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Interpretation biases and visual attention in the processing of ambiguous information in chronic pain

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Abstract

Background: Theories propose that interpretation biases and attentional biases might account for the maintenance of chronic pain symptoms, but the interactions between these two forms of biases in the context of chronic pain are understudied.

Methods: To fill this gap, 63 participants (40 females) with and without chronic pain completed an interpretation bias task that measures participants' interpretation styles in ambiguous scenarios and a novel eye-tracking task where participants freely viewed neutral faces that were given ambiguous pain/health-related labels (i.e. 'doctor', 'patient' and 'healthy people'). Eye movements were analysed with the Hidden Markov Models (EMHMM) approach, a machine-learning data-driven method that clusters people's eye movements into different strategy subgroups.

Results: Adults with chronic pain endorsed more negative interpretations for scenarios related to immediate bodily injury and long-term illness than healthy controls, but they did not differ significantly in terms of their eye movements on ambiguous faces. Across groups, people who interpreted illness-related scenarios in a more negative way also focused more on the nose region and less on the eye region when looking at patients' and healthy people's faces and, to a lesser extent, doctors' faces. This association between interpretive and attentional processing was particularly apparent in participants with chronic pain.

Conclusions: In summary, the present study provided evidence for the interplay between multiple forms of cognitive biases. Future studies should investigate whether this interaction might influence subsequent functioning in people with chronic pain.

1 | INTRODUCTION

Cognitive biases, including the tendency to negatively interpret ambiguous information, and the tendency to attend towards or away from concern-relevant stimuli, might underlie the chronicity of pain (Eccleston & Crombez, 1999; Todd et al., 2015; Vlaeyen & Linton, 2000). Although theories propose that different forms of cognitive biases might interact and together contribute to one's chronic pain (Crombez, Heathcote, & Fox, 2015; Todd et al., 2015), evidence regarding the associations between interpretive and attentional processing in chronic pain have been scarce. According to the threat interpretation model (Todd et al., 2015), the experience of pain, together with the extent to which pain-related information is interpreted as threatening, influence the presence of attentional biases. Nevertheless, to our knowledge, among the eye-tracking studies that investigate attentional biases in individuals experiencing chronic pain, none has assessed interpretation bias. This study provides the first such investigation.

Eye-tracking research in chronic pain frequently adopts pain-related/health-catastrophe words (e.g. blood, etc.) and pictures (e.g. pained faces, etc.) as visual stimuli (Fashler & Katz, 2016; Yang, Jackson, & Chen, 2013). While these stimuli are threat relevant to people with chronic pain, they might evoke similar responses in healthy controls due to the negative experience of pain. Few studies have investigated eye movements on stimuli that could be interpreted either positively, negatively or neutrally. Therefore, the present investigation adopted a novel paradigm where participants free-viewed neutral faces that were given pain/health-related labels (i.e. ‘doctor’, ‘patient’ and ‘healthy individual’). Compared to stimuli such as pained faces, neutral faces with identity labels might serve as ambiguous stimuli from which a viewer may infer pain/health-related information (e.g. do patients show evidence of contagious disease; do doctors have information about my disease state; are the supposedly healthy people showing signs of illnesses). Such stimuli therefore provide us with an opportunity to examine the interplay between a person's tendency to negatively interpret ambiguous information and the way in which they attend to stimuli that are conveying this information.

Additionally, although the mixed results in the eye-tracking literature could be attributed to within-group inter-subject variability in interpretation styles and the use of unambiguous stimuli, another limitation that might explain this inconsistency concerns eye movement analyses. Eye-tracking studies frequently predefine regions of interest and time segments and quantify eye movements according to these parameters. However, no consensus exists regarding how these criteria should be defined. Furthermore, traditional eye movement analyses assume all people with the same diagnosis (e.g. chronic pain) are identical regarding their attentional preferences. Within-group individual differences in eye movements have therefore largely been ignored. To address these issues, we adopted the Eye Movement analysis with Hidden Markov Models (EMHMM) approach, a data-driven method that accounts for individual differences in both spatial and temporal dimensions of eye movements (Chuk, Chan, & Hsiao, 2014). The EMHMM approach uses a machine-learning algorithm to cluster participants' eye movement patterns into multiple subgroups. For example, previous face recognition studies adopting this technique have found two distinct pattern groups (i.e. focusing more on the face centre/nose versus. focusing more on the eye region) in the general population (Chan, Chan, Lee, & Hsiao, 2018; Chuk et al., 2014).

In the context of the present study, the nose-centred and the eye-centred face-viewing patterns may be interpreted as tendencies to avoid or maintain eye contact with faces that are given different pain/health-related identity labels. Given that eyes usually carry more important information regarding one's emotion and physical sensations (Guarnera, Hichy, Cascio, Carrubba, & Buccheri, 2017; Prkachin, 2009), it is possible that the eye region on patients’ and doctors’ faces may be considered as more threat relevant to those with chronic pain or those with more negative interpretation styles. Consequently, these individuals may adopt an eye movement strategy that is either more nose-centred to avoid the distress evoked by the potentially threatening eye region (e.g. patients' eyes indicate their pain levels, doctors’ eyes contain negative information about my health, etc.), or more eye-centred due to empathic concerns (e.g. does the patient need my help, etc.) or to facilitate information gathering (e.g. does the doctor think I am in good health, etc.).

The present investigation examines interpretation biases for ambiguous scenarios and eye movements on faces with pain/health-related identity labels in participants with/without chronic pain. We hypothesized that people with chronic pain would endorse more negative interpretations for ambiguous scenarios compared to healthy controls. In terms of attentional processing, we made two competing hypotheses about the ways in which people with/without chronic pain might differ. Since theories and empirical studies suggest that both vigilance and avoidance might characterize attentional processes in chronic pain (Todd et al., 2015), we adopted a two-tailed hypothesis where people with chronic pain may be either more nose-centred or more eye-centred than healthy controls for neutral faces with different identity labels. If vigilance is the predominant mechanism, then participants with chronic pain might be more likely to focus on the eyes for faces that they deemed threatening compared to controls. On the other hand, if avoidance is the primary process, then people with chronic pain might be more likely to focus on the nose than the control group. Similarly, we also expected correlations between participants’ interpretation styles and their eye movements without specifying a direction. These correlations were expected to be stronger in people with chronic pain than in healthy controls.

2 | MATERIALS AND METHODS

2.1 | Participants

Ethical approval for this study was obtained from the Human Research Ethics Committee (HREC) of the University of

Hong Kong (reference number: EA1705032). The study was advertised through bulk emails sent to students and on noticeboards around the campus of the University of Hong Kong. The inclusion criteria were: (a) over 17 years of age, (b) able to read and understand Traditional Chinese, (c) normal or corrected-to-normal vision. Participants were excluded if they reported that they had a past or current psychiatric or neurological disease.

