicating that the subjects effectively distinguished the visual stimulus durations (**Figure 2**). The main effect of the session was not significant, but the interaction between the duration and session was [$F_{(24,696)}$ = 3.65, $P < 0.0001$, η_p^2 = 0.112]. *Post-hoc* Bonferroni analysis showed that the P_L for the 300-ms painful session was significantly smaller than those for the no-stimulus and 100-ms and 300-ms non-painful sessions with 1,200-ms duration ($P < 0.0001$, $P < 0.0001$, and $P = 0.021$, respectively).

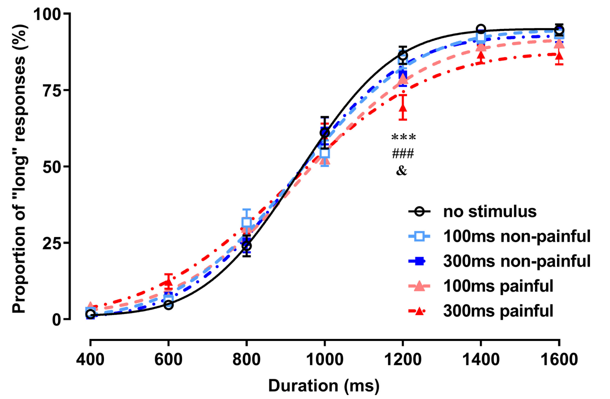

FIGURE 2 | Proportions of long responses and fitting curves for the five sessions of the temporal bisection task. ***$P < 0.001$, 300-ms painful vs. no stimulus; ###$P < 0.001$, 300-ms painful vs. 100-ms non-painful; &$P < 0.05$, 300-ms painful vs. 300-ms non-painful.

One-way RM ANOVA revealed significant differences in the WF among the no-stimulus, non-painful, and painful states [$F_{(2,58)}$ = 4.297, $P = 0.0182$, η_p^2 = 0.129; **Figure 3B**]. The average WF was significantly higher for painful sessions than for no-stimulus session ($P = 0.022$), suggesting that electrical stimulation reduced temporal sensitivity. No significant difference in the PSE was observed among the three states (**Figure 3A**). In addition, the PSE and WF did not differ among the five sessions (see **Supplementary Presentation 1**).

Relationships Among Questionnaire Results, Stimulus Intensity, and Time Perception

The results of the correlation analysis are presented in **Table 1**. The intensities of non-painful and painful stimulation correlated positively (r = 0.677, $P < 0.0001$), suggesting that subjects' sensitivity to these stimulation types was consistent. The PSEs for the no-stimulus and 300-ms non-painful and painful sessions correlated positively with the average intensity of painful stimulation (r = 0.522, P = 0.003; r = 0.381, P = 0.038; and r = 0.494, P = 0.006, respectively), reflecting an increase in the PSE with the current intensity. The PSEs for the 100-ms non-painful and 100- and 300-ms painful sessions correlated negatively with the FPQ score (r = –0.396, P = 0.031; r = –0.537, P = 0.002; and r = –0.489, P = 0.006, respectively), suggesting that subjects with strong fear of pain tend to have lower PSEs.

The PCS and CHPASS scores correlated negatively with the non-painful (r = –0.436, P = 0.0161 and r = –0.435, P = 0.0164, respectively) and painful (r = –0.447, P = 0.0134 and r = –0.449, P = 0.0129, respectively) current intensities, suggesting that subjects with stronger pain-catastrophizing cognition and pain anxiety tend to have lower sensory and pain thresholds. In

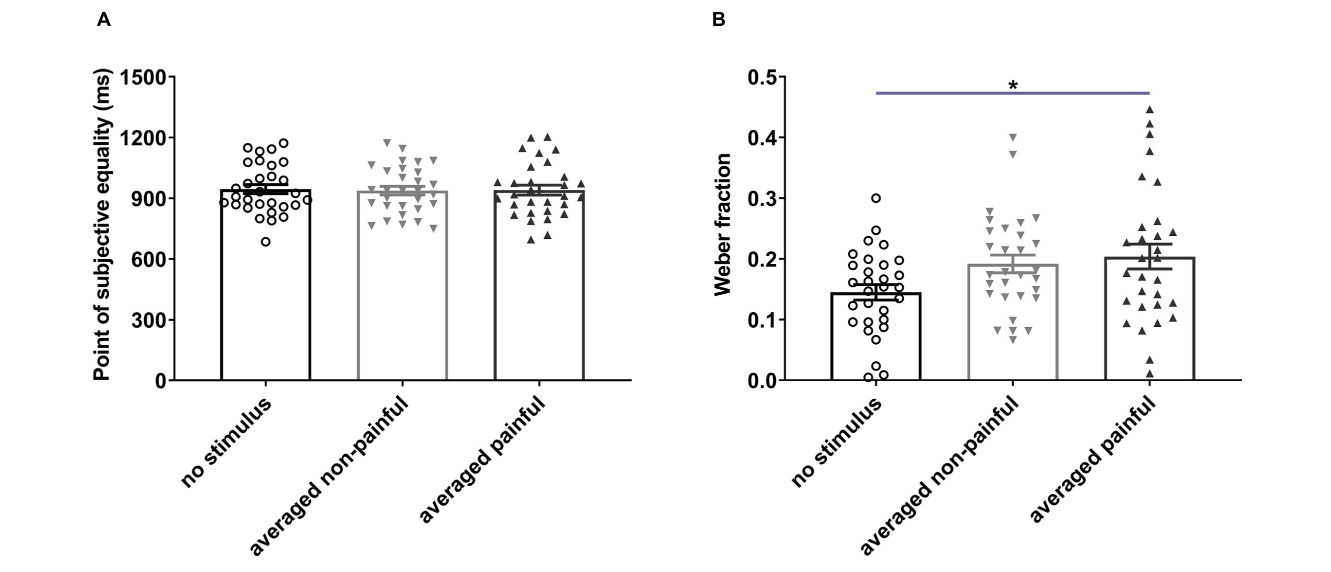

FIGURE 3 | Points of subjective equality **(A)** and Weber fractions **(B)** under different electrical stimulation conditions. Averaged non-painful: averaged PSE or WF of 100- and 300-ms non-painful sessions; Averaged painful: averaged PSE or WF of 100- and 300-ms painful sessions. *$P < 0.05$, averaged painful vs. no stimulus.

addition, the PCS score correlated negatively with the WF for no-stimulus sessions (r = –0.495, P = 0.005), and the CHPASS score correlated negatively with the WF for 100-ms non-painful sessions (r = –0.405, P = 0.027), reflecting associations of pain-catastrophizing cognition and pain anxiety with time sensitivity. The CHPASS score correlated positively with the PCS (r = 0.878, P < 0.001) and FPQ (r = 0.379, P = 0.039) scores, suggesting that individuals with stronger pain-related anxiety also have stronger pain-related catastrophic thinking and fear.

The multivariate linear regression analysis showed that the interaction between the session type and FPQ score was the only significantly predictor of PSEs [Pillai's V = 0.56, $F_{(4,19)}$ = 6.15, P = 0.002, η_p^2 = 0.56]. Closer inspection showed that the FPQ score significantly predicted the PSE for the 100-ms painful session (B = –5.39, β = –0.57, t = –2.97, P = 0.007) and 300-ms painful session (B = –3.48, β = –0.42, t = –2.40, P = 0.025). Besides, averaged painful intensity significantly predicted the PSE for the 300-ms painful session (B = 70.03, β = 0.53, t = –2.38, P = 0.027). Other factors had no predictive effect on the PSE, and no factor was predictive of the WF (see **Supplementary Table 1**).

