Running head: EYE MOVEMENTS AND PAIN

Pain-related attentional processes: a systematic review of eye-tracking research

Frederick H.F. Chan[1], Hin Suen[1], Todd Jackson[2,3], Johan W.S. Vlaeyen[4,5,6], Tom J. Barry[1,7*],

[1] Department of Psychology, The University of Hong Kong, Hong Kong

[2] Department of Psychology, University of Macau, Macau

[3] Key Laboratory of Cognition and Personality, Southwest University, Chongqing, China

[4] Research Group Healthy Psychology, KU Leuven, Belgium

[5] Department of Clinical Psychological Science, Maastricht University, Maastricht, the Netherlands

[6] Centre for Excellence on Generalization Research in Health and Psychopathology, KU Leuven, Leuven, Belgium

[7] Department of Psychology, The Institute of Psychiatry, Psychology and Neuroscience, King's College London, London, UK

*Corresponding author: A: Tom J. Barry, Department of Psychology, Jockey Club Tower, University of Hong Kong, Pokfulam Road, Hong Kong. T: +852 3917 8927; E: tom.j.barry@icloud.com, tjbarry@hku.hk.

Total word count (excluding abstract and references): 11973

Abstract word count: 187

Table (in appendix): 1

Figure (in appendix): 1

Abstract

Biases in the way that people direct their attention towards or away from pain-related information are hypothesised to contribute to the onset and severity of pain-related disorders. This systematic review summarised 24 eye-tracking studies (N = 1424) examining effects of chronic pain, stimulus valence, individual differences in pain-related constructs such as fear of pain and pain catastrophising, and experimentally-induced pain or pain-related threat on attentional processing of visual stimuli. The majority of studies suggest that people with and without chronic pain do not differ in their eye movements on pain-related stimuli, although there is preliminary evidence that gaze biases vary across subtypes of chronic pain and may be evident only for certain stimuli. In contrast, participants with and without chronic pain exhibit a general tendency to allocate more first fixations and total fixations upon pain-related compared to neutral stimuli. Fear of pain was found to have limited effects on eye movements, whereas the tendency to catastrophise about pain, the anticipation of pain, and actual experimental pain stimulation have had stronger associations with eye movements, although results have been mixed. Methodological limitations and future research directions are discussed.

Keywords: pain, attentional bias, eye tracking, systematic review

Introduction

Visual attentional biases, whereby people preferentially direct their attention towards or away from concern-relevant stimuli in their environment, have been linked to the course and severity of various mental health problems (Armstrong & Olatunji, 2012). For instance, a socially anxious person who fears negative evaluation or judgement from other people may preferentially attend to an angry face in a crowd of people at the expense of attending to other neutral or happy faces. Early research on attentional processes involved in affective disorders relied heavily on reaction time methodology whereby researchers inferred the direction and duration of attention towards or away from salient stimuli based on participants' behavioural responses. More recently, researchers have begun to measure overt components of attention by recording eye movements toward or away from stimuli throughout a viewing period (Armstrong & Olatunji, 2012; Chen & Clarke, 2017; Weierich et al., 2008). Given these precedents, eye-tracking technology has been adopted in examining attentional processes associated with pain-related disorders given that psychological processes that underlie fear and anxiety are also thought to influence the emergence, severity and maintenance of pain problems (Crombez et al., 2012; Eccleston & Crombez, 1999; Todd et al., 2015; Van Ryckeghem et al., 2019; Vlaeyen & Linton, 2000). To our knowledge, this literature has yet to be synthesised. The present review provides the first such synthesis.

We begin with an overview of psychological perspectives on pain and research on associations between attentional biases and pain. We then synthesise eye-tracking research within this context, considering different paradigms that have been used for stimulus presentations (e.g., free viewing of pain-related images), sample characteristics within these investigations (e.g., participants with chronic pain or those who have been induced to expect pain) and ways in which attentional biases have been operationalised and quantified (e.g., the location of the first fixation and the time spent fixating at this location). As such, this review

examines the current state-of-the-science regarding what we know and do not know about attentional biases and their role in pain, whilst informing future research directions.

The psychology of pain

Pain has been defined as "a distressing experience associated with actual or potential tissue damage with sensory, emotional, cognitive, and social components" (Williams & Craig, 2016). In its acute form, pain serves a warning function that is important for survival (Eccleston & Crombez, 1999). In its chronic form, pain persists or recurs for more than three to six months; chronic pain affects approximately 11.2% (pain every day for the past three months) to 55.7% (some pain in the past three months) of adults, and has consequences that can be severely debilitating (Nahin, 2015; Treede et al., 2019). Despite the prevalence and severity of chronic pain, our understanding of psychological processes that contribute to pain experiences remains limited.