Eligible and interested participants completed an online screening questionnaire (Chronic Pain Grade Questionnaire, CPGQ) via a link provided in the advertisements. The CPGQ contains seven items and is a reliable and valid measure of chronic pain severity (Smith et al., 1997). It classifies respondents into one of five categories according to their pain intensity and interference caused by pain: Grade 0, pain-free; Grade I, low intensity–low disability; Grade II, high intensity–low disability; Grade III, moderately limiting–high disability; Grade IV, severely limiting–high disability (Smith et al., 1997). We invited people who were classified into Grade 0, Grade I, Grade III and Grade IV to our experiments, excluding those whose scores fell within Grade II in order to ensure a clearer differentiation of pain experiences between the chronic-pain group and the control group. Although we originally planned to only include people who were classified as Grade 0 in the control group, this turned out to be unfeasible as few people were completely pain-free during the past 6 months (i.e. scoring zero for all seven items). Therefore, participants with Grade III and Grade IV comprised the chronic-pain group while those with Grade 0 and Grade I comprised the control group.

A total of 417 university students responded to the screening questionnaire. Seventy-six respondents were classified into Grade II and were therefore not invited to the experiments. All other respondents were contacted via email. Seventy-three university students participated in the experiments. Six participants (four females) were excluded due to poor calibration for the eye-tracking task. Four participants (three females) were excluded from the analysis due to fatigue during the experiments (e.g. they fell asleep). Our final sample comprised 63 participants (40 females, 63.5%). All were university students local to Hong Kong. Participants' ages ranged from 17 to 24 years ($M = 19.97$, $SD = 1.78$).

In our current sample, four participants met criteria for Grade 0 (pain-free) and 28 met criteria for Grade I (low intensity–low disability), which formed the control group ($n = 32$; 17 females, 53.1%). All participants in the control group reported no physical pain that persisted or recurred for the past 3 months. Twenty-one participants met the Grade III criteria (moderately limiting–high disability) and 10 met the Grade IV criteria (severely limiting–high disability), which formed the chronic-pain group ($n = 31$; 23 females, 74.2%). All participants in the chronic-pain group reported persistent bodily pain in the past 3 months. Primary pain complaints in the chronic-pain group included extremity pain ($n = 6$), back pain ($n = 5$), shoulder pain ($n = 5$), headache ($n = 4$), neck pain ($n = 3$), orofacial pain ($n = 3$), abdominal pain ($n = 2$) and pelvic pain ($n = 1$).

2.2 | Measures

2.2.1 | Questionnaires

The CPGQ was translated into Traditional Chinese and subsequently back translated into English to ensure the accuracy of translation. The CPGQ was used as a screening questionnaire in order to divide participants into a chronic-pain group and a control group (Smith et al., 1997). The CPGQ had an alpha of 0.94. The 7-item anxiety subscale of the 21-item Depression Anxiety Stress Scale (DASS-SF) (Antony, Cox, Enns, Bieling, & Swinson, 1998; Lovibond & Lovibond, 1995) was measured in order to control for the effect of general anxiety symptoms on interpretation biases and eye movements. Translation and back translation were also performed for this measure. Cronbach's alpha was 0.78 for the anxiety subscale.

2.2.2 | Interpretation bias task

To assess participants' interpretation styles, the Interpretation Bias Task (IBT) was adopted (Chan, Takano, Lau, & Barry, n.d.). The IBT consists of four domains of ambiguous scenarios describing immediate bodily injury, long-term illness, social rejection and performance failure. The situations reflect events that may occur at school/work, at home or during everyday life. In the current study, only scenarios in the immediate bodily injury and long-term illness domains were used.

An example of an immediate bodily injury scenarios is: 'Someone kicks a ball and it hits you in the face. In the mirror you see your face is covered in …'. Participants were first presented with each ambiguous situation and were then offered words that resolve the situation in a negative or benign manner, e.g., 'mud' or 'blood'. They were then asked to rate how likely each resolution would actually happen on a scale from 1 to 100 (1 = not at all likely; 100 = extremely likely). Higher likelihood ratings for the word 'blood' reflect a more negative interpretation while higher ratings for the word 'mud' indicate a more benign interpretation. Similarly, an example of ambiguous long-term illness situations is 'You take a pill every morning at breakfast. The pill is a …' followed by 'vitamin' and 'medicine'.

Interpretation bias in different domains could then be computed using a composite of two scores: (a) the mean likelihood of negative interpretations of the ambiguous situations (i.e. such that a larger score reflects the belief that negative interpretations are likely to be true); (b) the mean likelihood of benign interpretations (i.e. such that a higher score reflects the belief that benign interpretations are likely to be true). Therefore, interpretation biases in the two domains could be indexed by a negative and a benign score, which add up to four average scores in total.

2.3 | Materials and apparatus

Twenty-four coloured frontal view Asian face images (12 female faces and 12 male faces) with neutral expressions, from the Attention Brain & Cognition Lab at the University of Hong Kong, were used as stimuli in the eye-tracking task (Chan et al., 2018). All faces were unfamiliar to the participants. Face images were cropped according to the face shape to remove the ears and hair. The face sizes were adjusted to subtend eight degrees of visual angle horizontally (around 317 pixels), which was similar to viewing faces in a conversation (Hsiao, Cottrell, & Regan, 2008).

Eye movements were recorded by an EyeLink 1,000 eye tracker (SR Research). Participants sat 60 cm in front of a 22" CRT monitor with a resolution of 1,024 × 768 pixels. The tracking mode was pupil and corneal reflection, with a sampling rate of 1000Hz. Nine-point calibration was implemented at the beginning of the task and was repeated if the drift correction error was larger than one degree of visual angle during the task. A chin rest was used to reduce participants' head movements. In data acquisition, saccade motion threshold was 0.1° of visual angle, saccade acceleration threshold was 8,000°/square second, and saccade velocity threshold was 30 degree/s, which were the EyeLink defaults for cognitive research.

2.4 | Eye-tracking task

Participants were seated 60cm from a computer screen for the eye-tracking task during which they freely viewed the 24 neutral face images one at a time. The free-viewing task commenced after calibration and validation of eye fixations. At the beginning of each trial a fixation cross at the centre of the screen was shown for 500 ms and participants were instructed to gaze at the cross. Subsequently, a label indicating the identity of the following face was presented. Specifically, we presented one of the three labels (i.e. doctor, patient and healthy individual) at the centre of the screen for 1000 ms before the presentation of each face image. The labels were in Traditional Chinese and each consisted of four Chinese characters. Participants were told that the face shown in each trial possessed one of the three identities indicated by the labels. However, the sequence of labels and sequence of face images were completely counterbalanced such that one face might be recognized as a doctor by some participants and as a patient or healthy individual by some others. After the presentation of the label, one of the faces was presented for 5000 ms. Each face was only presented once and they were located either on the left or right of the screen. Participants were instructed to freely explore these faces as if they were watching television. No response needed to be given during the task. Following an inter-trial interval of 500 ms, the next trial started with a centred fixation cross. A total of 24 neutral faces were shown to the participants one at a time in a randomized order. The sequence, identity, gender and location of the face images were counterbalanced. For each participant, eight of the faces were labelled as doctors, while eight were labelled as patients and eight as healthy individuals, with equal numbers of male and female faces for each label.