DISCUSSION

This study showed that subjects receiving painful electrical stimulation had reduced temporal sensitivity and underestimated the duration of 1,200-ms neutral visual stimuli. Pain-related fear scores correlated negatively with PSEs for non-painful and painful sessions. In addition, pain-related catastrophizing and anxiety scores correlated negatively with WFs for no-stimulus and 100-ms non-painful sessions. These results confirm the effect of electrical stimulation–induced pain on time perception, and suggest that pain-related emotional and cognitive factors are involved in the processing thereof.

Pain induced by electrical stimulation may attract attention, resulting in the weakening of attention resources allocated

TABLE 1 | Coefficients of correlation (r) among stimulus intensity, pain-related scale scores, and temporal bisection results.

	Intensity		PCS	CHPASS	FPQ
	Non-painful	Averaged painful			
Intensity					
Averaged painful	**0.677*** **				
Questionnaires					
PCS	**–0.436***	**–0.447***			
CHPASS	**–0.435***	**–0.449***	**0.878*** **		
FPQ	–0.303	–0.199	0.267	**0.379***	
PSE					
No stimulus	0.359	**0.522** **	–0.175	–0.297	–0.236
100-ms non-painful	0.250	0.148	0.115	–0.030	**–0.396***
100-ms painful	0.086	0.211	–0.096	–0.197	**–0.537** **
300-ms non-painful	0.298	**0.381***	–0.035	–0.213	–0.224
300-ms painful	**0.375***	**0.494** **	–0.157	–0.322	**–0.489** **
WF					
No stimulus	0.249	0.130	**–0.495** **	–0.311	–0.212
100-ms non-painful	0.094	–0.025	–0.343	**–0.405***	0.214
100-ms painful	–0.191	–0.089	0.175	0.294	0.017
300-ms non-painful	–0.275	–0.225	0.056	0.029	0.255
300-ms painful	–0.069	–0.171	0.002	0.088	0.079

*PCS, Pain Catastrophizing Scale; CHPASS, Chinese Pain Anxiety Symptoms Scale; FPQ, Fear of Pain Questionnaire III; PSE, point of subjective equality; WF, Weber fraction. *$P < 0.05$, **$P < 0.01$, and ***$P < 0.001$. The bold values represent significant correlation.*

to the estimation of neutral visual stimulus duration; this factor may explain the weakening of temporal sensitivity and underestimation of the 1,200-ms duration during 300-ms painful sessions observed in this study. Pain indicates potential danger and can preferentially capture attention resources (Baliki and Apkarian, 2015), a phenomenon termed "attentional bias to pain" (Crombez et al., 2015). Zakay and Block (1995) proposed that attention plays a gating role in the processing of time estimation. Many studies have also confirmed that when more resources are allocated to other events, the resources involved in the internal clock will be reduced accordingly, resulting in the reduction of timing accuracy (Buhusi and Meck, 2009).

Another important factor affecting the processing of time perception is arousal (Gil and Droit-Volet, 2012; Yoo and Lee, 2015). High arousal levels can increase the pacemaker pulse rate, leading to the overestimation of time intervals. As a very important physiological phenomenon for survival, arousal to avoid danger can be caused by acute pain. Changes in alertness and attention caused by pain may jointly affect time perception. In this study, we found that pain induced by electrical stimulation reduced subjects' time sensitivity (increased WFs) and led to slight underestimation of stimulus durations, suggesting that the distraction caused by electrical stimulation–induced pain had a greater impact on time perception than did pain-related arousal.

The PSE is an important index of subjective time estimation. In this study, it correlated negatively with the FPQ score in the 300-ms painful and 100-ms painful and non-painful sessions, meaning that individuals with higher pain-related fear scores had smaller PSE values reflecting the overestimation of neutral visual stimulus duration. In the regression analysis, the FPQ score was associated with the PSE for the 100-ms and 300-ms painful session. Many researchers investigating the impact of fear on time perception have reached conclusions consistent with these findings. For example, Brown et al. (2007) found that rats' fear of foot shock led to the overestimation of time intervals. Such overestimation has also been observed with human subjects' viewing of short horror films (Martinez-Rodrigo et al., 2020) and fear-inducing pictures (Grommet et al., 2019). According to the scalar timing theory (Gibbon et al., 1984), arousal caused by fear accelerates the processing of time perception, resulting in duration overestimation. This study confirmed that this phenomenon is also associated with pain-related fear state. The correlation of pain-related fear scores with time perception not only in painful sessions, but also in non-painful session, suggests that pain-related emotional components affect time perception in the absence of pain perception.

In this study, we used the Pain Catastrophizing Scale to explore individuals' negative thinking. The PCS score correlated negatively with the WF in no-stimulus sessions, suggesting that individuals with more pain catastrophizing usually have greater time sensitivity. One possible explanation for this association is that individuals with higher PCS scores amplify the threat of potential pain, thereby enhancing their arousal to this threat specifically and the environment in general. The results of this study confirm the association of pain-related cognitive factors with time perception.

Another possible explanation for the study findings is that pain-related negative cognition indirectly affects time perception by affecting pain-related emotions and pain perception. The positive correlation between PCS and CHPASS scores in this study is consistent with previous findings (Lee et al., 2013) and is well understood, as stronger catastrophizing about pain may lead to greater pain-related anxiety. In addition, we found that PCS and CHPASS scores correlated negatively with the current intensity, suggesting that higher levels of pain-related emotions and cognition render subjects more sensitive to pain, reducing the current intensity required to achieve the same pain score. The effects of pain-related catastrophic thinking and anxiety on pain sensitivity have been demonstrated in many studies (Failla et al., 2020; Grouper et al., 2021; Kim et al., 2021). Taken together, the significant correlations observed in this study between the current intensity and the PSE and PCS and CHPASS scores suggest that the impacts of pain-related cognitive, emotional, and sensory factors on time perception may be direct and/or indirect.

Study Limitations

In this study, the order of the five sessions was random and the subjects knew that they would feel electrical stimulation–induced pain at some point. Thus, they were likely to be anticipating such pain (i.e., be affected by pain-related emotional and cognitive factors) during the no-stimulus and non-painful sessions. This factor may have reduced differences among sessions in the effects of pain on time perception. However, a main focus of this study was to determine whether pain-related emotional and cognitive traits were associated with time perception in the absence of pain perception. In addition, the randomization of the session order helped to balance the learning effect caused by the repeated execution of temporal bisection tasks. Another limitation is that we do not assess pain-related emotion and cognition after each session, which prevented us from detecting between-session differences therein and their effects on time perception. Despite these shortcomings, however, this study demonstrated that individuals' pain-related fear, anxiety, and disastrous thinking patterns are related significantly to (and may affect the processing of) time perception. The use of more sophisticated study designs in future research will help to reveal in greater detail the impacts of multiple dimensions of pain on time perception and the mechanisms underlying these effects.

