

**The user wants me to translate a Chinese academic title to English. Let me analyze the requirements: 1. This is a title, not a full paper with paragraphs 2. There are no LaTeX commands, placeholders, or citation commands 3. There are no ...tags 4. It's a single line of text 5. I need to use acad...**

**Authors:** The user has provided a very short input: “杨周”. This appears to be a Chinese name. The task is to translate from Simplified Chinese to English with the highest accuracy and academic tone, following all the critical requirements and output rules.

Let me analyze the input: - It's just two characters: “杨周” - This is a Chinese name, likely a person's name - In Chinese names, the family name comes first, followed by the given name - “杨” (Yáng) is a common Chinese surname - “周” (Zhōu) is another common Chinese surname, but can also be a given name

Given the context of academic paper translation, “杨周” could be: 1. A person's full name (surname + given name) 2. Two separate surnames referring to two different people (e.g., “Yang and Zhou” ) 3. Part of a citation or reference

Since there's no context provided, I need to make the most reasonable academic translation. In academic contexts, Chinese names are typically: - Translated using Pinyin - With the surname first, followed by the given name - Sometimes with the surname capitalized (YANG Zhou) or separated (Yang Zhou)

However, the most standard and widely accepted format in modern academic writing is to use Pinyin with proper capitalization: “Yang Zhou” where “Yang” is the surname and “Zhou” is the given name.

But wait, I need to check if there are any tags, LaTeX commands, or other structural elements. The input is just “杨周” with no tags, no LaTeX, no citations.

According to the output rules: - Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent) - Keep one output paragraph per input paragraph; do not merge or split paragraphs - Maintain exact count and IDs of ...tags

Since there are no tags in the input, I should not add any. The input is just a name, which could be considered a paragraph on its own.

The most accurate translation would be the Pinyin representation: “Yang Zhou”

However, I should consider if this might be two separate names. In Chinese academic writing, when listing multiple authors, it could be written as “杨周” meaning “Yang and Zhou”. But without any context or punctuation, this is ambiguous, Zhu Jiawen, Su Lin, The user has provided a single name: “熊明洁”. This is a Chinese name, and they want me to translate it. However, the instructions say I’m a professional scientific translator specializing in academic papers, and I need to preserve LaTeX commands, citation commands, and tags.

But the input is just a name. Let me think about what the user wants: 1. They might want the English transliteration of this Chinese name 2. They might want me to treat this as a test case 3. They might have made a mistake and only sent a name

Given the context of the instructions (academic paper translation, preserving structural elements), and that the input is just “熊明洁” without any tags, LaTeX, or citations, I should:

1. Provide the standard English transliteration of the name
2. Since there are no tags in the input, I don’t need to add any
3. Follow the “OUTPUT RULES” which say “Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent).”

The name “熊明洁” is: - 熊 (Xióng) - surname - 明洁 (Míngjié) - given name

Standard transliteration would be “Xiong Mingjie” (with the surname first, as is common in academic contexts, or “Mingjie Xiong” if following Western name order).

In academic papers, Chinese names are typically: - Written in Pinyin - Surname first, given name second (preserving Chinese order) - Sometimes with given name hyphenated: “Xiong Ming-jie” or “Xiong Mingjie”

The most standard and widely accepted format in academic literature is “Xiong Mingjie” (surname first, no hyphen).

Since the input is just a name and there are no structural tags, I should just provide the transliterated name as the output, with no additional formatting or explanation.

Let me check the instructions again: - “Return ONLY the translated text for the given input” - “Keep one output paragraph per input paragraph; do not merge or split paragraphs.” - “Maintain exact count and IDs of …tags”

Since there are no tags in the input, I don’t need to add any. The input is just a name, so the output should be just the transliterated name., The user has provided a name “Todd Jackson” and a set of instructions for translating

academic papers from Simplified Chinese to English. However, there is no actual Chinese text to translate. The instructions are very specific about preserving LaTeX commands, math placeholders, citation commands, and particularly the `...tags`.

Since there is no Chinese content provided, I should respond by indicating that no translation can be performed without the source text. However, I must follow the output rules which state “Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent).”

But there is no input text to translate. The user just gave a name “Todd Jackson” which doesn’t seem to be Chinese text requiring translation. This appears to be either a test or an incomplete request.

Given the constraints: 1. I must preserve all tags if they exist 2. I must only return translated text 3. I must not add explanations

Since there is no Chinese text with tags, I cannot produce a valid translation. The name “Todd Jackson” is already in English, so no translation is needed.

I should probably return nothing or indicate the issue, but the rules say “Return ONLY the translated text” . This is a contradictory situation.

Let me re-read the instructions carefully. The user provided: - A name “Todd Jackson” - Detailed translation instructions

The instructions say “Translate from Simplified Chinese to English” . Since “Todd Jackson” is not Simplified Chinese, there’s nothing to translate.

However, the system seems to be expecting me to follow the translation protocol. Perhaps this is a test to see if I follow the rules precisely.

The most appropriate response would be to note that no Chinese text was provided for translation. But the output rules explicitly state “Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent).”

This is a dilemma. If I provide an explanation, I violate the output rules. If I provide nothing, I might not be helpful.

Wait, let me reconsider. Perhaps “Todd Jackson” is meant to be the entire input, and I should treat it as already being in English, thus requiring no translation. In that case, the “translated text” would just be “Todd Jackson” itself.

But that seems too simplistic and doesn’t test any of the translation requirements.

Alternatively, maybe the user intended to paste Chinese text but forgot, Yang Zhou

**Date:** 2023-09-26T00:00:00+00:00

## Abstract

Using a dot-probe visual task and a visual task incorporating real pain stimuli, with pain-neutral and neutral-neutral pictures as experimental materials, we employed eye-tracking technology to measure dynamic gaze bias indices toward pain cues in chronic pain patients and further examined the predictive role of these indices on changes in chronic pain intensity and functional impairment six months later. The study found that in the dot-probe visual task, chronic pain patients exhibited significantly greater gaze bias toward pain cues compared to neutral cues during the first three time windows (0~500 ms, 500~1000 ms, 1000~1500 ms), but no difference was observed in the fourth time window (1500~2000 ms). In the visual task incorporating real pain stimuli, chronic pain patients showed significantly greater gaze bias toward pain cues than neutral cues across all four time windows. Both hierarchical standard multiple regression models and machine learning regression models found that the late-stage gaze bias toward pain cues in chronic pain patients across both tasks (in the two time windows of 1000~1500 ms and 1500~2000 ms) could independently predict the maintenance of chronic pain intensity and functional impairment six months later. The results indicate that although chronic pain patients exhibit gaze bias toward pain cues from early stages of attention, only late-stage gaze bias can predict the maintenance of chronic pain.

## Full Text

### Preamble

#### **The Gaze Biases Towards Pain-Related Information During the Late Stages Predict the Persistence of Chronic Pain: Evidence from Eye Movements**

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### Abstract

Using a dot-probe visual task and a visual task incorporating real pain stimulation, with pain-neutral and neutral-neutral picture pairs as experimental materials, this study employed eye-tracking technology to measure dynamic gaze bias indices for pain cues in chronic pain patients and further examined the predictive role of these indices on changes in chronic pain intensity and functional impairment six months later. The study found that in the dot-probe visual task, chronic pain patients exhibited significantly greater gaze bias toward pain cues than neutral cues during the first three time windows (0-500 ms, 500-1000 ms, 1000-1500 ms), but no difference was observed in the fourth time window (1500-

2000 ms). In the visual task incorporating real pain stimulation, chronic pain patients showed significantly greater gaze bias toward pain cues than neutral cues across all four time windows. Both hierarchical standard multiple regression models and machine learning regression models revealed that late-stage gaze bias toward pain cues (1000-1500 ms and 1500-2000 ms time windows) in both tasks independently predicted the maintenance of chronic pain intensity and functional impairment six months later. These results indicate that although chronic pain patients demonstrate gaze bias toward pain cues from early attentional stages, only late-stage gaze bias predicts the maintenance of chronic pain.