2.5 | Procedure

After providing informed consent participants completed the anxiety subscale of DASS-SF and the bodily threat and illness domains of IBT. Participants also did a dominant eye test as only the dominant eye movements were recorded during the eye-tracking task. They were then seated in front of a computer for the free-viewing task, after which they were compensated with cash reward and given a debriefing form.

2.6 | Eye movement analysis with hidden Markov Models (EMHMM)

The current study adopted a data-driven machine-learning approach (i.e. EMHMM; retrieved from http://visal.cs.cityu.edu.hk/research/emhmm/) to analysing eye movement data on face images with different identities (i.e. doctors, patients and healthy individuals). A hidden Markov model (HMM) is a type of machine-learning model for sequential data, which assumes that the observed data arises from an underlying dynamic process (Chan et al., 2018). The underlying states are non-observable, thus hidden, but can be estimated from the probabilistic associations between the observable data (i.e. sequence and duration of fixations) and the states, as well as the transition probabilities between the states (Chan et al., 2018). Applying this model in eye-tracking studies, the observable data correspond to eye fixation sequences, with each observation comprising both fixation location and fixation duration. Each hidden state of the HMM represents a region of interest with duration (ROID), which contains the location and fixation duration of an ROI (Chuk, Chan, &

Hsiao, 2017). This approach assumes that fixation locations and durations within an ROID follow a normal (Gaussian) distribution. Therefore, each ROID can be represented by a three-dimensional Gaussian emission, with two dimensions indicating the spatial distribution of fixations and one dimension indicating the temporal distribution of fixations (Chuk, Chan, et al., 2017).

The EMHMM approach directly uses HMMs to model each participant's eye movements without predefining spatial ROIs or temporal segments. Specifically, based on the sequence, location and duration of fixations, the HMM uses a probabilistic model to estimate the numbers, locations, sizes and fixation durations of the ROIDs (Chuk, Chan, et al., 2017). Using this approach, the properties of ROIDs are no longer predefined by experimenters but are automatically estimated for each individual. This approach also generates the initial ROID probabilities and a transition matrix for each participant, which indicates the probability an individual first fixates on an ROID, and the probability to shift the eye gaze from one ROID to another ROID during the task.

After each participant's eye movement pattern is summarized with personalized ROIDs and transition probabilities among the ROIDs, EMHMM enables participants to be clustered into groups based on similarities and differences among their HMMs using the variational hierarchical estimation maximization (VHEM) algorithm (Coviello, Chan, & Lanckriet, 2012). The VHEM algorithm clusters a given collection of HMMs into groups of HMMs that are similar to each other and summarizes each group by a representative HMM (common pattern). In Coviello et al. (2012), the VHEM algorithm was compared to several alternative algorithms for clustering HMMs and it was shown to be able to leverage large amounts of data with shorter learning times and reduced memory requirements while also improving model robustness. The extent to which an individual's eye movement pattern is similar to the representative HMM can be calculated as the log-likelihood of the individual's eye fixations being from this common pattern group, which reflects individual differences on a continuum (Chuk et al., 2014). Through clustering participants' eye movements during face recognition into two groups, Chuk et al. (2014) discovered two face-viewing patterns: people with a 'holistic' viewing pattern who had most fixations located at the centre of the faces (i.e. nose-centred), in comparison to people with an 'analytic' pattern who primarily focused on the eye region (i.e. eye-centred). It is of note that the terms 'holistic' and 'analytic' do not imply underlying cognitive mechanisms of each pattern (Chuk et al., 2014). Rather, they only indicate participants' fixation distributions on face stimuli. Therefore, here we renamed the holistic pattern as nose-centred pattern, and analytic pattern as eye-centred pattern as the original terms might seem more relevant to face recognition rather than selective attention.

2.7 | Analytical procedure

A MATLAB toolbox was used to analyse eye movements by EMHMM. The eye movement data were split into three sets based on the identity labels (i.e. fixations on doctors' faces, fixations on patients' faces and fixations on healthy people's faces) and were run separately using the toolbox. First, each individual's HMM of eye movement pattern was trained based on the assumptions that the target ROID of next fixation depends completely on the current ROID (Chuk, Chan, et al., 2017). Following previous EMHMM studies, we only analysed the first three fixations in each trial as it has been found that these early fixations were associated with face recognition performance and cognitive functioning while later fixations were not (Chan et al., 2018; Chuk, Crookes, Hayward, Chan, & Hsiao, 2017). The average duration of the first three fixations in the current sample was 280.73 ms (SD = 200.30 ms). Thus, the total duration of the first three fixations in each trial was similar to the exposure time in previous studies using reaction time paradigms (most studies presented two images simultaneously for 500 or 1250 ms) or eye-tracking paradigms (average viewing time for each stimulus ranged from 500 to 1000 ms in most studies). Only analysing the first three fixations in each trial would therefore allow for more appropriate comparisons between the current and previous studies. All the hyperparameters of the HMM, including the number of ROIDs (number of hidden states), were automatically estimated from a participant's data using a Bayesian method (Chan et al., 2018; Chuk, Chan, et al., 2017; Chuk, Crookes, et al., 2017). In particular, for each individual, six candidate HMMs were trained with numbers of ROIDs (numbers of hidden states) ranging from one to six. Each of the six candidate HMMs was trained for 200 times with different random initializations,[1] and the one with the largest marginal likelihood was retained. During the training procedure, the shape, size, location and number of ROIDs, as well as the transition probabilities between ROIDs, were completely determined by the data. Since we trained HMMs separately for fixations on faces with different identities, each individual had three unique HMMs, one for doctors' faces, one for patients' faces, and one for healthy people's faces, resulting in 189 individual HMMs in total.