CONCLUSION

The results of this study show that electrical stimulation–induced pain can reduce temporal sensitivity with no obvious effect on subjective perception. Furthermore, pain-related emotional and cognitive factors have potential effects on time perception at the individual level. This study revealed close correlations between pain-related fear and subjective time estimation, as well as between pain coping strategies and pain-related anxiety and time sensitivity. These results suggest that more attention needs to be paid to individuals' regulation of pain-related emotional and cognitive factors when exploring the impact of pain on time perception. The findings of this study provide important clues for further research of this nature.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Institutional Review Board of the Institute of Psychology, Chinese Academy of Sciences. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

NW, J-YW, and FL contributed to the conception and design of the study. C-CW performed the experiment and the statistical analysis. C-CW and NW wrote the first draft of the manuscript. Y-HZ revised the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Color Sensitivity of the Duration Aftereffect Depends on Sub- and Supra-second Durations

*Bingxin Lin[1,2,3], Youguo Chen[1,2,3], Li Pan[1,2,3], Gang Du[1,2,3] and Xiting Huang[1,2,3]**

[1]*Faculty of Psychology, Southwest University, Chongqing, China,* [2]*Center of Studies for Psychology and Social Development, Southwest University, Chongqing, China,* [3]*Time Psychology Research Center, Southwest University, Chongqing, China*

The perception of duration becomes biased after repetitive duration adaptation; this is known as the duration aftereffect. The duration aftereffect exists in both the sub-second and supra-second ranges. However, it is unknown whether the properties and mechanisms of the adaptation aftereffect differ between sub-second and supra-second durations. In the present study, we addressed this question by investigating the color sensitivity of the duration aftereffect in the sub-second (Experiment 1) and supra-second (Experiment 2) ranges separately. We found that the duration aftereffect in the sub-second range could only partly transfer across different visual colors, whereas the duration aftereffect in the supra-second range could completely transfer across different visual colors. That is, the color-sensitivity of the duration aftereffect in the sub-second duration was stronger than that in the supra-second duration. These results imply that the mechanisms underlying the adaptation aftereffects of the sub-second and supra-second ranges are distinct.

Keywords: duration aftereffect, color sensitivity, sub-second, supra-second, perception

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Huazhan Yin,
Hunan Normal University, China

Reviewed by:
Haojiang Ying,
Soochow University, China
Xue Dong,
Institute of Psychology (CAS), China

***Correspondence:**
Xiting Huang
xthuang@swu.edu.cn

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INTRODUCTION

The perception of time relates closely to many cognitive functions. For example, estimations of interval timing in the milliseconds-to-seconds range are important for motor control and language processing (Meck, 2005). However, the perception of duration is biased in some cases. Researchers have found that a duration aftereffect is induced by duration adaptation, similar to the tilt aftereffect and motion aftereffect (Heron et al., 2012; Li et al., 2015b). After repetitive exposure to a stimulus of relatively short duration, the subsequent stimulus is perceived to be of longer duration, and after repetitive exposure to a stimulus of relatively long duration, the subsequent stimulus is perceived to be of shorter duration.

There is an extensive body of research on the properties of the duration aftereffect. Findings have revealed that the duration aftereffect is sensory-specific (Heron et al., 2012), such as being contingent on auditory frequency but not on the visual orientation of a stimulus (Li et al., 2015b). Moreover, the region of spread of the duration aftereffect depends on the size of the adapting stimulus; the larger the adapting stimulus, the greater the spatial spread of the aftereffect (Fulcher et al., 2016). However, these studies examined duration in the sub-second range. Recent studies have found that duration aftereffects also exist in the supra-second range (Shima et al., 2016; Li et al., 2017b). Are the properties and mechanisms of the duration aftereffect in the supra-second range consistent with those found in the previous studies of the sub-second range? This is not yet known. Several studies have suggested differences in the mechanisms by which sub-second and supra-second durations are processed (Lewis and Miall, 2003a; Hayashi et al., 2014). Lewis and Miall (2003b) proposed the existence of automatic and cognitively controlled timing systems by analyzing previous neuroimaging studies of sub- and supra-second durations. The perception of a duration of less than 1 s is automatic, without being subject to attentional modulation. The "automatic" timing system is closely linked to the motor and premotor circuits. However, the perception of durations greater than 1 s requires attention and memory; thus, this represents a "cognitively controlled" timing system that draws heavily upon the prefrontal and parietal cortices. The features and mechanisms of the duration aftereffect in the sub-second range may not apply to the supra-second range, given the differences between the systems that process sub-second and supra-second stimuli.

Studies have found that visual areas are organized into two functionally specialized processing pathways: the dorsal and ventral streams (Ungerleider, 1995; Kastner and Ungerleider, 2000). The dorsal stream is crucial for spatial vision, which is necessary to appreciate the spatial relations among objects and guide movements toward objects in space. The ventral stream is important for object vision, which is responsible for identifying stimulus attributes such as shape, color, and texture. More importantly, Battellil et al. (2008) proposed both "where" (dorsal stream) and "what" (ventral stream) pathways, which play critical roles in perceiving the timing of visual events. However, most previous studies of the factors that influence the visual duration aftereffect focused on the dorsal stream such as by considering position (Li et al., 2015a; Maarseveen et al., 2017), size (Fulcher et al., 2016), and orientation (Li et al., 2015b). Few studies focused on the ventral stream. Therefore, we investigated the sensitivity of the duration aftereffect to color from the "ventral stream" perspective.

An unsolved problem is whether the neural underpinnings of duration adaptation in the sub-second and supra-second ranges are the same. Fortunately, investigation of the color sensitivity of the duration aftereffect, namely its specificity or invariance across different colors, may reveal the neural mechanisms underlying duration adaptation. This is because the primary visual cortex contains large populations of color-selective neurons (Engel and Furmanski, 2001; Nishida et al., 2003; Nieman et al., 2005; Parkes et al., 2009). The most color-selective neurons may relay color signals in V1, as opposed to later visual areas (Wachtler et al., 2003; Engel, 2005). Therefore, if the duration aftereffect exhibits strong color-sensitivity, this could be explained as the sub-second duration adaptation involving primarily the early visual cortex; conversely, weak color-sensitivity would suggest greater involvement of later visual cortical regions. Due to differences in processing mechanisms between the sub-second and supra-second durations, we expected the sub-second duration aftereffect to exhibit relatively strong color-sensitivity and the supra-second duration aftereffect to exhibit relatively weak color sensitivity. In the present study, we designed two experiments to investigate whether the sub-second/supra-second duration aftereffect could be transferred across different visual colors to verify whether the duration aftereffects in the sub-second and supra-second ranges have distinct mechanisms. In the first experiment, the subjects adapted to a visual stimulus (white disk) with a given duration (sub-second), which was presented in the center of the screen. The subjects were then tested with disks of random colors (white or red) at the same position. The goal of Experiment 1 was to evaluate whether the sub-second duration aftereffect could transfer across different visual colors. The design of the second experiment was similar to that of the first experiment, except that the durations of adapting stimuli and test stimuli were in the supra-second range. The goal of Experiment 2 was to evaluate whether the supra-second duration aftereffect could be transferred across different visual colors. This study examined whether stimulus duration can affect the color sensitivity of the duration aftereffect to explore whether the mechanism underlying the duration aftereffect is different between the sub-second (Experiment 1) and supra-second (Experiment 2) durations.

EXPERIMENT 1

The aim of Experiment 1 was to investigate the color sensitivity of the duration aftereffect in the sub-second range.

Materials and Methods

Participants

Twenty participants (eight men, mean age: 21.85 ± 1.81 years) were unaware of the experimental purpose. All participants provided written informed consent, which was approved by the Local Ethics Committee of the Southwest University of China and was conducted in accordance with the Declaration of Helsinki. All participants were right-handed and had normal or corrected-to-normal vision.

Stimuli and Apparatus

The visual stimulus was a white or red disk (0.5°), presented at the center of a CRT monitor (100 Hz refresh rate, 1,024 × 768 pixels), with a gray background (12.8 cd/m^2). The participants were seated at a viewing distance of approximately 70 cm. E-Prime 2.0 software (Psychology Software Tools, Inc., Pittsburgh, PA) was used to control the presentation and the stimuli's timing, and to record the data.