Recent theories suggest that individual differences in the allocation of attention to internal and external pain stimuli can explain why some people experience heightened pain, functional impairment, and avoidance of daily activities that they believe will cause pain (Crombez et al., 2012; Eccleston & Crombez, 1999; Todd et al., 2015; Van Ryckeghem et al., 2019; Vlaeyen & Linton, 2000). In particular, people who experience or anticipate pain might prioritise the processing of bodily signals of pain and pain-related information from the external environment (e.g., objects that might induce pain) because they believe that such prioritisation enables them to better manage pain or prevent its occurrence (Crombez et al., 2012; Eccleston & Crombez, 1999; Todd et al., 2015). However, excessive attention towards pain-related information, particularly at the expense of attending to fear-disconfirming information and experience that is related to one's activities and goals, might result in heightened expectations of pain, increased pain intensity, and interference with daily activities (Crombez et al., 2012; Todd et al., 2015; Van Ryckeghem et al., 2019; Vlaeyen & Linton, 2000).

Therefore, understanding whether and how people who experience pain allocate attention and process information differently than do people who are pain-free is essential. In particular, it is important to improve our understanding of the ways in which attentional processes manifest themselves and are causally related to the development and exacerbation of pain and functional impairment. To date, numerous researchers have examine attentional biases in the context of pain, and results have been synthesised within meta-analyses (Crombez et al., 2013; Roelofs et al., 2002; Schoth et al., 2012; Todd et al., 2018). These investigations have provided foundations for the development of attentional bias modification training that targets maladaptive pain-related attentional processes as well as symptoms of chronic pain (Heathcote et al., 2018; Schoth et al., 2013), although mechanisms of change within these interventions have been hard to establish (Todd et al., 2018). Notably, however, a majority of these studies have relied on reaction time paradigms. Therefore, overt pain-related visual attentional processes assessed by eye-tracking technology are relatively less well understood. We must improve this understanding if we are to advance and modify current bias modification interventions within the context of ongoing pain.

Pain and reaction time measures of attentional biases

Most reaction time investigations of pain-related attentional biases have used modified Stroop tasks, modified spatial cueing tasks and dot-probe tasks, among which the latter have been most frequently adopted. In dot-probe investigations, participants view pain-related cues (e.g., sensory pain words, pained faces, images of painful movements) paired with neutral cues (e.g., neutral words, neutral faces, benign movements) on a screen and are then asked to identify a target that appears in one of the two locations previously occupied by the cues. Greater attentional bias towards pain-related information is inferred when one responds faster to targets that appear in locations formerly occupied by pain-related cues.

Early studies using dot-probe tasks typically presented word stimuli to participants and results suggested a bias towards sensory pain words in chronic pain patients (Dehghani et

al., 2003). This bias was found to be more pronounced in both acute and chronic pain patients compared to pain-free controls (Haggman et al., 2010). More recently, researchers have started to use pictorial stimuli depicting facial expressions and daily activities in dot-probe investigations. For example, Roelofs and colleagues (2005) found that chronic pain patients had difficulty disengaging from painful movement pictures. Additionally, Khatibi and colleagues (2009) found that while chronic pain patients with low fear of pain demonstrated avoidance of painful expressions, those with high fear exhibited a bias towards such stimuli. To date, three meta-analyses have reported on dot-probe task performance in the context of pain; all of them reported a small but significant bias towards sensory pain words in chronic pain patients compared to healthy controls ($d = 0.20\text{-}0.36$) (Crombez et al., 2013; Schoth et al., 2012; Todd et al., 2018).

The aforementioned studies suggest that chronic pain patients are more likely to orient towards and maintain attention on pain-related stimuli compared to pain-free controls. However, reaction time paradigms only provide a snapshot of attention following stimulus offsets and neglect its potentially dynamic course over the duration of stimulus presentations. Although some studies have also investigated the time course of attentional biases using dot-probe tasks with two stimulus presentation durations (e.g., 500ms and 1250ms) (Liossi et al., 2009), eye-tracking technology that directly records participants' eye movements during the entire course of stimulus presentation has been suggested to provide a more reliable measure of visual attentional biases (Skinner et al., 2018), and may offer novel insights for this field.