The individual HMMs were then clustered into groups using the VHEM algorithm (Coviello et al., 2012). Based on previous studies (Chan et al., 2018; Chuk et al., 2014; Zhang, Chan, Lau, & Hsiao, 2017) and our own hypotheses, we clustered the individual HMMs observed in the current study into two groups. The clustering algorithm was run separately for the three labels. Since the numbers of ROIDs could vary between labels and between individuals, the median number of ROIDs among individuals were used as the number of hidden states for the clustering algorithm. In the current study, the median numbers of ROIDs were two for all three labels and therefore all representative HMMs generated by the toolbox had two ROIDs. Similar to training individual models, the clustering algorithm was performed 200 times with different initializations, and the clustering result with the highest expected log-likelihood was selected. This resulted in two representative HMMs for doctors' faces, two representative HMMs for patients' faces, as well as two representative HMMs for healthy people's faces. Finally, the mean log-likelihoods (MLL) of participants' eye movement data were calculated. Specifically, the log-likelihoods of each individual's data to the representative HMMs were calculated. The MLLs indicated how likely a given individual's eye movement data belonged to each representative HMM. The larger the MLL, the more similar a participant is to a representative HMM. Following a previous study (Chan et al., 2018), the MLL data were then transformed into a unified measure called the H-A scale ('H' and 'A' correspond to 'holistic' and 'analytic' patterns found in the study) that quantifies the degree of similarity of individual HMMs to the representative HMMs. For consistency, we renamed the H-A Scale as E-N Scale ('E' for 'eye-centred' and 'N' for 'nose-centred'). The E-N Scale values were calculated using the following formula:

$$E-NScale = \frac{(Eye-centredMLL)-(Nose-centredMLL)}{|Eye-centredMLL|+|Nose-centredMLL|}$$

A more positive value indicated that a person is more eye-centred, and a more negative value indicated a higher similarity to the nose-centred pattern. Each individual had three E-N Scale values for eye movements on doctors', patients' and healthy people's faces, respectively. The E-N Scale values were then used as continuous variables in subsequent data analyses.

We calculated IBT scores for immediate bodily injury and long-term illness domains based on a previous factor-analytic study (Chan et al., n.d.). We also calculated the total score of the anxiety subscale of DASS-SF. To test the differences in interpretation biases between those with and without self-reported chronic pain, we performed a three-way mixed ANOVAs on IBT scores with pain status (chronic pain versus control) as the between-subject factor and domain (immediate bodily threat versus long-term illness) and valence (benign versus negative) as the within-subject factors. For IBT scores, the statistical power for detecting a significant group effect (p < .05) was 0.70 for medium and 0.98 for large effects (G*Power 3.1.9.4) (Faul, Erdfelder, Lang, & Buchner, 2007); the statistical power for detecting a significant moderate interaction effect was 0.99. We also performed a 2 (groups: chronic pain versus control) × 3 (labels: doctor versus patient versus healthy individual) mixed ANOVA on eye movement indices (i.e. E-N Scale values) to examine whether people with chronic pain differ from healthy controls in their attentional processing of faces with different pain/health-related identities. Greenhouse–Geisser corrections were applied when assumptions of sphericity were not met. For eye movement indices, the statistical power for detecting a significant group effect was 0.67 for moderate and 0.97 for large effects (Faul et al., 2007); the statistical power for detecting a significant moderate interaction effect was 0.99. If any significant main effect or interaction was found, we followed up with other comparisons to examine the findings in more detail. To examine the associations between interpretation biases and eye movements on faces with health-related identities, we then performed correlation tests between IBT scores and E-N Scale values. We also examined to what extent these correlations differ as a function of group by conducting correlation tests separately for those with and without chronic pain. The statistical power for detecting a significant moderate correlation was 0.99 (Faul et al., 2007). Since there have been numerous findings suggesting the effect of general anxious symptoms on interpretive and attentional processing (Armstrong & Olatunji, 2012; Barry, Vervliet, & Hermans, 2015; Blanchette & Richards, 2010; Mobini, Reynolds, & Mackintosh, 2013; Stuijfzand, Creswell, Field, Pearcey, & Dodd, 2018), we ran all above-mentioned analyses with the anxiety subscale score of DASS-SF as a covariate.

3 | RESULTS

3.1 | Participant characteristics

People in the chronic-pain group did not differ significantly from those in the control group in age, $t(61) = 0.99$, $p = .326$, $d = 0.25$, 95% CI [−0.25, 0.74], or gender ratio, $\chi^2(1) = 3.02$, $p = .082$, $\varphi = 0.22$, 95% CI [.00, 0.47]. The chronic-pain group and the control group differed significantly in their general anxiety symptoms, $t(50.24) = 4.05$, $p < .001$, $d = 1.02$, 95% CI [0.49, 1.54], with the chronic-pain group having a higher mean on the anxiety subscale of the DASS-SF.

3.2 | Group differences in interpretation biases

To examine differences in interpretation biases between those with and without chronic pain, we conducted a three-way mixed ANOVA onIBT scores with pain status (chronic pain versus control) as the between-subject factor, domain (immediate bodily injury versus long-term illness) and valence (benign versus negative) as the within-subject factors, and anxiety symptoms as the covariate. There was no main effect of pain status,[2] $F(1, 60) = 0.65$, $p = .422$, $\eta^2 = 0.01$, 90% CI [0.00, 0.09]. There was also no interaction between pain status and domain, $F(1, 60) = 0.38$, $p = .538$, $\eta^2 = 0.01$, 90% CI [0.00, 0.07], or interaction between pain status, domain and valence, $F(1, 60) = 2.66$, $p = .108$, $\eta^2 = 0.04$, 90% CI [0.00, 0.15].

Results revealed a large main effect of domain, $F(1, 60) = 28.77$, $p < .001$, $\eta^2 = 0.32$, 90% CI [0.17, 0.45], and a large main effect of valence, $F(1, 60) = 28.78$, $p < .001$, $\eta^2 = 0.32$, 90% CI [0.17, 0.45]. These main effects were characterized by a large interaction between domain and valence, $F(1, 60) = 89.60$, $p < .001$, $\eta^2 = 0.60$, 90% CI [0.46, 0.68]. We then followed this interaction up with paired-samples *t* tests between the four IBT scores while controlling for anxiety symptoms. Results suggested that participants generally endorsed more benign interpretations for long-term illness situations ($M = 76.11$, $SE = 1.66$) than immediate bodily injury situations ($M = 50.43$, $SE = 1.69$), $F(1, 61) = 140.60$, $p < .001$, $\eta^2 = 0.70$, 90% CI [0.58, 0.76]. In contrast, participants endorsed more negative interpretations for immediate bodily injury situations ($M = 49.19$, $SE = 1.93$) than long-term illness situations ($M = 43.53$, $SE = 1.78$), $F(1, 61) = 4.55$, $p = .037$, $\eta^2 = 0.07$, 90% CI [0.00, 0.19].

There was also a moderate interaction between pain status and valence, $F(1, 60) = 6.12$, $p = .016$, $\eta^2 = 0.09$, 90% CI [0.01, 0.22]. To follow this interaction up, we performed independent-samples *t* tests for benign interpretation scores and negative interpretation scores separately, controlling for anxiety symptoms. Results revealed no significant difference in benign interpretation scores for both domains between participants with chronic pain ($M = 61.63$, $SE = 2.17$) and healthy controls ($M = 64.86$, $SE = 2.13$), $F(1, 60) = 1.00$, $p = .321$, $\eta^2 = 0.02$, 90% CI [0.00, 0.10]. However, people with chronic pain ($M = 50.09$, $SE = 2.31$) endorsed significantly more negative interpretations for both immediate bodily injury and long-term illness scenarios than healthy controls ($M = 42.74$, $SE = 2.27$), $F(1, 60) = 4.60$, $p = .036$, $\eta^2 = 0.07$, 90% CI [0.00, 0.19].