Procedure

Experiment 1 consisted of four blocks, each of which contained an adaptation phase and a test phase (**Figure 1**). In the adaptation phase, participants adapted to a white disk, which was serially presented 100 times. Within each block, the duration of the adaptation stimuli was fixed at either 200 or 800 ms. The inter-stimulus interval was randomly jittered between 500 and 1,000 ms, while the test phase followed a short pause. During the test phase, each trial started with four top-up adapting stimuli (white

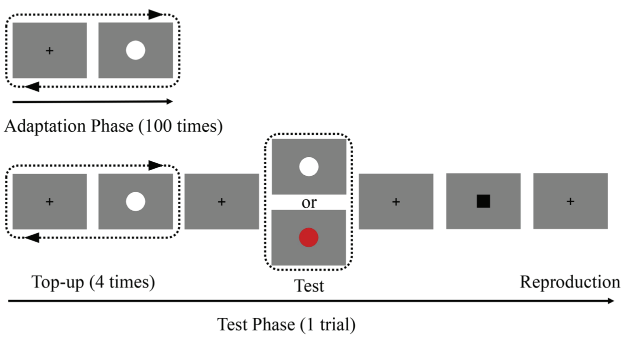

FIGURE 1 | Schematic representation of the experiment. In the adaptation phase, participants viewed 100 repetitions of the adaptation stimulus (white disk; 200 or 800 ms) in the center of the screen. In the subsequent test phase, participants were asked to press the "ENTER" key to reproduce the duration of the test stimulus when the black square appeared. The colors of the test stimuli were presented randomly.

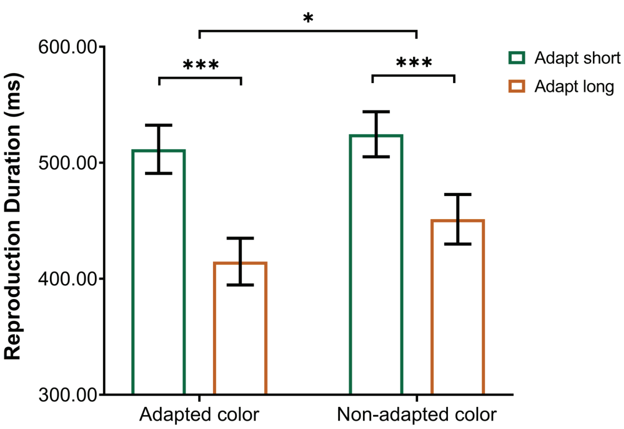

FIGURE 2 | Interaction between the conditions of Experiment 1. Error bars represent standard errors. *$p < 0.05$, ***$p < 0.001$.

disk; the same duration as the adaptation phase) followed by a test stimulus (white or red disk). There was a 2,000-ms pause between the final top-up adaptor and the test stimulus. That is, the colors of the adapting stimuli and test stimuli were either the same (white) or different (red). To reduce the noise associated with the responses, a pause was randomly jittered between 500 and 1,000 ms after the test stimuli. A black square ($0.40 \times 0.40°$) was then displayed to remind the participants to prepare for the reproduction of the duration. Once the black square appeared, participants were required to press the "ENTER" key, which was held as accurately as possible for the duration of the test stimulus. During each block, the durations of the adapting and top-up stimuli were identical and fixed. However, the test stimulus durations varied randomly according to the following distribution: approximately 80% lasted 500 ms, approximately 10% lasted 300 ms, and the remaining 10% lasted 700 ms. Trials that lasted 300 ms and 700 ms were adopted to avoid the participants from duplicating the duration through a repetitive motor response pattern. There were two adaptation duration conditions: "adapt short" (200 ms) and "adapt long" (800 ms), each of which consisted of two blocks. Furthermore, there were two test color conditions in each block: "adapted color" (same as the adapting stimulus color) and "non-adapted color" (different from the adapting stimulus color). In total, there were four conditions. For each condition, participants completed 48 trials, including 40 trials with a test duration of 500 ms. Approximately, 10–12 min were required to complete each of the four blocks. After each block, there was a minimum 2-min break. All blocks and the trials in each block were completed in random order. Before the formal experiment, participants were required to complete several practice trials of the duration reproduction task.

Results and Discussion

In Experiment 1, we focused only on the duration reproduced by participants when the duration of the test stimulus was 500 ms. To control for outliers, we applied a procedure similar to that used in previous studies (Li et al., 2017b). For each participant, all reproduction durations that were more than ±3 standard deviations from the participant's mean reproduction duration for the corresponding condition (4.09% of all trials) were not included in further data analysis.

A repeated-measures ANOVA was performed on the remaining reproduction durations, with adaptation duration (adaptation short, adaptation long) and test color (adapted color and non-adapted color) as within-subject factors. The results revealed a significant main effect of adaptation duration [$F(1,19) = 42.77$, $p < 0.001$, $\eta p^2 = 0.69$] with longer duration reproduction following adaptation to a 200-ms stimulus compared to adaptation to an 800-ms stimulus. That is, adaptation to a shorter duration resulted in a longer perceived duration of the test stimulus compared to adaptation to a longer duration. In addition, we found a significant main effect of test color [$F(1, 19) = 20.48$, $p < 0.001$, $\eta p^2 = 0.52$], reflecting longer reproduced duration in the "non-adapted color" condition than in the "adapted color" condition. Importantly, there was a significant interaction between adaptation duration and test color [$F(1,19) = 6.99$, $p < 0.05$, $\eta p^2 = 0.27$]. Tests of simple effects showed that the reproduction duration of the "adapt short" condition ($M = 511.62$ ms, $SD = 20.75$) was significantly larger than that of the "adapt long" condition ($M = 414.82$ ms, $SD = 20.12$) in the "adapted color" condition ($p < 0.001$); the reproduction duration of the "adapt short" condition ($M = 524.62$ ms, $SD = 19.45$) was also significantly larger than that of the "adapt long" condition ($M = 451.37$ ms, $SD = 21.36$) in the "non-adapted color" condition ($p < 0.001$). To break down this interaction, contrasts were used to compare "adapted color" to "non-adapted color" and "adapt short" to "adapt long." These contrasts revealed significant interactions when comparing "adapt short" to "adapt long" for "adapted color" compared to "non-adapted color" [$F(1, 19) = 6.99$, $p < 0.05$, $\eta p^2 = 0.27$]. As shown in the interaction diagram (**Figure 2**), these effects reflect that the reproduction duration of the "adapt short" condition was longer than that of the "adapt long" condition, and this difference was more pronounced for the "adapted color" than for the "non-adapted color" condition.

A measure similar to that used in previous studies was used to compare the aftereffect magnitude (Li et al., 2015a; Fulcher et al., 2016), which consisted of the arithmetic difference between the mean reproduction duration for the two adaptation conditions (duration aftereffect magnitude = mean reproduction duration of the "adapt short" condition—mean reproduction duration of the "adapt long" condition).

Specifically, the aftereffect magnitude in the adapted color or non-adapted color was the arithmetic difference between the mean reproduction duration of the white or red test stimulus in the "adapt short" and "adapt long" conditions.

Single-sample *t*-tests revealed that the aftereffect magnitudes were significantly larger than zero when the color of the test stimulus was the same as the adapted color ($M = 96.80$, $SD = 67.57$, $t\ (19) = 6.41$, $p < 0.001$) or non-adapted color ($M = 73.26$, $SD = 54.68$, $t\ (19) = 5.99$, $p < 0.001$). However, a paired-samples *t*-test (**Figure 3A**) revealed that the aftereffect magnitudes in the "adapted color" condition were significantly larger than those in the "non-adapted color" condition [$t\ (19) = 2.64$, $p = 0.016$]. These results suggest that, regardless of whether the color of the test stimulus was white or red, it produced a strong duration aftereffect in the sub-second range. However, the duration aftereffect in the sub-second range was only partly translation-invariant; that is, it partially transferred to the stimuli of different colors.

The results of Experiment 1 are consistent with those of previous studies, which found that duration adaptation occurs in the sub-second duration (Heron et al., 2012; Li et al., 2017a,b). The significant aftereffects for sub-second durations were observed not only when the color of the test stimulus was the same as that of the adaptation stimulus but also when it was different from the adaptation stimulus. Moreover, the results indicated that the duration aftereffect in the sub-second range could only partly transfer across different visual colors. In Experiment 2, we examined whether duration adaptation occurs in the supra-second duration and whether the aftereffect transfers across stimuli of different colors.