**Keywords:** chronic pain, pain intensity, functional impairment, gaze bias, eye tracking

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## 1. Introduction

Pain is a complex multidimensional subjective experience elicited by actual or potential noxious stimuli, comprising sensory-discriminative, affective-motivational, cognitive-evaluative, and behavioral response components (Price, 2000). When pain persists or recurs for more than three months, it becomes chronic pain. Chronic pain has a high prevalence and imposes substantial negative impacts on patients, families, and society. Chronic pain patients may exhibit “chronic pain syndrome,” characterized by high levels of work-related physical impairment, emotional distress, sleep disturbances, analgesic medication abuse or addiction, and excessive utilization of healthcare resources (Jensen & Turk, 2014).

In addition to physiological factors such as tissue damage and chronic disease, psychological factors are considered important etiological agents in chronic pain. Maintaining visual fixation on or avoidance of specific environmental cues is key to the emergence and development of various psychosomatic disorders (Armstrong & Olatunji, 2012). In recent years, researchers have suggested that attentional bias toward pain cues may play an important role in the formation and development of chronic pain (Jackson et al., 2019).

### 1.1 Theoretical Models of Attentional Bias to Pain Cues

The early classic Fear-Avoidance Model (Asmundson et al., 2004) explored the internal mechanisms underlying pain-related attentional bias from the perspective of pain fear as an emotional trait. Pain experiences cause individuals to develop fear of pain and related cues, prompting them to adopt various measures to avoid pain and reduce potential pain experiences. Compared to individuals

with low pain fear, those with high pain fear are more likely to develop attentional vigilance to pain cues, thereby triggering more avoidance behaviors (Yang Zhou et al., 2016; Vlaeyen & Linton, 2012). However, persistent avoidance behaviors reinforce attentional bias toward pain cues, intensify pain experiences, and consequently lead to pain chronicity. Chronic pain patients maintain a state of excessive sensitivity and fear toward pain cues over the long term, which disrupts normal physical and mental functioning.

Attentional Control Theory posits that cognitive resources are limited, and individuals maintain attention on current tasks by inhibiting interfering stimuli through attentional control (Wei Hua & Zhou Ren-Lai, 2019; Eysenck et al., 2007). The Visual Attentional Bias Competition Model indicates that attentional control operates in two ways: bottom-up and top-down attentional control (Desimone & Duncan, 1995). The former is primarily driven by stimulus properties, while the latter relates to individual goals and expectations. Typically, these two control modes interact and remain in balance. As a threat source, pain triggers stimulus-driven attentional control systems, directing attention to danger to protect individuals from injury or reduce harm, which has adaptive significance for survival. However, for chronic pain patients, excessive attention to pain and related cues may no longer be adaptive but instead lead to pain persistence and exacerbation (Sun Ze-Kun et al., 2015; Jackson et al., 2019).

In recent years, Todd et al. (2015) proposed the Threat Appraisal Model, which suggests that attentional bias toward pain cues promotes increased pain sensitivity and exacerbation of pain symptoms. Whether individuals exhibit attentional bias toward pain cues, and whether the component of this bias is avoidance or maintenance, depends on the salience meaning of pain cues. When pain cues are appraised as low threat, their salience meaning is small, and attentional bias manifests as attentional maintenance; when pain cues are appraised as high threat, individuals are more likely to develop attentional avoidance of pain cues due to fear. However, this theory awaits empirical testing.

## **1.2 Attentional Processing Bias Toward Pain Cues in Chronic Pain Patients**

Early studies using reaction time indices found that chronic pain patients exhibit attentional bias toward pain cues, primarily in middle and late attentional stages (Sun Ze-Kun et al., 2014; Crombez et al., 2013; Todd et al., 2018). Attentional bias toward pain cues in chronic pain patients does not depend on early attentional processing but is importantly related to refined conscious processing in sustained attention stages (Crombez et al., 2013; Schoth et al., 2012; Todd et al., 2018). For example, Crombez et al. (2013) conducted a meta-analysis of 18 reaction time-based studies and found that when pain cue presentation time was less than 1000 ms, no difference in attentional bias existed between chronic pain patients and healthy individuals; however, when presentation time exceeded 1000 ms, patients showed significant attentional bias toward pain cues,

with significant differences from healthy individuals. Schoth et al. (2012) meta-analyzed studies using dot-probe tasks and found that when pain cue presentation time exceeded 1250 ms, chronic pain patients showed significant attentional maintenance tendencies toward pain cues compared to healthy groups. Todd et al. (2018) also meta-analyzed 52 studies using dot-probe paradigms and found that chronic pain patients indeed exhibited attentional bias toward pain cues, manifesting as attentional maintenance.

Reaction time indices can only indirectly reflect attentional processing and suffer from insufficient precision (Schoth et al., 2012), whereas eye-tracking technology provides direct, dynamic visual attention information during stimulus presentation (Yang et al., 2012, 2013). In recent years, multiple studies have used eye-tracking technology to examine pain cue-related attentional bias. A recent review summarized this research, including 24 eye-tracking studies with a total of 1,424 participants, 13 of which included 486 chronic pain patients (Chan et al., 2020). Results showed that for early attentional maintenance indices—namely first fixation duration on pain cues—most studies found no differences between chronic pain patients’ fixations on pain versus neutral cues, nor differences between pain-free healthy individuals’ fixations on the two cue types (Lioffi et al., 2014; Mahmoodi-Aghdam et al., 2017; Mazidi et al., 2021; Sharpe et al., 2017; Sun et al., 2016; Todd et al., 2016; Vervoort et al., 2013; Yang et al., 2012, 2013). For total fixation time indices, some studies found that chronic pain patients’ total fixation time on pain cues was significantly longer than on neutral cues (Jackson et al., 2018b, 2019; Lee et al., 2019), while others found the same pattern in healthy groups (Jackson et al., 2018a; Ling et al., 2019; Pilch et al., 2020). Notably, most studies found no differences in gaze patterns between chronic pain patients and pain-free healthy individuals toward pain cues (e.g., pain-related words, facial expressions, and daily activity pictures) (Giel et al., 2018; Mahmoodi-Aghdam et al., 2017; Mazidi et al., 2021; Yang et al., 2013). These studies failed to find differences in attentional bias between chronic pain patients and healthy groups, possibly because pain cues, as salient environmental information, are prioritized by both chronic pain patients and pain-free healthy individuals. However, differences in attentional processing between the two groups may exist at specific stages of the attentional process. The aforementioned studies used total gaze bias indices, which cannot reflect dynamic changes in gaze patterns. The time course of gaze bias is uneven, and using time window segmentation can examine the dynamic process of attentional bias. Studies using this method have found that chronic pain patients show gaze differences between pain and neutral cues, with significant differences from pain-free individuals. For example, Lee et al. (2018) found that chronic pain patients’ fixation time on pain expression pictures in middle and late stages (500–3000 ms) was significantly higher than on neutral pictures, with no differences in early attention (0–500 ms). Other studies found that chronic pain patients had longer fixation times on pain cues during the 1000–2000 ms time window than healthy groups (Fashler & Katz, 2016). However, some studies using this method found no differences between chronic pain patients and

healthy groups (Fashler & Katz, 2014; Mazidi et al., 2021).

Inconsistent findings in chronic pain-related attentional bias research may also result from most studies presenting only visual pain cues without integrating real pain stimulation, which does not match patients' real-life situations and thus fails to effectively elicit attentional bias toward pain cues. Typically, pain cues appear accompanied by pain experiences, which enhance the threat level of pain cues. Chronic pain patients may be more likely to show obvious attentional bias toward cues accompanied by pain experiences. Jackson et al. (2018b) used both visual-only tasks and visual tasks incorporating real pain stimulation to examine chronic pain patients' gaze bias toward pain cues. However, this study used total gaze bias indices, leaving unknown whether chronic pain patients' gaze bias toward pain cues exists throughout the entire gaze process or only at specific stages. Therefore, this study will adopt these two paradigms, combined with time window segmentation, to further explore chronic pain patients' gaze bias toward pain cues and its dynamic process.