In summary, people with chronic pain had significantly more negative interpretations for ambiguous scenarios related to immediate bodily injury and long-term illness than people without chronic pain. There was also a general tendency in all participants to endorse more negative and fewer benign interpretations for immediate bodily injury scenarios compared to long-term illness scenarios.

3.3 | Eye movement patterns

In the current study, we found that participants' eye movements could be clustered into an eye-centred pattern and a nose-centred pattern consistently for faces with different identity labels. Figures 1–3 present these two common eye movement patterns for doctors', patients' and healthy people's faces, respectively. For illustrative purpose, we also generated the fixation heat maps for each representative HMM using iMap (Lao, Miellet, Pernet, Sokhn, & Caldara, 2017).

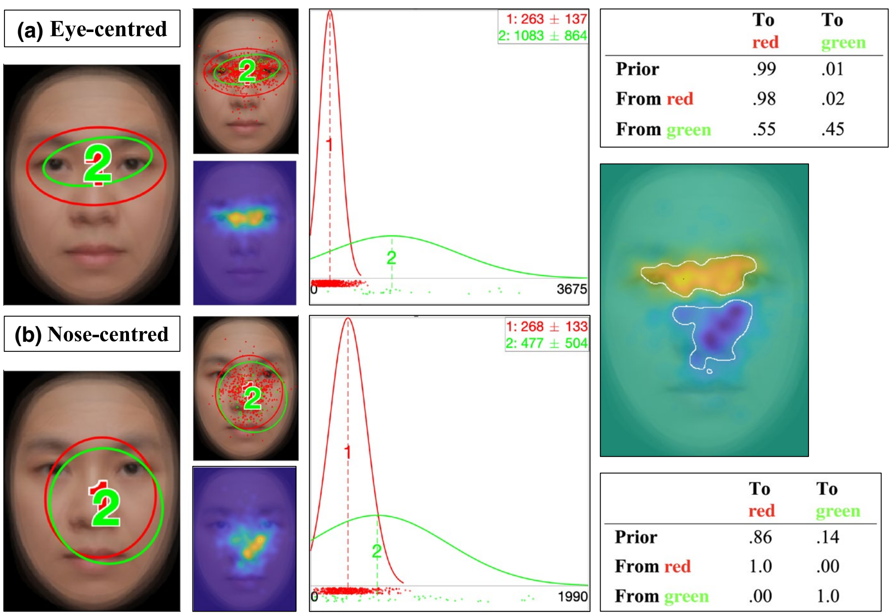
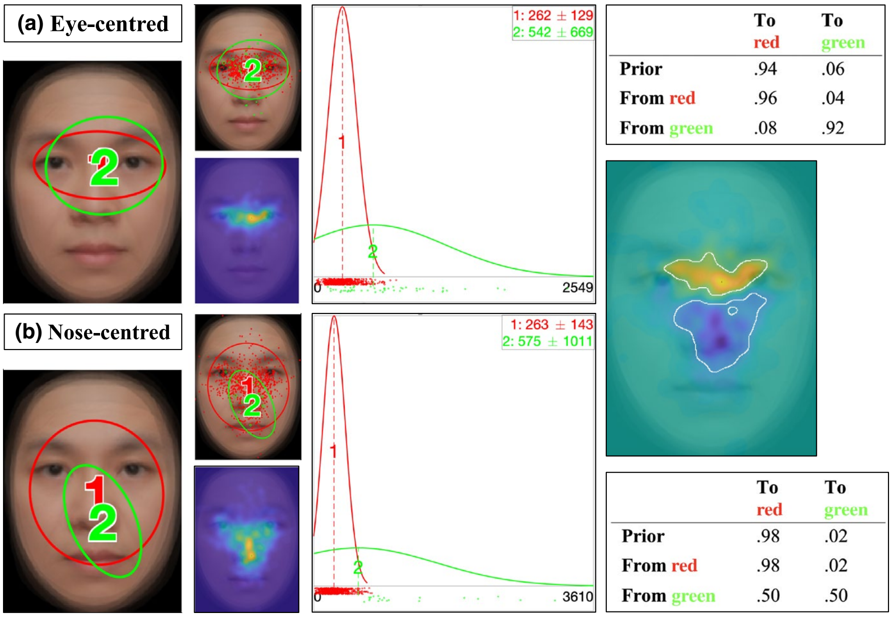


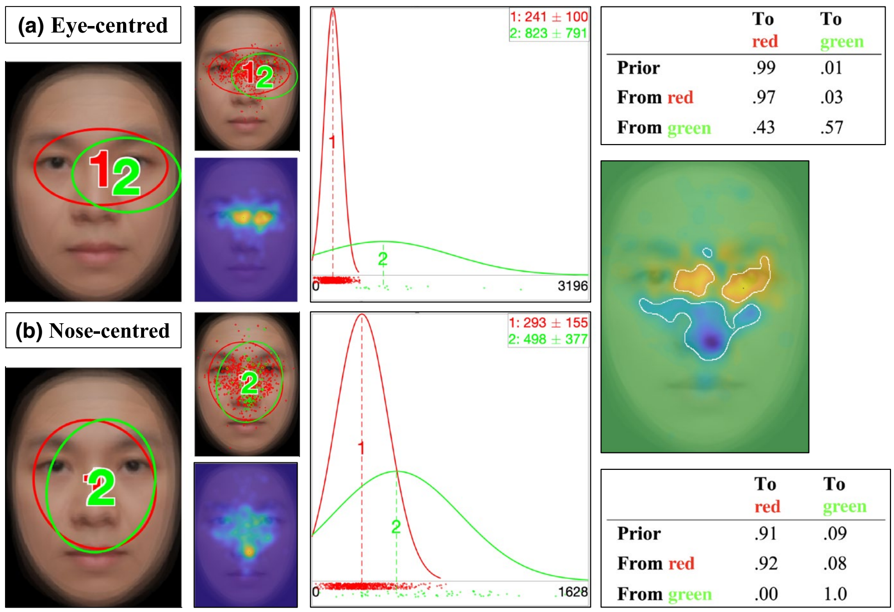
FIGURE 1 The eye-centred and nose-centred patterns for doctor-face-viewing. The top panel (a) shows the eye-centred pattern while the bottom panel (b) shows the nose-centred pattern. The images on the left in each panel show the spatial distribution of region of interest with durations (ROIDs). The smaller images show the assignment of actual fixations to different ROIDs and the corresponding fixation heat map. The duration distribution of ROIDs (in ms), and the transition probability matrix of the ROIDs are also shown in each panel. The priors in each matrix show the probability that first fixations in each trial located at each ROID. The image between the two transition matrices shows the difference heat map between the two patterns, with red and blue indicating positive and negative differences in fixation density and duration. The face image shown in the present paper is an average face image