EXPERIMENT 2

The aim of Experiment 2 was to investigate the color sensitivity of the duration aftereffect in the supra-second range.

Materials and Methods

Participants

Experiment 2 included 21 participants (nine men, mean age: 21.10 ± 1.37 years) who were naïve to the experimental purpose and did not participate in Experiment 1. All participants were right-handed, had normal or corrected-to-normal vision, and provided written informed consent before the experiment.

Stimuli and Apparatus

The stimuli and apparatus used were the same as those in Experiment 1.

Procedure

The procedure was similar to that used in Experiment 1, except for the following changes. First, the durations of the adapting stimuli and test stimuli were greater than one second: the adapting durations were 1,500 ms ("adapt short" condition) and 4,000 ms ("adapt long" condition). However, the test stimulus durations varied randomly according to the following distribution: approximately 80% lasted 2,750 ms, approximately 10% lasted 2,000 ms, and the remaining 10% lasted 3,000 ms. Second, for each of the four conditions, participants completed 38 trials including 30 trials with a test duration of 2,750 ms. Approximately, 20–25 min were required to complete each of the four blocks. After each block, there was a minimum 2-min break. The participants completed the experiment over 2 days, with two

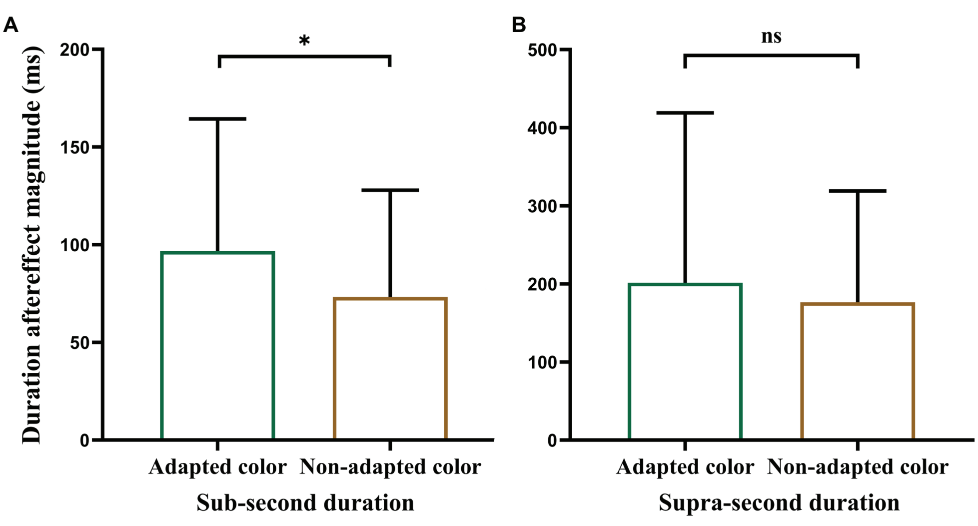

FIGURE 3 | Plot of paired-samples *t*-test. **(A)** Refers to Experiment 1 and **(B)** to Experiment 2. Error bars represent standard errors. *$p < 0.05$.

blocks per day (one for 1,500 ms and the other for 4,000 ms). Both blocks and the trials in each block were completed in random order.

Results and Discussion

In Experiment 2, we only focused on the duration reproduced by participants when the duration of the test stimulus was 2,750 ms. Using the same criteria as in Experiment 1, 3.85% of all trials were excluded from further analyses. Thereafter, using the same measure as in Experiment 1, the aftereffect magnitude of supra-second duration in each condition was calculated.

A 2 × 2 ANOVA for the reproduction durations of Experiment 2 revealed a statistically significant main effect of adaptation duration [$F(1, 20) = 28.86$, $p < 0.001$, $\eta p^2 = 0.59$], with longer duration reproduction in the "adapt short" condition ($M = 2293.21$ ms, $SD = 72.62$) than in the "adapt long" condition ($M = 2103.99$ ms, $SD = 82.42$). There was also a statistically significant main effect of test color [$F(1, 20) = 4.67$, $p = 0.043$, $\eta p^2 = 0.19$], with longer duration reproduction in the "non-adapted color" condition ($M = 2222.31$ ms, $SD = 70.49$) than in the "adapted color" condition ($M = 2174.88$ ms, $SD = 81.97$). However, the interaction was not significant [$F(1, 20) = 0.42$, $p = 0.52$, $\eta p^2 = 0.02$].

Single-sample t-tests revealed that aftereffect magnitudes were significantly larger than zero when the test stimulus color was the same as the adapted color ($M = 201.66$, $SD = 217.37$, t $(20) = 4.25$, $p < 0.001$) or non-adapted color ($M = 176.77$, $SD = 142.32$, t $(20) = 5.69$, $p < 0.001$). However, a paired-samples t-test (**Figure 3B**) revealed that there was no significant difference between the aftereffect magnitudes in the "adapted color" and "non-adapted color" conditions [t $(20) = 0.65$, $p = 0.52$]. These results suggest that, regardless of whether the color of the test stimulus was white or red, it produced a strong duration aftereffect in the supra-second range. Moreover, the duration aftereffect in the supra-second range was translation-invariant; that is, it could completely transfer to the stimuli of different colors.

In Experiment 2, consistent with previous studies (Shima et al., 2016; Li et al., 2017b), we found a significant aftereffect after adapting to supra-second durations, regardless of whether the color of the test stimulus was consistent with the adapted stimulus. Moreover, the results indicated that the duration aftereffect in the supra-second range could completely transfer across different visual colors. That is, the duration adaptation of supra-second duration showed color invariance.

GENERAL DISCUSSION

In the present study, we investigated the color sensitivity of the duration aftereffect in the sub-second or supra-second range. First, we provided further evidence that adaptation to stimuli of both sub-second and supra-second durations could induce duration aftereffects. Moreover, the duration aftereffect in the sub-second range could only partly transfer across different visual colors, whereas the supra-second duration aftereffect could completely transfer across different colors. That is, the color-sensitivity of the duration aftereffect in the sub-second duration was stronger than it was in the supra-second duration. The results of different color sensitivities of duration aftereffects in the sub-second and supra-second ranges suggest that the mechanisms underlying the adaptation aftereffects of the sub-second and supra-second ranges are distinct.

First, for the aftereffect produced by the sub-second duration, regardless of whether the color of the test stimulus was consistent with the adaptation stimulus, we observed a significant duration aftereffect. This is consistent with the results of most previous studies (Heron et al., 2013; Li et al., 2015a). Thereafter, for the aftereffect produced by the supra-second duration, we observed a significant duration aftereffect, regardless of the test stimuli's colors. Although there are few studies of the duration aftereffect in the supra-second range, the results of previous studies concur that duration adaptation also occurs for supra-second durations (Shima et al., 2016; Li et al., 2017b).

Previous researches have studied the mechanisms of the duration aftereffect in the sub-second range. Heron et al. (2012) found that the sub-second duration aftereffect was sensory-specific, which indicated that the adaptation of the sub-second duration was occurred at a relatively early stage of visual and auditory sensory processing. Furthermore, Fulcher et al. (2016) found that the larger the adapting stimulus, the greater the spatial spread of the sub-second duration aftereffect, which indicated that the sub-second duration selective neurons pool spatial information across earlier stages of visual processing. Are the properties and mechanisms found in the studies of duration aftereffects in the sub-second range also applicable to aftereffects in the supra-second range? Our research answers this question by examining the color sensitivity of the duration aftereffect in the sub-second and supra-second ranges simultaneously. We found a difference between the color sensitivities of the duration aftereffects in the sub-second and supra-second ranges. Specifically, the duration aftereffect in the sub-second range could only partly transfer across different visual colors, whereas the duration aftereffect in the supra-second range could completely transfer across different visual colors.