### **1.3 Predictive Role of Pain Cue-Related Attentional Bias on Chronic Pain Development**

Attentional bias toward pain cues in chronic pain patients may influence chronic pain development. Several studies using reaction time indices have provided evidence (Chapman & Martin, 2011; Schoth et al., 2012; Sharpe et al., 2014; Van Ryckeghem et al., 2012). For example, Van Ryckeghem et al. (2012) tracked 74 chronic pain patients, measured attentional bias using a spatial cueing paradigm at baseline, and assessed patients' pain severity and functional impairment daily for two weeks, finding that stronger attentional bias toward pain cues predicted more severe daily pain later, though this effect disappeared after adding control variables. Stronger attentional bias toward pain cues was associated with stronger correlations between daily pain severity and functional impairment during the two-week tracking period. Sharpe et al. (2014) tracked 100 chronic back pain patients and found that baseline attentional bias toward affective pain words could predict chronic pain status three to six months later, while attentional bias toward sensory pain words related to functional impairment levels six months later. These reaction time-based studies suggest that pain cue-related attentional bias indices may relate to chronic pain development. Jackson et al. (2019) also found using eye-tracking indices that total fixation time on pain pictures could predict chronic pain development six months later. Longer total fixation time on pain cues predicted stronger maintenance of chronic pain intensity and functional impairment six months later. However, this study did not examine dynamic changes in attention. Whether all stages or only specific stages of gaze bias toward pain cues play a key role in chronic pain development remains unknown.

In summary, this study aims to combine dot-probe visual tasks and visual tasks incorporating real pain stimulation to further explore the dynamic process of chronic pain patients' gaze bias toward pain cues and its predictive role on

chronic pain development six months later.

In the pain-related attentional bias domain, Priebe et al. (2015) used a time window segmentation method, dividing the 2000 ms presentation of pain expression face pictures into four time windows (0–500 ms, 500–1000 ms, 1000–1500 ms, 1500–2000 ms) to examine dynamic gaze bias toward pain expression face pictures. This study will use this eye-tracking data analysis method to explore the dynamic process of chronic pain patients' gaze bias toward pain cues. Hierarchical standard multiple regression models and machine learning regression models will be used to examine the predictive role of pain cue gaze bias indices on chronic pain intensity and functional impairment six months later.

Based on previous research (Fashler & Katz, 2016; Lee et al., 2018; Mazidi et al., 2021), this study hypothesizes: (1) In the dot-probe visual task, chronic pain patients will show significantly greater gaze bias toward pain cues than neutral cues during middle and late attentional stages (500–1000 ms, 1000–1500 ms, 1500–2000 ms time windows); (2) In the visual task incorporating real pain stimulation, chronic pain patients will show significantly greater gaze bias toward pain cues than neutral cues throughout the entire attentional process (0–500 ms, 500–1000 ms, 1000–1500 ms, 1500–2000 ms time windows); (3) Gaze bias indices toward pain cues in middle and late stages (500–1000 ms, 1000–1500 ms, 1500–2000 ms time windows) can independently predict chronic pain intensity and functional impairment levels six months later.

## 2. Methods

### 2.1 Participants

GPower 3.1 was used to estimate the required sample size. With a significance level of  $\alpha = 0.05$  and an effect size  $f$  of 0.17, a total sample size of at least 49 was needed to achieve 95% statistical power. This study recruited 94 patients experiencing chronic musculoskeletal pain (69 women), such as neck, shoulder, and low back pain. Age ranged from 18 to 71 years ( $M = 27.45$ ,  $SD = 11.53$ ), and 83% of participants had high school education or higher. Mean pain duration was 39.14 months ( $SD = 66.27$ , range: 3 to 462 months). Some participants took analgesic medication to reduce pain. To minimize drug effects on experimental results, participants were required to stop using analgesics one day before the experiment. Participants had normal or corrected-to-normal vision and no neurological or psychiatric disorders affecting comprehension.

### 2.2 Apparatus and Materials

**2.2.1 Eye Tracker** An Eyelink 1000 eye tracker manufactured by SR Research (Canada) was used in remote mode with a sampling rate of 500 Hz. Spatial accuracy was  $\leq 0.5^\circ$ , and resolution was  $\leq 0.01^\circ$ . Pictures were presented on a 23.6-inch 60 Hz screen connected to an 8-GHz Dell computer. Participants sat 70 cm from the screen, forming a horizontal-vertical viewing area. Participants were asked to minimize head movements during the experiment to ensure

accurate eye tracking. A standardized calibration procedure was conducted before the formal experiment. During formal tasks, eye movement temporal and spatial information was recorded throughout picture presentation in each trial.

**2.2.2 Pain Stimulation** An electrical stimulator was used to induce pain stimulation, connected to stainless steel copper-core bipolar electrodes—a cylindrical anode ( $\varnothing$ : 1.4 mm) surrounding a needle cathode (length: 0.1 mm,  $\varnothing$ : 0.2 mm). The induced single pain stimulus was a constant current pulse lasting 0.5 ms, producing a needle-prick-like pain sensation. The electrode was placed on participants' left forearm. Each participant's pain threshold current value was tested using methods based on those employed by Yang et al. (2016). In the visual task incorporating real pain stimulation, the delivered electrical stimulation was three times the pain threshold current value, inducing a clear needle-prick pain sensation.

**2.2.3 Picture Materials** Pain and neutral pictures used in previous research were adopted as stimulus materials (Meng et al., 2012). Pictures depicted common daily scenes such as cutting vegetables or paper trimming, with some showing injury images and others showing painless versions of the same scenes. This study used 16 pain pictures and 48 neutral pictures, with 16 neutral pictures paired with pain pictures and the remaining 32 neutral pictures forming 16 neutral-neutral pairs. Each single picture measured 11 cm  $\times$  10 cm, with a viewing angle of  $8.99^\circ \times 8.17^\circ$ . Images appeared on a black screen background, distributed symmetrically on both sides of the screen, with 10 cm between the two pictures in each pair. Brightness, contrast, color, and clarity were standardized for each picture. Each pair was matched in content and perceived motion. Pain pictures evoked significantly higher pain intensity, negative valence, and arousal than neutral pictures.

### 2.3 Questionnaires

**Chronic Pain Grade Scale-Chinese Version (Wong & Fielding, 2011)** measured chronic pain intensity and functional impairment. Pain intensity was calculated as the sum of three items: current pain, worst pain, and average pain over the past three months. Each item was rated on a scale from 1 (no pain at all) to 10 (unbearable pain). Functional impairment was calculated as the sum of three items: impairment in daily activities, social activities, and work/learning ability. Each item was rated from 1 (no hindrance at all) to 10 (cannot perform any activity). In this study, Cronbach's  $\alpha$  was 0.79 at baseline and 0.76 at six months for the pain intensity subscale, and 0.88 at baseline and 0.82 at six months for the functional impairment subscale.

**Pain Catastrophizing Scale (Sullivan et al., 1995)** contains 13 items assessing pain catastrophizing characteristics, including rumination, magnification, and helplessness. Items are rated from 0 (never) to 4 (always) and summed to calculate total pain catastrophizing. The scale's factor structure and validity

have been validated in Chinese samples (Yap et al., 2008). Cronbach' s  $\alpha$  was 0.94 in this study.

**Center for Epidemiologic Studies Depression Scale (Yen et al., 2009)** contains 20 items assessing the frequency of specific depressive symptoms experienced in the past week. The scale is rated from 0 (rarely or none of the time, less than 1 day) to 3 (most of the time, 5-7 days), with items summed to calculate total depression score. The scale' s factor structure, reliability, and validity have been validated in Chinese samples (Yen et al., 2009). Cronbach' s  $\alpha$  was 0.93 in this sample.

Demographic data included age, gender, education level, primary pain site, pain duration, and current analgesic medication use.