	To red	To green
Prior	.94	.06
From red	.96	.04
From green	.08	.92

	To red	To green
Prior	.98	.02
From red	.98	.02
From green	.50	.50

FIGURE 2 The eye-centred (a) and nose-centred (b) patterns for patient-face-viewing



	To red	To green
Prior	.99	.01
From red	.97	.03
From green	.43	.57

	To red	To green
Prior	.91	.09
From red	.92	.08
From green	.00	1.0

FIGURE 3 The eye-centred (a) and nose-centred (b) patterns for healthy-individual-face-viewing

Table 1 presents the number of participants classified into the eye-centred and the nose-centred groups for each label.

In Figure 1a (i.e. eye-centred pattern for doctor's faces), it can be seen that the two ROIDs are located on the eye region. Participants in this group (n = 38) typically started by looking at the red region (99%) with short fixations (M = 263 ms, SD = 137 ms), after which they most likely (98%) remained looking at the same region with fixations of similar durations or they sometimes (2%) shifted to the green region with longer fixations (M = 1083ms, SD = 864ms). In comparison, as shown in Figure 1b, participants in the nose-centred pattern group (n = 25) had two ROIDs that centred around the nose. These two ROIDs were spatially overlapping but had different distributions of fixation duration (red: M = 268 ms, SD = 133 ms; green: M = 477 ms, SD = 504 ms). Based on the assumption that each ROID follows a three-dimensional normal distribution, the fixation density would be the highest at the centre and lowest near the border of each ROID. Therefore, although the ROIDs of the nose-centred pattern also covered the eye region, participants in this group had fewer fixations on the eyes compared to the eye-centred group, which was also illustrated by the difference heat map. The difference heat map showed that the first group focused more on the eyes and less on the nose than the second group, and therefore they are referred to as eye-centred and nose-centred groups, respectively.

Similarly, the images in Figures 2–3 showed the distinctions between the two common patterns. It is of note that participants might not use the same strategy across faces with different labels consistently. Therefore, unlike the number of people classified into the eye- and nose-centred groups for doctors' faces, 29 and 32 participants were categorized as being eye-centred for patients' and for healthy people's faces respectively, while 34 and 31 participants were grouped into the nose-centred pattern for these two identities.

3.4 | Group differences in eye movements

To examine differences in participants' eye movements between groups and as a function of the labels associated with each face, we conducted a 2 (groups: chronic pain versus control) × 3 (labels: doctor versus patient versus healthy individual) mixed ANOVA on the E-N Scale values. There was no significant main effect of label, $F(1, 60) = 1.56$, $p = .216$, $\eta^2 = 0.03$, 90% CI [0.00, 0.12], or group, $F(1, 60) = 0.48$, $p = .490$, $\eta^2 = 0.01$, 90% CI [0.00, 0.08], nor any interaction between label and group, $F(1, 60) = 0.78$, $p = .450$, $\eta^2 = 0.01$, 90% CI [0.00, 0.09]. In summary, there was no difference in eye movements between those with and without chronic pain or between different face identities.

TABLE 1 Number of participants classified as having eye-centred and nose-centred patterns for each identity label using eye movements were analysed with the Hidden Markov Models

	Eye-centred	Nose-centred
Doctor		
Total	38	25
Control	18	14
Chronic pain	20	11
Healthy people		
Total	32	31
Control	14	18
Chronic pain	18	13
Patient		
Total	29	34
Control	12	20
Chronic pain	17	14

3.5 | Interpretation biases and eye movements

To examine the associations between interpretation biases and eye movements, we first conducted partial correlations between IBT scores and E-N Scale values while controlling for general anxiety symptoms using the whole sample. Table 2 presents the results of these partial correlations. Notably, those who endorsed more negative interpretations for ambiguous long-term illness scenarios used an eye movement strategy that was less similar to an eye-centred strategy, and more similar to a nose-centred strategy, (i.e. lower E-N Scale values) for patients' and healthy individuals' faces. There was also a marginally significant negative correlation between the tendency to endorse more negative interpretations for long-term illness situations and the tendency to focus on the eye region of doctors' faces, $r(60) = -0.23$, $p = .075$. No other correlation was statistically significant.

Similar partial correlation tests were also conducted separately for those with and without chronic pain. Table 3 presents the correlations for the healthy controls and Table 4 presents the results for the participants with chronic pain. Interestingly, no correlation between interpretation bias scores and eye movements was found for the control group (see Table 3). However, in those with chronic pain, those with more negative interpretation styles for long-term illness scenarios were less similar to an eye-centred pattern, and more

TABLE 2 Correlations between interpretation biases and eye movements across groups

	1	2	3	4	5	6	7
1. Immediate bodily injury—benign	—						
2. Immediate bodily injury—negative	0.13	—					
3. Long-term illness—benign	0.45**	0.07	—				
4. Long-term illness—negative	0.11	0.42**	0.07	—			
5. E-*N* Scale—doctor	−0.08	−0.16	−0.12	−0.23	—		
6. E-*N* Scale—healthy people	−0.06	0.01	−0.01	−0.26*	0.72**	—	
7. E-*N* Scale—patient	−0.07	−0.16	−0.09	−0.27*	0.84**	0.74**	—

Notes: The correlation tests were performed with the anxiety subscale of DASS-SF as a covariate.

Abbreviations: E-*N* Scale—doctor, participants' E-*N* Scale values when looking at doctors' faces; Immediate bodily injury—benign, the benign interpretation score for immediate bodily injury scenarios.

*$p < .05$.

**$p < .01$.

TABLE 3 Correlations between interpretation biases and eye movements in the control group

	1	2	3	4	5	6	7
1. Immediate bodily injury—benign	—						
2. Immediate bodily injury—negative	0.11	—					
3. Long-term illness—benign	0.39*	0.19	—				
4. Long-term illness—negative	0.13	0.26	0.09	—			
5. E-*N* Scale—doctor	−0.16	−0.18	0.02	−0.22	—		
6. E-*N* Scale—healthy people	0.04	0.19	0.08	−0.11	0.75**	—	
7. E-*N* Scale—patient	0.01	−0.08	0.07	−0.30	0.85**	0.79**	—

Notes: The correlation tests were performed with the anxiety subscale of DASS-SF as a covariate.

*$p < .05$.