When a stimulus is perceived, its color signals are transmitted along the ventral visual stream, from V1 to V2, V4, and ultimately to the inferior temporal cortex (Conway et al., 2010). Many neurons present at all levels of the visual cortex selectively respond to colors (Engel, 2005). Previous studies of color perception have shown that color-selective neurons tend to coincide with regions called blobs (Livingstone and Hubel, 1984); the color-responsive regions that are associated with blobs are joined by color "bridges" spanning adjacent blobs (Landisman and Ts'o, 2002). Therefore, a region of neurons responds when adapting to one color. The color-selective neurons that are consistent with adaptation have the strongest response, but other associated neurons may respond, albeit not as strongly. Moreover, neural recording studies have shown that the most color-selective neurons may relay color signals in V1 (Wachtler et al., 2003), and color adaptation research has found that later visual areas in the cortex may adapt more strongly than earlier visual areas

(Engel, 2005). These studies of color selectivity support our results. For the sub-second duration, which involved greater processing in the early visual cortex, when individuals adapted to a white stimuli, the neurons selective for white may have exhibited the strongest response; neurons selective for red may have also responded, but their response was likely weaker. Therefore, we found that while both white and red stimuli had adaptive effects, the aftereffect for white stimuli was stronger than that for red stimuli. The results of the sub-second duration showed a partial transfer effect. For the supra-second duration that involved greater processing in the later visual cortex, the adaptation of color-selective neurons was stronger than that of the early visual cortex. Therefore, when individuals adapted to white stimuli, both white and red test stimuli had adaptive effects, and there was no difference in the aftereffects between the two. The supra-second duration results indicated a complete transfer effect. Our results show that mechanisms underlying the sub-second and supra-second duration aftereffects are different. The sub-second duration adaptation more involves the early visual cortex, while the supra-second duration adaptation more involves the later visual cortical regions. Meanwhile, the results also indicate that the duration aftereffects also exist for both low-level (early visual cortex) and high-level (later visual cortex) adaptations. Prior studies have confirmed this possibility; the coding of visual duration exists in multi-stages (Ivry and Schlerf, 2008; Merchant et al., 2013; Heron et al., 2019).

In the present study, we investigated the color sensitivity of the duration aftereffect in both the sub-second and supra-second ranges. Some important questions remain. Although the current study explores the mechanisms of the duration aftereffect of the sub-second and supra-second durations, the neural mechanisms underlying color perception are complex. The stimulus used in most previous studies of the duration aftereffect was a white Gaussian blob with a gray background. To facilitate comparison with previous results, we used white or red disks and a gray background. However, Mullen and Kingdom (2002) found that the two cone-opponent systems (red-green and blue-yellow systems) used by human color vision are functionally distinct. Recently, researchers found a surfeit of red and blue hue (end spectral of visible light) responses in V1 (Liu et al., 2020). Therefore, more differentiated colors should be considered in future research.

CONCLUSION

The current study investigated the color sensitivity of the visual duration aftereffect in the sub-second and supra-second ranges. We found that the duration aftereffect in the sub-second range could only partly transfer across different visual colors, whereas the duration aftereffect in the supra-second range could completely transfer across different visual colors. The results show a difference between the color sensitivities of aftereffects produced by adapting to the sub-second and supra-second durations, which indicates that the mechanisms of duration aftereffect in sub-second and supra-second durations are different.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Faculty of Psychology, Southwest University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

BL: conceptualization, methodology, formal analysis, investigation, writing—original draft, writing—review and editing, and visualization. YC: conceptualization, methodology, formal analysis, writing—review and editing, and visualization. LP and GD: review and editing. XH: conceptualization, writing—review and editing, supervision, project administration, and funding acquisition. All authors contributed to the article and approved the submitted version.

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How Does Emotion Influence Time Perception? A Review of Evidence Linking Emotional Motivation and Time Processing

Philip A. Gable[1]*, *Andrea L. Wilhelm*[1] and *Bryan D. Poole*[2]

[1] Department of Psychological and Brain Sciences, University of Delaware, Newark, DE, United States, [2] Department of Behavioral and Social Sciences, Lee University, Cleveland, TN, United States

Emotions have a strong influence on how we experience time passing. The body of research investigating the role of emotion on time perception has steadily increased in the past twenty years. Several affective mechanisms have been proposed to influence the passing of time. The current review focuses on how three dimensions of affect—valence, arousal, and motivation—are related to time perception. The valence-based model of time perception predicts that all positive affects hasten the perception of time and all negative affects slow the perception of time. Arousal is thought to intensify the effects of the influence of valence on time perception. In much of this past work, motivational direction has been confounded with valence, whereas motivational intensity has been confounded with arousal. Research investigating the role of motivation in time perception has found that approach-motivated positive and negative affects hasten the perception of time, but withdrawal-motivated affects slow the perception of time. Perceiving time passing quickly while experiencing approach-motivated states may provide significant advantages related to goal pursuit. In contrast, perceiving time passing slowly while experiencing withdrawal-motivated states may increase avoidance actions. Below, we review evidence supporting that approach motivation hastens the passing of time, whereas withdrawal motivation slows the passing of time. These results suggest that motivational direction, rather than affective valence and arousal, drive emotional changes in time perception.

Keywords: emotion, time perception, motivation, affect, valence

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Nandakumar Narayanan,
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Francesca Benuzzi,
University of Modena and Reggio
Emilia, Italy

Correspondence:
Philip A. Gable
pagable@gmail.com

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INTRODUCTION

Objective time and perceived time are distinct constructs. Perceived time is dependent on internal and external factors, such as affective states (James, 1890; Fraisse, 1978). Idioms and anecdotal evidence have corroborated decades of past research, which confirms that affective states permeate subjective experience (Izard, 2009) and change the perception of time. “Time flies when you are having fun.” “A watched pot never boils.” In this article, we first review research on how three dimensions of affect—valence, arousal, and motivation—are related to time perception. We then discuss recent research suggesting motivation, rather than valence or arousal, best explains the relationship between emotion and time perception.

AFFECTIVE MECHANISMS DRIVING CHANGES IN TIME PERCEPTION

Valence and Arousal

Valence is the subjective evaluation of an affective state that ranges from positive to negative (Lazarus, 1991; Harmon-Jones et al., 2011). Past research has shown that positively valenced stimuli are often judged for shorter durations than negatively valenced stimuli (Angrilli et al., 1997; Droit-Volet et al., 2004; Noulhiane et al., 2007). Conversely, negative stimuli are often judged for longer durations than positive or neutral stimuli (Stetson et al., 2007; Grommet et al., 2011).

Most of the studies comparing positive and negative valence, however, used highly arousing stimuli and failed to distinguish affective valence from arousal. Arousal is a "non-specific, energizing force that intensifies and strengthens either approach or withdrawal" (Bradley and Lang, 2007, p. 606); it can be measured subjectively (from "calm" to "excited") or by activation of the sympathetic nervous system (Duffy, 1957, 1962; Gable and Harmon-Jones, 2013).

Highly arousing affective images are often judged as being displayed for longer durations than less arousing or neutral images (Gil and Droit-Volet, 2012). In addition, highly arousing faces are typically judged as being displayed for longer durations than neutral faces (Droit-Volet et al., 2004; Effron et al., 2006; Noulhiane et al., 2007; Tipples, 2008). Fayolle et al. (2015) induced arousal by giving participants a mild electric shock during a time bisection task. Participants judged stimulus durations as longer during trials that contained an electric shock than trials that did not. In another study (Mella et al., 2011), participants compared the duration of neutral, low-arousal negative, and high-arousal negative audio cues while skin conductance responses were recorded. When participants were asked to focus their attention on the emotional intensity of a stimulus, they reported the negative high-arousal cues as lasting longer and experienced higher autonomic arousal than when they focused attention on time. However, discrepancy between arousal and time perception led the researchers to conclude that there may not be a direct relationship between arousal and time perception.