## 2.4 Experimental Tasks

**2.4.1 Task 1: Dot-Probe Visual Task** Instructions were presented orally and on-screen. Each trial began with a “+” fixation point presented at the center of the computer screen for 1000 ms, followed by pictures for 2000 ms. During picture presentation, participants were instructed to freely view the pictures. The eye tracker recorded eye movement information throughout picture presentation. After picture offset, a probe appeared at the location of one of the pictures, and participants were required to quickly and accurately judge the probe' s location by pressing the “A” or “L” key for left or right, respectively. The probe disappeared after the participant' s response or after 3000 ms. Finally, a 300 ms blank screen ended the trial. The flowchart for a single trial is shown in Figure 1 [Figure 1: see original paper].

**Figure 1** Flowchart of a single trial in the dot-probe task

Participants then completed 8 practice trials, including 4 pain-neutral and 4 neutral-neutral picture pairs. Pictures used in the practice phase were not included in the formal experiment. The formal task consisted of 4 blocks, each containing 32 trials, for a total of 128 trials. Picture types included 16 pain-neutral and 16 neutral-neutral pairs, with each pair presented randomly 4 times. The positions of each picture pair and probe on the screen were balanced. The order of trials within blocks and the order of blocks were randomized. Participants rested for 1 minute between blocks.

**2.4.2 Task 2: Visual Task Incorporating Real Pain Stimulation** Task 2 was similar to Task 1, but instead of a probe following picture presentation, real pain stimulation might occur. Specifically, after pain-neutral picture pairs appeared, there was a 25% probability of electrical stimulation delivery; no stimulation followed neutral-neutral picture pairs. Participants were only informed that pain cues might be accompanied by electrical stimulation but were not told the specific probability. This task was consistent with those used in Jackson et al. (2018a, 2018b). To reduce task monotony, participants judged whether they

felt pain stimulation in each trial. Eye movements were recorded during picture presentation.

Instructions were presented orally and on-screen. Each participant's pain threshold was tested. The pain stimulation intensity used in the task was three times the individual's pain threshold. The flowchart for a single trial in the formal task is shown in Figure 2 [Figure 2: see original paper].

Each trial began with a "+" fixation point at the center of the screen for 1000 ms, followed by pictures for 2000 ms. After picture offset, a 300 ms blank screen appeared. When pain-neutral pictures appeared, 25% of trials were randomly selected to deliver a 10 ms pain stimulus. When neutral-neutral pictures appeared, no pain stimulus was delivered. Participants were required to quickly and accurately judge whether they felt pain stimulation by pressing the "1" or "2" key for yes or no, respectively. Key assignments were balanced between and within participants. The pain judgment interface disappeared after the participant's response or after 4000 ms. Finally, a 300 ms blank screen ended the trial.

**Figure 2** Flowchart of a single trial in the visual task incorporating real pain stimulation

During the task implementation phase, participants first completed 8 practice trials, including 4 pain-neutral and 4 neutral-neutral picture pairs. Pictures used in the practice phase were not included in the formal experiment. The formal task consisted of 128 trials divided into 4 blocks, with 32 trials per block. The order of trials within blocks, block order, picture presentation, and rest settings were the same as in Task 1.

## 2.5 Research Design and Procedure

Both tasks used a 2 (cue type: pain, neutral)  $\times$  4 (time window: 0-500 ms, 500-1000 ms, 1000-1500 ms, 1500-2000 ms) two-factor within-subjects design to measure chronic pain patients' gaze bias indices for pain cues across different time windows and further examine their predictive role on changes in chronic pain intensity and functional impairment six months later.

This study was approved by the Medical Ethics Committee of the Ninth People's Hospital of Chongqing. Participants were recruited through advertisements posted at university hospitals, community hospitals, and campus electronic bulletin boards. Inclusion criteria were chronic musculoskeletal pain lasting three months or more. After completing baseline chronic pain assessments, 94 participants completed laboratory tasks and a six-month follow-up assessment. Upon arriving at the laboratory, experimenters introduced the main experimental tasks to participants. Task 1 involved viewing pictures and responding to the location of a subsequent probe while eye movements were recorded throughout picture viewing. Task 2 involved viewing pictures, responding to whether pain stimulation occurred, while eye movements were recorded throughout picture

viewing. After signing informed consent, the formal experiment began, requiring approximately 45 minutes to complete. Participants received monetary compensation after the experiment. Six months later, experimenters contacted each participant to reassess chronic pain intensity and functional impairment.

## 2.6 Data Analysis

This study primarily analyzed eye movement indices during picture presentation in Tasks 1 and 2. The 2000 ms picture presentation was divided into four time windows: 0–500 ms, 500–1000 ms, 1000–1500 ms, and 1500–2000 ms. The picture area in each time window served as the region of interest, with total fixation time within the region used for subsequent data analysis. The gaze bias index was calculated by subtracting total fixation time on paired neutral pictures from total fixation time on target pictures (pain pictures in pain-neutral pairs; the first picture in neutral-neutral pairs) in each trial. The study also analyzed reaction time indices in Task 1 for pain-neutral and neutral-neutral pictures followed by probes consistent or inconsistent with target location. Because each picture pair was presented for 2 seconds (a relatively long duration), reaction time indices indirectly reflected gaze bias toward previous pictures, reducing index sensitivity, whereas eye movement indices directly reflected gaze bias toward pictures. Additionally, previous studies using this paradigm found no results for reaction time indices (Yang et al., 2012, 2013). Therefore, this study focused on analyzing and discussing eye movement indices during picture presentation.

First, separate 2 (cue type: pain, neutral)  $\times$  4 (time window: 0–500 ms, 500–1000 ms, 1000–1500 ms, 1500–2000 ms) repeated measures ANOVAs were conducted on gaze bias indices in Tasks 1 and 2 to measure gaze bias toward pain cues across the four time windows. A 2 (picture pair type: pain-neutral, neutral-neutral)  $\times$  2 (probe position: consistent, inconsistent) repeated measures ANOVA was conducted on reaction time indices in Task 1 to measure whether pain cues affected participants' reaction times for probe location judgment, thereby inferring attention allocation during pain cue presentation. ANOVA results were corrected using Bonferroni correction. Then, bivariate correlation analyses were conducted to examine relationships among demographic variables, depression, pain catastrophizing, chronic pain intensity, chronic pain functional impairment, gaze bias indices for pain cues across four time windows in both tasks, probe reaction time indices in Task 1, and chronic pain intensity and functional impairment six months later. Based on correlation results, hierarchical standard multiple regression models and machine learning regression models were used to evaluate the predictive effects of gaze bias indices for pain cues across different time windows and probe reaction time indices on chronic pain intensity and functional impairment six months later. In hierarchical standard multiple regression models, significant baseline variables (chronic pain intensity or functional impairment, demographic variables) were entered in Step 1, significant psychometric variables in Step 2, and significant gaze bias in-

indices for pain cues across different time windows and probe reaction time indices were entered separately in Step 3 to test the independent predictive effects of pain cue gaze bias indices on chronic pain intensity and functional impairment. In machine learning regression models, 94 samples from participants served as training data. Significant gaze bias indices for pain cues across different time windows and probe reaction time indices were used as input features, along with significant psychometric variables. Six-month pain intensity and functional impairment served as target variables. Using Python 3.11.3 with sklearn 1.2.2, five regression models were constructed: Random Forest, Support Vector Machine, K-Nearest Neighbors, Multi-Layer Perceptron, and Least Absolute Shrinkage and Selection Operator, to test the predictive effects of each significant pain cue gaze bias index and probe reaction time index on six-month chronic pain intensity and functional impairment.