**$p < .01$.

TABLE 4 Correlations between interpretation biases and eye movements in the chronic-pain group

	1	2	3	4	5	6	7
1. Immediate bodily injury—benign	—						
2. Immediate bodily injury—negative	0.24	—					
3. Long-term illness—benign	0.49**	0.03	—				
4. Long-term illness—negative	0.14	0.52**	0.07	—			
5. E-*N* Scale—doctor	−0.002	−0.17	−0.27	−0.25	—		
6. E-*N* Scale—healthy people	−0.11	−0.28	−0.09	−0.49**	0.69**	—	
7. E-*N* Scale—patient	−0.09	−0.32	−0.22	−0.28	0.84**	0.67**	—

Notes: The correlation tests were performed with the anxiety subscale of DASS-SF as a covariate.

*$p < .05$.

**$p < .01$.

similar to a nose-centred pattern when looking at healthy people's faces (see Table 4).

In summary, people who showed a tendency to interpret ambiguous illness-related information in a negative way focused more on the nose region and less on the eye region of faces of patients and healthy people than those who did not possess such an interpretation bias. Also, among people with chronic pain, but not those without pain, the tendency to interpret illness-related scenarios in a negative way was associated with greater attention towards the nose area of people labelled as healthy.

4 | DISCUSSION

The current article assessed interpretation biases and eye movements around faces with different pain/health-related labels in young adults with and without self-reported chronic pain and examined the relations between different forms of cognitive biases. To our knowledge, this is the first study to assess the IBT in young adults with and without chronic pain and is also the first eye-tracking study to assess multiple forms of biased cognition in a sample with chronic pain. Additionally, this study presents the first use of a machine-learning data-driven approach to analysing eye movement data in attentional bias research in the context of pain. In particular, our data showed that participants with chronic pain endorsed more negative interpretations for ambiguous scenarios but did not differ in attentional processing of faces with different identities compared to healthy controls. However, interpretative and attentional tendencies were related to one another in so far as participants who showed a stronger negative interpretation bias tended to focus more on the nose region of neutral faces than those who showed a weaker bias. This association also seemed to be particularly prominent in people with chronic pain when looking at faces labelled as healthy.

A recent systematic review and meta-analysis (Schoth & Liossi, 2016) has confirmed that individuals with chronic pain favoured pain/illness-related interpretations for ambiguous information. Studies included in this synthesis of literature, however, mostly used word and face stimuli with none using tasks that involved ambiguous scenarios. Using the IBT, our study suggests that young adults with chronic pain endorsed significantly more negative interpretations for ambiguous scenarios related to immediate bodily injury and long-term illness compared to people who were pain-free, even when controlling for general anxiety symptoms. Our results not only add to the growing body of evidence on biased interpretation styles in people with chronic pain but also suggest the suitability of using the IBT in adult samples with chronic pain. To date, the IBT and its variations have only been adopted in adolescent samples. In Heathcote and colleagues' study (2016) where this task was first developed, adolescents with more pain issues in the past 3 months endorsed more negative and fewer benign interpretations for situations across bodily threat and social domains. In their subsequent study (Heathcote, Jacobs, Eccleston, Fox, & Lau, 2017), adolescent patients diagnosed with chronic pain endorsed fewer benign interpretations for bodily threat situations but not for social situations. Our findings, taken together with these previous studies, suggest that both adolescents and adults with chronic pain endorse more negative and fewer benign interpretations for ambiguous pain/illness-related scenarios compared to those without pain problems. However, contrary to Heathcote et al second study that only found a difference in benign interpretation scores (Heathcote et al., 2017), we only found a difference in negative interpretation scores. This could be due to an age difference in interpretation processes as Heathcote et al. recruited participants aged 10–18 years while our participants were aged 17–24 years. This could also be attributed to cultural or linguistic factors as Heathcote et al. (2017) recruited people fluent in English from the United Kingdom whereas we recruited Chinese-speaking participants from Hong Kong. Future studies should investigate age and cultural differences in interpretation styles in order to develop more specific interventions for various subgroups within patients with chronic pain.

Contrary to our hypothesis, no difference was found in eye movements between those with and without chronic pain. This null finding could be attributed to within-group variability in eye movement patterns. As shown in Table 1, both groups were comprised of participants with eye-centred and nose-centred patterns for each face identity. It is possible that people with chronic pain might process ambiguous stimuli in different ways, with some of them being vigilant towards, and some others being avoidant of, the eye region of neutral faces. Thus, taking the means of eye movement indices for each group might mask the distinct strategies adopted by each individual. Relatedly, the ways in which people attend to ambiguous stimuli might not be solely dependent on their pain status. As proposed by the threat interpretation model (Todd et al., 2015), the experience of pain and the tendency to interpret pain-related stimuli as threatening together contribute to the presence of attentional bias. It is possible that within the chronic-pain group, only those with more negative interpretations would show a bias in the way that they attend to pain-related stimuli. Indeed, this is supported by our correlational analysis which showed that interpretation biases were associated with eye movements on faces labelled as healthy in participants with chronic pain but not in healthy controls. Another potential explanation is that the labels indicating health-related identities might have insufficient personal relevance for our sample. Since the current study was only a preliminary investigation of the effect of identity labels on the attentional processing of faces, we adopted labels that were more general rather than pain specific. Labels such as 'patient' and 'doctor' might therefore be unable to elicit threat responses in people with chronic pain. Future studies may need to use more specific labels such as 'pain-free healthy individual', 'patients with chronic pain' or 'pain specialist' to examine more pain-specific cognitive biases. Also, as the current sample consists of university students who self-reported their pain severity, their experience in hospital settings might be limited compared to those diagnosed with chronic pain. Future studies with clinical samples are warranted.

Nevertheless, our analyses revealed that those who favoured more negative interpretations for long-term illness situations were more nose-focused when looking at patients' and healthy people's faces. More interestingly, the link between interpretation styles and eye movements was only evident in people with chronic pain but not in healthy controls. These findings could be interpreted in the context of the approach/avoidance paradox. As suggested by Goubert, Vervoort, and Crombez (2009), the observation of pain in others may activate two competing mechanisms: an egoistic motivation to reduce personal anxiety and discomfort (i.e. avoidance), and an altruistic motivation to help others in need (i.e. approach). Since pain-related stimuli are associated with potential threat, the initial viewing of such information may automatically activate a threat detection system that elicits an aversive state of personal distress rather than empathic processes such as sympathy and compassion (Goubert et al., 2009; Vervoort, Trost, Prkachin, & Mueller, 2013; Yan, Pei, & Su, 2017). Only in subsequent stages when the threat value is attenuated by the interpretation of pain-related stimuli, approach motivation may arise (Goubert et al., 2009). In the context of the current study, the nose-centred pattern may represent an avoidant tendency while the eye-centred pattern may resemble approach behaviour because the eye region has been suggested to carry more important information about one's emotions and physical sensations such as pain than other facial features (Guarnera et al., 2017; Prkachin, 2009). Although the stimuli used in the present study are not directly related to pain, people who interpreted illness-related scenarios in a more negative manner might also interpret these stimuli as more indicative of pain experience or negative health status. Therefore, people who interpreted these neutral faces as carrying more negative information might then avoid looking at the eye region in order to minimize the negative affect that it might evoke. For example, those who hold negative interpretations for long-term illness scenarios might avoid looking at patients' or healthy people's eyes for fear that their eyes may convey information about their pain severity or negative illness experience. In contrast, those who endorse more benign interpretation styles may consider the threat value as being mild and therefore would focus more on the eyes to sympathize with or to help others in need. For observers with negative interpretation styles, the avoidance of pain/health-related stimuli may prevent direct confrontations that are necessary for adjusting their initial threat appraisals. The heightened threat expectation may then maintain a fearful state and result in habitual avoidance of pain/health-related stimuli in these individuals which, in the long run, are associated with worse outcomes in chronic pain (Boyer et al., 2006; Sharpe, Haggman, Nicholas, Dear, & Refshauge, 2014; Vervoort et al., 2013).