In sum, the valence-based model of time perception predicts that all positive affects hasten the perception of time and all negative affects slow the perception of time. Arousal is thought to intensify the effects of the influence of valence on time perception. However, some of the research supporting a valence-based model relies on comparisons between positive and negative affective states. Such comparisons do not reveal whether positive states hasten perceptions of time, or whether negative states slow perceptions of time. Papers that compare neutral and affective stimuli do not test mechanisms driving the relationship between affect and time perception.

Much past research contradicts the valence model. For example, many studies have found that negative affects, like sadness and anger, can hasten the perception of time passing (Gil and Droit-Volet, 2009; Gable et al., 2016; Benau and Atchley, 2020; Yin et al., 2021). Thus, valence must not be the underlying mechanism causing affect to influence time perception. Perhaps another dimension of affect is altering the perception of time passing, one that is frequently confounded with affective valence. Below, we present evidence suggesting motivation as the affective mechanism influencing time perception.

Motivation in Affect

The body of research on emotion and time perception has largely ignored the influence of motivation on time perception. Motivation refers to the action tendencies, or the urge to approach or withdraw, inherent in affect. Some affects are approach motivating, encouraging an organism to move toward a desired goal (Gable and Dreisbach, 2021). Conversely, some affects are withdrawal motivating, encouraging an organism to move away from an aversive stimulus (Gable and Harmon-Jones, 2013).

Approach and withdrawal motivation can be high or low in motivational intensity. For example, some positive affects are high in approach motivation (e.g., desire); other positive affects are low in approach motivation (e.g., contentment). Motivational intensity may also vary within affects of the same valence. Some negative affects are high in withdrawal motivation (e.g., disgust); other negative affects are low in withdrawal motivation (e.g., worry; Gable and Harmon-Jones, 2008, 2010b).

Motivational direction is not synonymous with valence. Much past work has confounded affective valence and motivational direction, such that all positive affects are assumed to be approach motivated and all negative affects are assumed to be withdrawal motivated. However, much research suggests this is not the case. For example, anger is a negative affect associated with approach motivation (Carver and Harmon-Jones, 2009; Harmon-Jones et al., 2011). Anger high in motivational intensity narrows an organism's cognitive and attentional scope and can motivate goal acquisition (Gable et al., 2015; Threadgill and Gable, 2020). Similarly, sadness is a negative affect that can be associated with approach motivation (Higgins et al., 1997; Carver, 2004; Gable et al., 2016). Sadness low in motivational intensity broadens an organism's cognitive and attentional scope in the face of lost goals (Gable and Harmon-Jones, 2010b) and can encourage an organism to seek new goals.

Arousal is often confounded with motivational intensity. In some cases, arousal can be a proxy for motivational intensity. Physiological and subjective measures of arousal can indicate the motivational intensity inherent in an affective state (Bradley and Lang, 2007). However, arousal and motivational intensity are not identical (Gable and Harmon-Jones, 2013). For example, arousal does not have a motivational direction. Highly arousing positive and negative affects are both high in arousal, but are opposite in motivational direction.

Much research has revealed the importance of motivational direction and intensity on cognitive and behavioral processes. We (Gable and Poole, 2012; Gable et al., 2016) proposed the mechanistic role of motivation in time perception, called the Motivational Dimensional Model of Time Perception. According to the model, approach motivation should hasten the perception of time and withdrawal motivation should slow the perception of time. Motivational intensity is predicted to enhance the influence of motivational direction. The body of research supporting the role of motivation has steadily increased. Below, we review evidence supporting that approach motivation hastens the passing of time, whereas withdrawal motivation slows the passing of time.

Approach-Motivated Positive and Negative Affects Hasten Time Perception

Past work based on a valence model of time perception confounded motivational direction with affective valence. We review work directly supporting the influence of approach motivation in hastening the perception of time in both positive and negative affects.

In one experiment, Gable and Poole (2012; Study 1) presented participants with pictures during a time bisection task. One third of pictures were neutral pictures, one third were positive pictures that elicited a low approach motivation, and one third were positive pictures that elicited a high approach motivation. Results revealed that participants perceived time passing faster after viewing the highly approach motivating pictures relative to the other picture types.

In a second experiment (Gable and Poole, 2012; Study 2), participants viewed the same set of pictures (dessert pictures), but approach motivation was increased in one group of participants, but not the other. To increase approach motivation, participants in one condition were told they would receive some of the desserts after the experiment, whereas participants in the other condition were not given these instructions. Afterward, participants reported how quickly time passed while viewing the pictures. Consistent with predictions, participants who expected to receive the dessert items experienced greater approach motivation and reported time passing faster than participants who did not expect to receive the dessert items.

Sadness and anger are negative affects associated with approach motivation. Recent research has found that sadness and anger may hasten the perception of time. In two experiments, Gable et al. (2016) tested whether sadness would shorten duration judgments. When viewing sad films or sad images, participants reported time passing faster than participants who viewed neutral films or images. Similarly, Benau and Atchley (2020) found that participants who recalled a sad memory showed bias toward shorter duration estimates in a temporal judgment task.

At first glance, research suggesting sadness hastens time perception appears to contradict other studies that link sadness and depression with a slowed perception of time, since both are often associated with withdrawal motivation (Thönes and Oberfeld, 2015; Kent et al., 2019). However, sadness can be either approach-motivating or withdrawal-motivating. For example, Gable et al. (2016; Study 4) had participants write about a past event while in a sad, approach-motivated state or while in a sad, withdrawal-motivated or inactive state. Consistent with predictions, participants who wrote about a sad event associated with approach motivation perceived time as passing more quickly during a subsequent retrospective temporal judgment task compared with participants who wrote about a sad event associated with withdrawal motivation or inaction.

Other work has examined the influence of anger on time perception. Some studies found that viewing static (Droit-Volet et al., 2004; Tipples, 2008; Kliegl et al., 2015) and dynamic (Li and Yuen, 2015) angry faces leads to a slowed perception of time or no effect at all (Grondín et al., 2015). Conversely, other studies have found that participants report time passing more quickly when viewing facial expressions depicting anger (Yin et al., 2021) and pain (Ballotta et al., 2018).

To test the role of approach motivation in negative affects more directly, Gable et al. (2016) directly tested whether manipulating approach motivation within negative states of sadness (Study 4) and anger (Study 5) would shorten the perception of time by directly manipulating approach motivation within the same affective state. States that were either high in approach motivation or low in approach motivation were evoked by having participants write about times when they experienced such states in the past. Results of both studies revealed that sad or angry states associated with approach motivation cause time to hasten relative to sad or angry states associated with inaction.

Together, these studies support that approach-motivated affective states hasten the perception of time. Importantly, approach-motivated affects appear to hasten the perception of time, regardless of whether they are positive or negative in valence. These results contradict the valence-based model of time perception and instead suggest motivation is responsible for changes in time perception.

Withdrawal-Motivated Negative Affect Slows Time Perception

Other recent work has investigated how withdrawal-motivated negative affects may be related to time perception. For example, Mioni et al. (2020) presented participants with disgust faces, happy faces, appetitive images (e.g., food, animals), and aversive images (e.g., infections, feces). Participants viewed images between 400–1600 ms and estimated how long each image was presented. When participants viewed disgust faces or aversive images, participants overestimated the passing of time. Similarly, Gable et al. (2016) presented participants with disgust images high or low in withdrawal motivation. Disgust images high in withdrawal intensity caused time to slow relative to disgust images low in withdrawal intensity and a neutral state. Together, these results suggest that negative affects high in withdrawal motivation slow the perception of time passing.