### 3. Results

#### 3.1 Gaze Bias Toward Pain Cues

**3.1.1 Task 1: Dot-Probe Visual Task** A  $2$  (cue type: pain, neutral)  $\times$  4 (time window: 0-500 ms, 500-1000 ms, 1000-1500 ms, 1500-2000 ms) repeated measures ANOVA was conducted with gaze bias index as the dependent variable. Descriptive data are shown in Table 1. Heat maps of attention allocation across the four time windows during pain-neutral picture presentation are shown in Figure 3(A). Results showed a significant main effect of cue type,  $F(1, 93) = 88.36$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.49$ . Pairwise comparisons indicated that participants' gaze bias toward pain cues ( $M = 49.63$ ,  $SE = 4.97$ ) was significantly greater than toward neutral pictures ( $M = 2.10$ ,  $SE = 1.79$ ). The main effect of time window was significant,  $F(3, 91) = 54.88$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.64$ . Pairwise comparisons showed that gaze bias in the second time window ( $M = 56.87$ ,  $SE = 4.00$ ) was significantly greater than in the first ( $M = 10.15$ ,  $SE = 1.40$ ), third ( $M = 22.00$ ,  $SE = 4.89$ ), and fourth time windows ( $M = 14.43$ ,  $SE = 4.87$ ). The interaction between cue type and time window was significant,  $F(3, 91) = 59.62$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.66$ . Simple effects analysis showed that, as depicted in Figure 4 Figure 4: see original paper, gaze bias toward pain cues was significantly greater than toward neutral cues in the first, second, and third time windows ( $ps < 0.001$ ), but no difference existed in the fourth time window ( $p = 0.39$ ).

A  $2$  (cue type: pain-neutral, neutral-neutral)  $\times$  2 (probe position: consistent, inconsistent) repeated measures ANOVA was conducted with reaction time as the dependent variable. Reaction times for pain-neutral and neutral-neutral pictures followed by probes consistent or inconsistent with target location were:  $M(\text{pain-neutral, consistent}) = 615.37$  ms,  $SD = 132.39$ ;  $M(\text{pain-neutral, inconsistent}) = 608.02$  ms,  $SD = 122.96$ ;  $M(\text{neutral-neutral, consistent}) = 607.15$  ms,  $SD = 120.14$ ;  $M(\text{neutral-neutral, inconsistent}) = 605.25$  ms,  $SD = 129.14$ . Results showed no significant main effect of cue type,  $F(1, 93) = 1.30$ ,  $p = 0.26$ , no significant main effect of probe position,  $F(1, 93) = 1.17$ ,  $p = 0.28$ , and no significant interaction between cue type and probe position,  $F(1, 93) = 0.43$ ,  $p$

= 0.51.

**3.1.2 Task 2: Visual Task Incorporating Real Pain Stimulation** A 2 (cue type: pain, neutral)  $\times$  4 (time window: 0-500 ms, 500-1000 ms, 1000-1500 ms, 1500-2000 ms) repeated measures ANOVA was conducted with gaze bias index as the dependent variable. Descriptive data are shown in Table 1. Heat maps of attention allocation across the four time windows during pain-neutral picture presentation are shown in Figure 3 Figure 3: see original paper. Results showed a significant main effect of cue type,  $F(1, 93) = 83.76$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.47$ . Pairwise comparisons indicated that participants' gaze bias toward pain cues ( $M = 52.40$ ,  $SE = 5.30$ ) was significantly greater than toward neutral pictures ( $M = 4.28$ ,  $SE = 1.13$ ). The main effect of time window was significant,  $F(3, 91) = 22.53$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.43$ . Pairwise comparisons showed that gaze bias in the second time window ( $M = 55.76$ ,  $SE = 6.67$ ) was significantly greater than in the first ( $M = 6.64$ ,  $SE = 1.25$ ), third ( $M = 32.11$ ,  $SE = 4.69$ ), and fourth time windows ( $M = 18.86$ ,  $SE = 4.40$ ). The interaction between cue type and time window was significant,  $F(3, 91) = 19.37$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.39$ . Simple effects analysis showed that, as depicted in Figure 4 Figure 4: see original paper, gaze bias toward pain cues was significantly greater than toward neutral cues across all four time windows ( $ps \leq 0.046$ ).

**Table 1** Fixation Durations (ms) on Pain and Neutral Cues in Chronic Pain Patients

Time Window	0-500 ms M (SD)	500-1000 ms M (SD)	1000-1500 ms M (SD)	1500-2000 ms M (SD)
<b>Task 1:</b>				
<b>Dot- Probe Visual Task</b>				
Pain-Neutral Pictures	82.52 (27.96)	264.47 (61.59)	226.26 (60.44)	211.80 (58.31)
Neutral-Neutral Pictures	63.81 (28.87)	148.23 (43.71)	181.20 (54.15)	193.30 (59.40)
Pain Cue Gaze Bias	18.70 (22.23)	116.24 (73.37)	45.06 (83.36)	18.50 (83.71)

Time Window	0-500 ms M (SD)	500-1000 ms M (SD)	1000-1500 ms M (SD)	1500-2000 ms M (SD)
<b>Task 2: Visual Task In- corpo- rating Real Pain Stimu- lation</b>				
Pain-Neutral Pictures	90.80 (29.75)	271.43 (53.08)	245.50 (56.90)	227.85 (48.48)
Neutral-Neutral Pictures	81.58 (33.05)	163.98 (104.21)	186.61 (57.43)	193.80 (46.96)
Pain Cue Gaze Bias	9.23 (18.34)	107.45 (124.90)	58.88 (84.31)	34.05 (74.51)

**Figure 3 [Figure 3: see original paper]** Heat maps of chronic pain patients' fixations on pain-neutral pictures across four time windows in Task 1 (Figure A) and Task 2 (Figure B)

**Figure 4 [Figure 4: see original paper]** Gaze bias toward pain cues across four time windows in chronic pain patients for Task 1 (Figure A) and Task 2 (Figure B) (\*  $p < .05$ ; \*\*\*  $p \leq .001$ )

### 3.2 Correlation Analysis of Six-Month Chronic Pain Intensity and Functional Impairment with Baseline Variables

Correlations between six-month chronic pain intensity and functional impairment with baseline chronic pain intensity, baseline functional impairment, age, pain catastrophizing, depression, and gaze bias indices for pain cues across different time windows in both tasks are shown in Table 2 .

Six-month chronic pain intensity and functional impairment showed significant correlations with baseline chronic pain intensity, baseline functional impairment, age, and pain catastrophizing ( $r_s > 0.22$ ,  $p_s < 0.03$ ). Patients who were older and had higher pain catastrophizing scores reported higher chronic pain intensity and functional impairment six months later. The correlation between six-month chronic pain intensity and baseline depression was not significant ( $p = 0.22$ ), but the correlation between six-month functional impairment and baseline depression was significant ( $r = 0.20$ ,  $p = 0.05$ ), indicating that patients

with higher depression levels reported greater functional impairment six months later.

Six-month chronic pain intensity and functional impairment showed no significant correlations with gaze bias indices for pain cues in the first two time windows (0-500 ms, 500-1000 ms) across both tasks ( $r_s < 0.17$ ,  $p_s > 0.11$ ), but showed significant correlations with gaze bias indices in the last two time windows (1000-1500 ms, 1500-2000 ms) across both tasks ( $r_s > 0.22$ ,  $p_s < 0.04$ ). Specifically, chronic pain patients who showed stronger gaze bias toward pain cues in the third and fourth time windows of both tasks reported higher pain intensity and functional impairment six months later. No significant correlations were found between six-month chronic pain intensity or functional impairment and probe reaction time indices in Task 1 ( $r_s < 0.03$ ,  $p_s > 0.16$ ).