Although the association between participants' tendency to negatively interpret long-term illness scenarios and to adopt a more nose-centred strategy for doctors' faces was only marginal in the current study, our results may have important implications on patient–doctor relationship. Communication with patients with chronic pain has often been described by healthcare professionals as time-consuming, demanding and emotionally challenging (Matthias & Bair, 2010). Studies to date also suggest that patients with chronic pain and healthcare providers are likely to have competing attitudes and goals (Frantsve & Kerns, 2007) and that doctors frequently underestimate pain intensity and interference in patients (De Ruddere et al., 2014). Productive relationships between patients and physicians are an important factor in determining patients' treatment adherence, health outcomes and satisfaction (Haskard Zolnierek & DiMatteo, 2009; Matthias & Bair, 2010). However, observation studies report that doctors frequently avoid discussions of emotional and social impacts of patients' problems, which in turn results in patients being reluctant to disclose vital information that are essential for accurate diagnoses and suitable treatment plans (Ha & Longnecker, 2010; Maguire & Pitceathly, 2002). Numerous studies to date have identified a range of communication errors evident in patient–doctor communication, among which a lack of eye contact has been one of patients' major complaints (Kee, Khoo, Lim, & Koh, 2018; Silverman & Kinnersley, 2010). According to Ong, Haes, Hoos, and Lammes (1995), visual cues like eye contact and body positioning account for more than 50% of affective communication in medical consultations. Indeed, there is substantial evidence suggesting the importance of maintaining eye contact during medical interviews in facilitating information gathering in patients and improving satisfaction (Gorawara-Bhat & Cook, 2011; Khan, Hanif, Tabassum, Qidwai, & Nanji, 2014; Silverman & Kinnersley, 2010). It may therefore be plausible that avoiding eye contact in patient–doctor communication can deteriorate the relationship between patient and doctor and negatively impact patients' treatment experience and prognosis. From the results of the current study, there is evidence indicating that people who have more negative interpretation styles for illness situations avoid looking at doctors' eyes. Future studies may need to determine whether this association is evident in both patient and provider samples, and whether it contributes to worse outcomes in patients.

It is of note that all significant correlation findings in the current study were between eye movement indices and negative interpretation scores for long-term illness scenarios but not immediate bodily injury scenarios. This suggests the content specificity of interpretation biases and the IBT. Although participants with chronic pain endorsed more negative interpretations for both domains of situations, only those who negatively interpreted illness situations were more nose-centred when viewing faces with pain/health-related identity labels. It may be that the free-viewing task in the current study has created an ambiguous situation that approximates real-life social interactions in hospital contexts where people meet doctors, patients and healthy people. The identity labels used in the present study seem to be more related to long-term illnesses rather than immediate bodily injury as most injuries that occur in daily life, and which were referred to in the IBT, might not require hospital/clinic visits. Future studies may investigate whether eye movements on pain-specific visual stimuli are associated with interpretations for bodily injury situations only. Evidence for the content specificity of these cognitive biases will then feed into further research that advances and modifies current interventions targeting these mechanisms.

Despite the novelty of the current study, several limitations warrant acknowledgement. First, we did not perform a check to determine whether participants believed that the persons presented to them actually possessed their assigned labels. Second, we only assessed the immediate bodily injury and long-term illness domains of the IBT but not the social rejection and performance failure domains so as not to overburden participants with chronic pain. Therefore, we cannot conclude if biased interpretations in adults with chronic pain also generalize to other contexts. Finally, the grouping in the current study was based on participants' self-report of their pain experience. Although the CPGQ has previously been found to correspond with chronic pain severity and is associated with other measures of pain disability (Smith et al., 1997), participants with chronic pain in the current study did not possess clinical diagnoses and therefore their pain experiences might not be as debilitating as those of clinical patients.

To date, few studies have examined multiple forms of cognitive biases in combination in the context of pain. Schoth, Beaney, Broadbent, Zhang, and Liossi (2019), and Schoth, Parry, and Liossi (2018), for example, compared biased interpretation, attention and memory in people with and without chronic headache. However, the first study only identified a link between interpretation and attentional biases in the healthy control group (Schoth et al., 2018), and this association was not evident in the second study (Schoth et al., 2019). Todd, Sharpe, Colagiuri, and Khatibi (2016) assessed eye movements on word and face stimuli and interpretation biases for ambiguous facial expressions in healthy participants. Similarly, no relation between these two forms of biases was found (Todd et al., 2016). The current study is one of the first to demonstrate an interaction between interpretive and attentional processing in illness contexts and particularly those that involve understanding social communication of pain/health-related information. Our results supported the presence of interpretation biases in those with chronic pain and an association between this bias and the tendency to avoid eye contact when looking at neutral faces with pain/health-related labels attached to them. Future testing is warranted to investigate how this interaction might lead to the chronicity of pain and how it might influence interactions with people associated with each label.

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CONFLICT OF INTEREST

None.

AUTHORS' CONTRIBUTIONS

Frederick H.F. Chan was involved in methodology, data analysis and writing—original draft. Hin Suen was involved in methodology and data collection. Janet H. Hsiao and Antoni B. Chan were involved in writing—review and editing. Tom J. Barry was involved in methodology, writing—review and editing, supervision and funding acquisition. All authors discussed the results and commented on the manuscript.

SIGNIFICANCE

Adults with chronic pain interpreted ambiguous pain/health-related scenarios more negatively than healthy controls. A data-driven machine-learning approach to eye movement analyses revealed novel associations between interpretation biases and attentional processing.

ENDNOTES

[1] 200 times is a good balance between training time and breadth of the search, and training the HMM for more than 200 times does not provide any substantial benefit.

[2] 90% CI was reported for ^{2} as calculating the 95% CI might result in a CI that includes 0, while ^{2} cannot be smaller than 0.

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