In another study, Matsuda et al. (2020) used a concealment manipulation to evoke guilt, a withdrawal-motivated negative affect. Participants were instructed to conceal an item from the experimenter during the study. Then, participants were made to feel guilty (vs. non-guilty) by viewing images of the concealed item (vs. another item). Individuals in the guilty condition had increased withdrawal motivation, perceived time as passing slower when viewing the images, and perceived all images as being displayed longer than participants in the non-guilty condition.

Other studies have manipulated withdrawal motivation by increasing physical effort, because effort is aversive (Richter et al., 2016). Hanson and Lee (2020) asked participants to run on an incline for 30 min at a pace that was somewhat hard or very hard. When participants were engaging in the hardest intensity of exercise, time slowed as compared to the easiest intensity. Similarly, Zhang et al. (2019) found that when individuals were asked to imagine lifting heavier items, they were more likely to overestimate time passing. These findings suggest that greater withdrawal motivation due to a highly effortful task can cause time to be perceived as passing more slowly.

DISCUSSION

Much recent research suggests that motivation may be a mechanism driving distortions of time perception in affective states. Approach motivation often hastens the perception of time for both positive and negative affects. Conversely, withdrawal motivation often slows the perception of time. Perceiving time passing quickly while experiencing positive affects may provide significant advantages related to goal pursuit. For example, affects high in approach motivation "should be associated with the perception of time passing faster...as organisms shut out irrelevant stimuli, perceptions, and cognitions" to accomplish a goal (Gable and Poole, 2012, p. 880). This is consistent with past research demonstrating a hastening of time when participants' attention is distracted from processing temporal information (e.g., Macar et al., 1994). A hastened perception of time perception may encourage goal acquisition by increasing the hedonic value of objects or goals (Sackett et al., 2010) or helping an organism make predictions about the environment (e.g., perceive the presence of danger or goals; Meck, 2005). Conversely, affects high in withdrawal motivation may increase avoidance actions by increasing the perceived time spent in the presence of aversive objects or situations.

Research on neurotransmitters and neural structures further strengthens the link between affect, motivation, and time perception. For example, dopamine levels relate to reward processing and anticipation, and govern time estimation in mice (Soares et al., 2016). Further, dopamine levels in the dorsal striatum (Meck, 2006; Agostino and Cheng, 2016), the medial prefrontal cortex (Cheng et al., 2016), and the amygdala (Shionoya et al., 2013) reflect changes in time perception. Other neurotransmitters, such as norepinephrine, have also been implicated in attentional and temporal processing (e.g., Penney et al., 1996). These connections between time perception and neural structures and neurotransmitters related to motivation suggest there is a strong link between motivational processes and time perception.

Attention in Time Perception

In the current review, we focus on the role of motivation, as opposed to affective valence, to influence time perception. However, some research on time perception posits that cognitive mechanisms of attention alter time perception during affective states (Angrilli et al., 1997). We discuss this model below.

Some past research has suggested that affective states may shift cognitive mechanisms of attention toward or away from key information (e.g., stimulus duration, bodily states, temporal processing), which may lead to a hastened or slowed time perception (Hawkins and Tedford, 1976). Burle and Casini (2001) found a hastening of time perception when attention was manipulated independently from arousal. In addition, Bar-Haim et al. (2010) found that briefly exposing anxious participants to threatening stimuli captured their attention but slowed time perception.

Much past work has linked attention with affective states (Easterbrook, 1959; Derryberry and Tucker, 1994; Gasper and Clore, 2002; Lacey et al., 2021). More recently, attentional scope has been linked with affective states high and low in motivational intensity. That is, positive and negative affects high in motivational intensity narrow attentional scope, whereas positive and negative affects low in motivational intensity broaden attentional scope (Gable and Harmon-Jones, 2008, 2010a,b). Thus, it is possible that motivational intensity inherent in affect drives changes in participants' attention, which, by extension, drives changes in time perception. However, positive and negative affects high in motivational intensity have demonstrated opposite effects on time perception (Gable and Poole, 2012, Experiment 3). Therefore, attention seems like an unlikely mechanism for the affective influence on time passing.

Arousal in Time Perception

Past research has also suggested that arousal may drive changes in time perception, with highly arousing stimuli slowing the perception of time (Droit-Volet et al., 2004; Effron et al., 2006; Noulhiane et al., 2007; Tipples, 2008; Mella et al., 2011; Gil and Droit-Volet, 2012; Fayolle et al., 2015). Recent research has explored the connectedness of bodily mechanisms, such as being aware of one's arousal state through heart rate (Di Lernia et al., 2018). However, results of this theory result in varied outcomes in regard to arousing stimuli and experience (Droit-Volet and Gil, 2016; Di Lernia et al., 2018). One reason for the inconsistent outcomes may be that past work has failed to operationalize arousal. Arousal might manifest as a subjective experience or a physiological response. This has led some researchers to conclude that arousal is "too broad of a concept to predict behavior, or indeed to convey meaning" (Neiss, 1990, p.101).

In addition, it is likely that past research has confounded arousal with motivation. For example, positive affects such as desire and negative affects such as anger are both high in arousal but are opposite in motivational direction (approach vs. withdrawal). Approach-motivated positive affects high in arousal hastened time perception relative to withdrawal-motivated negative affects high in arousal (Gable and Poole, 2012). In addition, directly manipulating approach motivation within two negative affects (i.e., sadness and anger) caused time to hasten (Gable et al., 2016), contradicting predictions of the arousal-based model of time perception.

However, because arousal is often used as a proxy for motivation (Bradley and Lang, 2007), research cannot completely rule out arousal as an explanation for changes in time perception. Future research should clarify what type of arousal is being measured or manipulated (i.e., subjective or physiological). Further, research should more closely examine whether motivation, but not arousal, *per se*, mediates the relationship between affect and time perception.

SUMMARY

The current review demonstrates that positive and negative affects varying in motivational direction have diverse effects on time perception. Both positive and negative affects related to approach motivation hasten time perception, whereas negative affects related to withdrawal motivation slow time perception. These results suggest that motivational direction, rather than affective valence and arousal, drive changes in time perception.

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All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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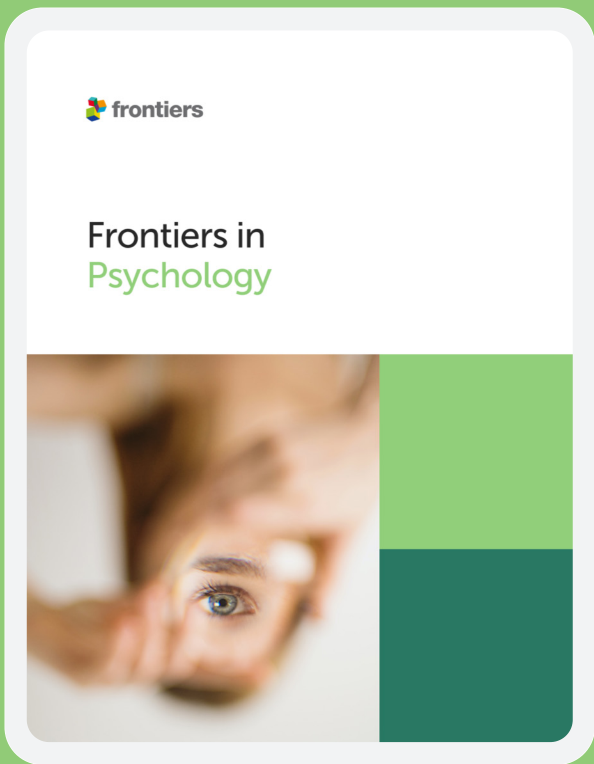

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