### 3.3 Predictive Models for Six-Month Chronic Pain Intensity and Functional Impairment

Hierarchical standard multiple regression models were constructed for six-month chronic pain intensity and functional impairment (see Table 3). Based on correlation analysis results, in the chronic pain intensity regression model, baseline pain intensity and age were entered in Step 1, pain catastrophizing in Step 2, and gaze bias values for pain cues in the third and fourth time windows from both tasks were entered separately in Step 3 to examine the independent predictive effects of different time window gaze bias indices on six-month chronic pain intensity (see sub-models 1-4 in Model 1). Models 1 and 2 assessed the predictive effects of gaze bias indices for pain cues in the third and fourth time windows (1000-1500 ms, 1500-2000 ms) of Task 1, along with other baseline variables, on chronic pain changes. The models showed that after controlling for other relevant variables, gaze bias indices for pain cues in the third and fourth time windows (1000-1500 ms, 1500-2000 ms) of Task 1 significantly predicted six-month chronic pain intensity (see Figure 5 [Figure 5: see original paper]),  $\beta = 0.01$ ,  $t = 2.45$ ,  $p = 0.05$ ,  $\Delta R^2 = 0.05$  (Model 1),  $\beta = 0.02$ ,  $t = 3.39$ ,  $p = 0.02$ ,  $\Delta R^2 = 0.08$  (Model 2). Models 3 and 4 assessed the predictive effects of gaze bias indices for pain cues in the third and fourth time windows (1000-1500 ms, 1500-2000 ms) of Task 2, along with other baseline variables, on chronic pain changes. Consistent with Models 1 and 2, after controlling for other relevant variables, gaze bias indices for pain cues in the third and fourth time windows (1000-1500 ms, 1500-2000 ms) of Task 2 also significantly predicted six-month chronic pain intensity (see Figure 5 [Figure 5: see original paper]),  $\beta = 0.01$ ,  $t = 2.94$ ,  $p = 0.004$ ,  $\Delta R^2 = 0.07$  (Model 3),  $\beta = 0.01$ ,  $t = 2.65$ ,  $p = 0.01$ ,  $\Delta R^2 = 0.05$  (Model 4).

In the chronic pain functional impairment regression model, based on correlation analysis results, baseline functional impairment and age were entered in Step 1, pain catastrophizing and depression in Step 2, and gaze bias values for pain cues in the third and fourth time windows from both tasks were entered separately in Step 3 to examine the independent predictive effects of different time window

gaze bias indices on six-month functional impairment (see sub-models 5–8 in Model 2). Models 5 and 6 assessed the predictive effects of gaze bias indices for pain cues in the third and fourth time windows (1000–1500 ms, 1500–2000 ms) of Task 1, along with other baseline variables, on functional impairment. The models showed that after controlling for other relevant variables, gaze bias indices for pain cues in the third and fourth time windows (1000–1500 ms, 1500–2000 ms) of Task 1 marginally significantly predicted six-month functional impairment (see Figure 5 [Figure 5: see original paper]),  $\beta = 0.01$ ,  $t = 1.88$ ,  $p = 0.06$ ,  $\Delta R^2 = 0.03$  (Model 5),  $\beta = 0.01$ ,  $t = 1.91$ ,  $p = 0.06$ ,  $\Delta R^2 = 0.03$  (Model 6). Models 7 and 8 assessed the predictive effects of gaze bias indices for pain cues in the third and fourth time windows (1000–1500 ms, 1500–2000 ms) of Task 2, along with other baseline variables, on functional impairment. Consistent with Models 5 and 6, after controlling for other relevant variables, gaze bias indices for pain cues in the third and fourth time windows (1000–1500 ms, 1500–2000 ms) of Task 2 significantly or marginally significantly predicted six-month functional impairment (see Figure 5 [Figure 5: see original paper]),  $\beta = 0.01$ ,  $t = 2.46$ ,  $p = 0.02$ ,  $\Delta R^2 = 0.04$  (Model 7),  $\beta = 0.01$ ,  $t = 1.88$ ,  $p = 0.06$ ,  $\Delta R^2 = 0.03$  (Model 8).

Machine learning regression models were used with gaze bias indices for pain cues in the third and fourth time windows of Tasks 1 and 2, along with baseline pain intensity, age, and pain catastrophizing as input features, and six-month pain intensity as the target variable. Results for the five machine learning regression models are shown in Table 4, with the Random Forest model performing best. Correlations between gaze bias indices for pain cues in the third and fourth time windows of Tasks 1 and 2 and six-month chronic pain intensity predictions generated by the machine learning regression models were all significant ( $r_s \geq 0.28$ ,  $p_s \leq 0.006$ ). Fit indices between predicted and actual results were good ( $R^2 \geq 0.88$ ,  $MSE \leq 2.01$ ). Using gaze bias indices for pain cues in the third and fourth time windows of Tasks 1 and 2, along with baseline functional impairment, age, pain catastrophizing, and depression as input features, and six-month functional impairment as the target variable, the five machine learning regression models were constructed (see Table 4). Again, the Random Forest model performed best. Correlations between gaze bias indices for pain cues in the third and fourth time windows of Tasks 1 and 2 and six-month functional impairment predictions were all significant ( $r_s \geq 0.23$ ,  $p_s \leq 0.02$ ). Fit indices between predicted and actual results were good ( $R^2 = 0.90$ ,  $MSE \leq 2.25$ ). Thus, Random Forest model results from machine learning were consistent with hierarchical standard multiple regression model results.

**Table 2** Correlations Between Six-Month Chronic Pain Intensity, Functional Impairment and Baseline Variables (N = 94)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Pain Intensity: 6 months	—														
2. Functional Impairment: 6 months	.72***														
3. Pain Intensity: Baseline	.42***	.38***													
4. Functional Impairment: Baseline	.43***	.55***	.72***												
5. Age	.30**	.35**	.30**	.26*	—										
6. Depression	.14	.20*	.30**	.35**	.11	—									
7. Pain Catastrophizing	.37***	.41***	.56***	.64***	.46***	.40***									

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<b>Task</b>															
<b>1:</b>															
<b>Dot- Probe</b>															
<b>Vi- sual Task</b>															
8.		.14	.17	.12	.13	.09	.03	.08	—						
Pain															
Gaze															
Bias															
(Time															
Win- dow															
1)															
9.		.17	.11	.12	.06	.08	.02	.07	.47***						
Pain															
Gaze															
Bias															
(Time															
Win- dow															
2)															
10.		.35***	.32***	.30***	.27***	.23*	.13	.27**	.18	.39***					
Pain															
Gaze															
Bias															
(Time															
Win- dow															
3)															
11.		.37***	.41***	.30***	.33***	.21*	.14	.26*	.14	.27***	.59***				
Pain															
Gaze															
Bias															
(Time															
Win- dow															
4)															

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<b>Task 2: Visual Task Incorporating Real Pain Stimulation</b>															
12. Pain Gaze Bias (Time Window 1)		.27**23*	.18	.16	.16	.08	.20*	.49**35**28**	.26*	—					
13. Pain Gaze Bias (Time Window 2)		.46**40**30**29**24*	.15	.30**31**48**40**45**53**											
14. Pain Gaze Bias (Time Window 3)		.28**27**23*	.24*	.18	.12	.24*	.22*	.34**40**38**44**59**							

Variable 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
15. Pain Gaze Bias (Time Win- dow 4)	.39**	<b>.44**</b>	<b>.26*</b>	<b>.33**</b>	<b>.21*</b>	.16	.29**	.16	.30**	<b>.53**</b>	<b>.48**</b>	<b>.40**</b>	<b>.53**</b>	<b>.72**</b>

Note: \*  $p \leq .05$ ; \*\*  $p \leq .01$ ; \*\*\*  $p \leq .001$ . Bolded values indicate significant correlations between eye movement indices and six-month chronic pain intensity or functional impairment.

**Table 3** Regression Analyses for Chronic Pain Intensity and Functional Impairment

Model	Step 1	Step 2	Step 3
<b>Model 1: Six-Month Pain Intensity</b>			
Sub-model 1	Pain Intensity: Baseline < 0.001	Pain Catastrophizing < 0.001	Pain Gaze Bias (Time Window 3, Task 1) 0.05
Sub-model 2	Pain Intensity: Baseline < 0.001	Pain Catastrophizing < 0.001	Pain Gaze Bias (Time Window 4, Task 1) 0.02
Sub-model 3	Pain Intensity: Baseline < 0.001	Pain Catastrophizing < 0.001	Pain Gaze Bias (Time Window 3, Task 2) 0.004
Sub-model 4	Pain Intensity: Baseline < 0.001	Pain Catastrophizing < 0.001	Pain Gaze Bias (Time Window 4, Task 2) 0.01
<b>Model 2: Six-Month Functional Impairment</b>			
Sub-model 5	Functional Impairment: Baseline < 0.001	Pain Catastrophizing < 0.001	Pain Gaze Bias (Time Window 3, Task 1) 0.06
Sub-model 6	Functional Impairment: Baseline < 0.001	Pain Catastrophizing < 0.001	Pain Gaze Bias (Time Window 4, Task 1) 0.06

Model	Step 1	Step 2	Step 3
Sub-model 7	Functional Impairment: Baseline < 0.001	Pain Catastrophizing < 0.001	Pain Gaze Bias (Time Window 3, Task 2) 0.02
Sub-model 8	Functional Impairment: Baseline < 0.001	Pain Catastrophizing < 0.001	Pain Gaze Bias (Time Window 4, Task 2) 0.06

Note: Models 1 and 2 test the independent predictive effects of pain cue gaze bias indices in different time windows on six-month chronic pain intensity and functional impairment, respectively. Steps 1 and 2 are identical across Models 1 and 2. Steps 3 (sub-models 1-4 and 5-8) test the predictive effects of pain cue gaze bias in the third and fourth time windows from Task 1 (dot-probe) and Task 2 (real pain stimulation) on chronic pain intensity and functional impairment changes. Bolded p-values emphasize significant or marginally significant main predictive results.

**Figure 5 [Figure 5: see original paper]** Predictive effects of pain cue gaze bias in the third and fourth time windows of Tasks 1 and 2 on chronic pain intensity and functional impairment

**Table 4** Machine Learning Regression Models for Chronic Pain Intensity and Functional Impairment

	Random Forest	Support Vector Machine	K-Nearest Neighbors	Multi-Layer Perceptron	Primary Predictors
<b>Six-Month Pain Intensity Prediction</b>					
r	.32***	.28**	.25*	.29**	.26* Pain Gaze Bias (Time Window 3, Task 1)

	Random Forest	Support Vector Machine	K-Nearest Neighbors	Multi-Layer Perceptron	LASSO	Primary Predictors
p	<.001	<.001	<.001	<.001	<.001	Pain Gaze Bias (Time Window 4, Task 1)
R <sup>2</sup>	.88	.85	.82	.86	.83	Pain Gaze Bias (Time Window 3, Task 2)
MSE	2.01	2.35	2.67	2.28	2.51	Pain Gaze Bias (Time Window 4, Task 2)
<b>Six-Month Functional Impairment Prediction</b>						
r	.28**	.24*	.22*	.25*	.23*	Pain Gaze Bias (Time Window 3, Task 1)
p	<.001	<.001	<.001	<.001	<.001	Pain Gaze Bias (Time Window 4, Task 1)
R <sup>2</sup>	.90	.87	.85	.88	.86	Pain Gaze Bias (Time Window 3, Task 2)

	Random Forest	Support Vector Machine	K-Nearest Neighbors	Multi-Layer Perceptron	LASSO	Primary Predictors
MSE	2.25	2.58	2.81	2.61	2.73	Pain Gaze Bias (Time Window 4, Task 2)

Note:  $r$  values and  $p$ -values indicate correlations and significance between pain cue gaze bias and predicted outcomes;  $R^2$  and MSE indicate fit indices between predicted and actual results.

#### 4. Discussion

Using dot-probe visual tasks and visual tasks incorporating real pain stimulation, this study measured the dynamic process of chronic pain patients' gaze bias toward pain cues and its predictive role on chronic pain development six months later. Results showed that in the dot-probe visual task, chronic pain patients exhibited significantly greater gaze bias toward pain cues than neutral cues during the first three time windows (0-500 ms, 500-1000 ms, 1000-1500 ms); in the visual task incorporating real pain stimulation, chronic pain patients showed significantly greater gaze bias toward pain cues than neutral cues across all four time windows (0-500 ms, 500-1000 ms, 1000-1500 ms, 1500-2000 ms). These results indicate that compared to the dot-probe visual task, patients' gaze maintenance bias toward pain cues was enhanced in the visual task incorporating real pain stimulation. Examining the magnitude of gaze bias across the four time windows in both tasks revealed that the attentional bias process toward pain cues in chronic pain patients was uneven, emerging in the first time window (0-500 ms), peaking in the second time window (500-1000 ms), then gradually decreasing in the third (1000-1500 ms) and fourth time windows (1500-2000 ms).

Further analyses using hierarchical standard multiple regression and machine learning regression models revealed that gaze bias indices for pain cues in the third (1000-1500 ms) and fourth time windows (1500-2000 ms) of both tasks predicted six-month chronic pain intensity and functional impairment. These predictive effects remained after controlling for baseline pain intensity, functional impairment, and other significant correlates. This indicates that greater late-stage gaze maintenance bias toward pain cues in chronic pain patients predicted higher reported pain intensity and functional impairment six months later. Although chronic pain patients exhibited gaze bias toward pain cues in early stages (0-500 ms, 500-1000 ms), particularly reaching peak bias values in the second time window (500-1000 ms), these early gaze bias indices did not predict chronic pain development. Notably, although in the dot-probe vi-

sual task, chronic pain patients showed no difference in gaze bias toward pain cues relative to neutral cues in the fourth time window (1500–2000 ms), it still demonstrated clear predictive effects on chronic pain development. Therefore, whether gaze bias toward pain cues differs from neutral cues and the magnitude of such differences may not significantly affect predictive power for chronic pain; rather, late-stage gaze maintenance bias toward pain cues can predict chronic pain development.

#### **4.1 Dynamic Process of Gaze Bias Toward Pain Cues in Chronic Pain Patients**

The study found that in the dot-probe visual task, chronic pain patients exhibited significantly greater gaze bias toward pain cues than neutral cues during the first three time windows (0–500 ms, 500–1000 ms, 1000–1500 ms). Chronic pain patients' attentional bias toward pain cues emerged from early attentional stages, maintained through middle and late stages, but disappeared in the final time window. The results for middle and late stage gaze bias toward pain cues were consistent with hypotheses. Inconsistent with hypotheses, gaze bias toward pain cues also appeared in early stages (0–500 ms). In the visual task incorporating real pain stimulation, chronic pain patients showed significantly greater gaze bias toward pain cues than neutral cues across all four time windows, meaning pain cue gaze bias persisted from early to late attentional stages, consistent with hypotheses. Real pain stimulation enhanced patients' gaze bias toward pain cues. These results for attentional bias toward pain cues in both tasks partially align with Lee et al. (2018), who found that chronic pain patients showed gaze bias toward pain expression pictures in middle and late stages (500–3000 ms) but not in early attention (0–500 ms). Multiple previous reaction time-based studies also indicated that attentional bias toward pain cues primarily appeared after longer presentation times. This discrepancy may be because, compared to Lee et al. (2018) who used a 300 Hz eye-tracking device, this study used a higher sampling rate device. Compared to reaction time indices, eye movement indices can more directly reveal initial attentional processing of cues.

Chronic pain patients' attentional maintenance tendency toward pain cues can be explained by Attentional Control Theory. Due to frequent exposure to pain cues and pain experiences, patients' automatic processing of pain cues keeps stimulus-driven attentional control systems frequently activated. Patients' life goals often focus on reducing or eliminating pain, with goal-driven attentional control systems constantly occupied by pain-related goals. However, attentional resources are limited. When pain occupies excessive attentional resources, patients struggle to control attention on more important daily goals. Patients' ability to resist task-irrelevant stimuli or shift attention based on task demands gradually declines, creating a vicious cycle where attention becomes more easily captured by pain cues and difficult to disengage from (Sun Ze-Kun et al., 2014; Jackson et al., 2019). Therefore, chronic pain patients exhibit attentional maintenance bias toward pain cues. These results also support the Fear-Avoidance Model

of pain, which hypothesizes that pain fear enhances patients' attentional bias toward pain cues, thereby avoiding activities that might trigger pain (Vlaeyen & Linton, 2012). Since this study did not directly collect perceived threat levels from chronic pain patients, whether Todd et al.'s (2015) Threat Appraisal Model can explain these results remains unknown. However, by comparing the visual dot-probe task and the visual task incorporating real pain stimulation, we can speculate that the visual dot-probe task, which only presents pain cues, has relatively lower threat level compared to the task incorporating real pain stimulation. Chronic pain patients showed gaze maintenance bias toward pain cues in this lower threat context. In the relatively higher threat context of the real pain stimulation task, patients did not show gaze avoidance toward pain cues as hypothesized by the model, but instead showed stronger gaze maintenance bias. Therefore, these findings may partially support Todd et al.'s (2015) Threat Appraisal Model.

Additionally, the Pain Schema Entanglement Model can explain chronic pain patients' gaze maintenance bias toward pain cues. Over time, patients' pain, illness, and self-schemas become entangled, leading chronic pain patients to enhance attentional bias toward schema-related cues and produce significant pain consequences that interfere with daily functioning (Pincus & Morley, 2001). The Misdirected Problem-Solving Model can also explain these results. Chronic pain patients, troubled by persistent pain, attempt various methods to alleviate pain, but continuous pain prevents pain relief goals from being achieved. Sustained attention to pain leads to hypervigilance and worry about pain cues, which in turn enhances attention to pain cues, creating a vicious cycle that exacerbates pain maintenance and development (Sun Ze-Kun et al., 2014).

#### 4.2 Gaze Bias Toward Pain Cues Predicts Chronic Pain Maintenance

The study found that gaze bias indices for pain cues in the third and fourth time windows (1000-1500 ms, 1500-2000 ms) of both the dot-probe visual task and the real pain stimulation visual task had significant or marginally significant predictive effects on six-month chronic pain intensity and functional impairment, and these effects remained after controlling for baseline pain indices and other relevant variables. This partially aligns with the hypothesis that gaze bias indices for pain cues in middle and late stages (500-1000 ms, 1000-1500 ms, 1500-2000 ms) could predict chronic pain development. Inconsistent with hypotheses, although chronic pain patients showed the strongest bias toward pain cues in the second time window (500-1000 ms), this stage's index did not predict chronic pain development. In summary, although chronic pain patients exhibited gaze maintenance bias toward pain cues in the first and second time windows (0-500 ms, 500-1000 ms), particularly reaching peak bias values in the second time window (500-1000 ms), these early gaze bias indices did not predict chronic pain development. Late-stage gaze maintenance tendency toward pain cues was an important predictor of chronic pain intensity and functional impairment. This differential result may occur because early vigilance to pain cues has impor-

tant adaptive significance for human survival and safety. Regardless of whether individuals have chronic pain, pain cues as salient threatening information in the environment attract attentional resources early on. Some eye-tracking studies have confirmed this, showing that in the early initial orienting stage, both chronic pain patients and pain-free healthy individuals exhibit gaze bias toward pain cues relative to neutral cues (Chan et al., 2020). Additionally, researchers have noted that attention to cues within the first 500 ms after visual cue onset is typically related to initial orienting, followed by attentional maintenance tendencies (Bradley et al., 2000). Early reaction time-based studies also found that chronic pain patients' attentional bias toward pain cues does not depend on early attentional processing but is importantly related to refined conscious processing in sustained attention stages (Crombez et al., 2013; Schoth et al., 2012). Differences between chronic pain and healthy groups in attentional bias toward pain cues mainly appear in middle and late stages, manifesting as attentional maintenance tendencies in chronic pain patients. Therefore, early gaze bias toward pain cues is not significantly associated with chronic pain development, whereas late-stage gaze bias has greater significance for chronic pain development.

This study examined attentional bias indices from all gaze stages, used both hierarchical standard multiple regression and machine learning regression models to explore the predictive effects of attentional bias indices, further clarifying and extending previous research (Jackson et al., 2019), and providing more specific predictive indices for chronic pain development in patients. This study employed two visual tasks with and without real pain stimulation. Task 1 only presented pain-related pictures, reflecting typical minor injuries occurring in daily life without producing potential or actual pain. Task 2 introduced pain warning information and real pain, making the experiment more ecologically valid. We can hypothesize that individuals who show high vigilance to pain cues in these tasks may have similar difficulties disengaging from external and internal pain cues in daily activities. Allocating more attentional resources to pain cues may lead to relatively poorer pain outcomes. Individuals frequently exposed to pain cues may become more sensitive to them, with attention becoming more difficult to disengage (Eysenck et al., 2007).

Attentional bias toward pain cues plays an important role in chronic pain maintenance and development. This study is the first to evaluate chronic pain patients' gaze bias toward pain cues at all stages and its risk for chronic pain prognosis. In chronic pain interventions, researchers have attempted to improve pain experiences through attentional bias modification training. Early researchers trained individuals to orient attention toward or away from pain-related information to alter chronic pain patients' pain experiences (Sharpe et al., 2012, 2015). Training patients to divert attention away from pain and related cues may be an effective way to improve pain experiences (Kreddig et al., 2022). Studies have conducted attentional bias modification training to weaken patients' attentional bias toward pain information and improve chronic pain (Carleton et al., 2011; Heathcote et al., 2018; Schoth et al., 2012; Sharpe et al., 2012, 2015). Attention

training has primarily used dot-probe tasks, with probes always appearing after neutral cues in pain-neutral pictures or words, guiding participants to allocate attentional resources to neutral rather than pain cues. For example, Sharpe et al. (2012) Study 1 conducted attention training with 27 chronic pain patients using 500 ms stimulus presentation, finding no significant difference in attentional bias between baseline and 3-month follow-up. In Study 2, researchers increased attention training to 4 sessions plus 8 weeks of CBT, using the same procedure as Study 1, yet still found no difference in attentional bias before and after training. Heathcote et al. (2018) also used dot-probe procedures to conduct 4 weeks of attention training with 23 chronic pain patients (2 sessions per week) using 500 ms stimulus presentation, finding no significant effect of attention training on attentional bias compared to placebo and no-training groups, and pain increased in the attention training group compared to controls after 3 months with no change in physical function. Schoth et al. (2012) used 1250 ms stimulus presentation and found that chronic pain patients' attentional bias decreased to near zero after 8 training sessions, with improved pain and functional impairment. These studies suggest that using shorter pain cue presentation times in attentional bias modification yields less obvious intervention effects, while longer presentation times may enhance therapeutic benefits. This aligns with our findings that late-stage gaze bias indices toward pain cues are closely related to chronic pain development, providing a reference for setting appropriate pain cue presentation durations in attentional bias modification. Future attentional bias modification training could extend pain cue presentation time to 2000 ms.

Furthermore, based on our results, we speculate that late-stage gaze maintenance bias toward pain cues could serve as an important observation index in attentional bias modification training—observing whether late-stage gaze bias toward pain cues changes may predict training effectiveness. Effective attentional bias modification may better improve chronic pain patients' attentional control over pain cues, thereby improving pain intensity, functional impairment, and emotional distress. Future research could further explore whether modifying late-stage gaze maintenance bias toward pain cues has intervention benefits for chronic pain.

This study has limitations. First, chronic pain patients were analyzed as a group without examining individual differences. For example, gender, age, and specific pain types may differ in gaze bias patterns. Future research could explore attentional bias in individuals with certain characteristics to generate greater therapeutic significance. Additionally, although we found that chronic pain patients exhibit gaze bias toward pain cues, participants' degree of self-involvement also affects gaze bias magnitude. For instance, whether pain cues related to one's own chronic pain site produce greater gaze bias warrants future investigation. Recently, researchers have examined neurophysiological indices of attentional bias toward pain cues (Fernandes-Magalhaes et al., 2022; Zhang et al., 2023). Future research could further examine predictive factors for chronic pain development and maintenance from neurophysiological perspectives and their intervention effects.

In summary, this study used eye-tracking technology combined with longitudinal methods, employing dot-probe visual tasks and visual tasks incorporating real pain stimulation, and using both hierarchical standard multiple regression and machine learning regression models to explore the dynamic process of chronic pain patients' gaze bias toward pain cues across four time windows and its predictive role on chronic pain development six months later, examining the gradual relationship between the dynamic process of gaze bias toward pain cues and chronic pain development. The main finding was that late-stage gaze maintenance bias toward pain cues (1000–1500 ms, 1500–2000 ms) predicted the maintenance of chronic pain intensity and functional impairment six months later.

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