Pain and eye-tracking measures of attentional biases

Within the domain of eye-tracking studies on pain-related attentional biases, there is substantial variability in participant groups that have been studied, stimulus presentation methods that have been used, and ways in which attention components have been operationalised. Most eye-tracking systems adopted within the scope of the current review sampled gaze behaviour at frequencies ranging from 30 to 1000 Hz. For example, a 250 Hz

eye-tracker registers a sample once every 4ms. The introduction of eye-tracking technology therefore allows for a more direct and continuous measure of overt components of visual attention compared to the snapshot provided by reaction time paradigms.

Regarding samples, several studies have compared eye movements between people with and without chronic pain. Chronic pain of at least three months duration has been examined most often in such research (Fashler & Katz, 2014). In some of these studies, participants reported heterogeneous primary pain sites (Yang et al., 2013), while other studies assessed participants who reported the same pain site (e.g., chronic headache) (Liossi et al., 2014). Some studies have also employed pain-free participants and examined effects of individual differences factors (e.g., fear of pain, pain catastrophising) on eye movements (Heathcote et al., 2017; Yang, Jackson, Gao, & Chen, 2012). Effects of experimentally-induced pain given before (Sun et al., 2016) or after stimulus presentations (Jackson et al., 2018a) has been the focus of other accounts. Finally, a number of studies have used paradigms in which participants were threatened or reassured about pain prior to the eye-tracking tasks (Sharpe et al., 2017).

In terms of stimulus presentation paradigms, a majority of studies have adopted dot-probe tasks and free-viewing tasks. Dot-probe tasks used in eye-tracking studies have been similar to those used in the reaction time literature. In free-viewing tasks, participants were typically asked to freely explore one (Schoth, Wu, et al., 2019) or more (Priebe et al., 2015) visual stimuli simultaneously presented in random locations as if they were watching television. In some studies, participants were informed about locations in which emotional stimuli (i.e., happy or sad face) would appear prior to free-viewing (Giel et al., 2018). In others, free-viewing of certain visual stimuli was followed by possible pain stimulation versus its absence (Jackson et al., 2018a, 2018b). In addition, one study used a visual search task in which participants were shown one emotional target (i.e., a pain-related, angry or happy face) embedded among seven identical distractors (i.e., neutral faces) and were

instructed to search for the target image among competing distractors (Schoth, Godwin, Liversedge, & Liossi, 2015).

These paradigms have afforded researchers with numerous methods for quantifying visual attentional biases. In eye-tracking studies, fixations reflect the maintenance of gaze on a single location for a fixed time (i.e., 100ms or longer) while saccades occur when gaze shifts from one point to another. Some researchers have also distinguished between fixations and visits wherein each visit is defined as one or more consecutive eye movements within a given region of interest (ROI) and each visit ends when gaze shifts outside of the ROI (Fashler & Katz, 2014). Thus, it is possible for a person to make several fixations within a single visit. Given this distinction, the duration of a visit equals the total duration of any eye movement that occurs within a single visit to an ROI regardless of whether the eye movement meets criteria for a fixation.

In the present review, eye movement indices were divided into three categories: initial orienting, attentional engagement and attentional maintenance. Indices of initial orienting include first fixation proportion and first fixation latency, which refer to the proportion of first fixations that fall within a particular ROI and the time needed to initially fixate on an ROI, respectively (Yang et al., 2012). To quantify attentional engagement, researchers have used indices including total fixation counts and total visit counts, which are the total number of fixations/visits that occur within an ROI (Fashler & Katz, 2014). In terms of attentional maintenance, some studies quantified durations of first fixations/visits, some quantified average durations of fixations/visits, and some others calculated total gaze duration based on the sum of all fixation durations within an ROI (Yang et al., 2012). These indices were then either directly used in analyses or further transformed into attentional bias scores by subtracting the indices for neutral stimuli from those for pain-related or affectively-valenced stimuli (Sun et al., 2016). Most studies quantified these indices within experimenter-defined ROIs and time segments. By doing this, changing patterns of viewing throughout stimulus

presentations could be quantified so that initial orienting for pain-related information and subsequent maintenance or avoidance of such information could be discerned.

Although some previous studies treated total fixation/visit count as measures of attentional maintenance, in the present review we refer to these as measures of attentional engagement because fixation/visit count data represent the frequency with which participants fixate on or visit a particular stimulus category while fixation duration data represent the tendency to maintain attention on specific stimuli. As suggested by some studies (Jackson et al., 2018a; Yang et al., 2012), higher total fixation counts might reflect a pattern of more frequent disengagement followed by re-engagement, rather than a pattern of continuous dwelling. These two groups of indices are, therefore, fundamentally distinct and warrant separate consideration. In addition, these eye movement indices might be reflective of overt attention but not covert attention, which could occur in the absence of saccadic eye movements registered by eye-tracking (e.g., prior to initial fixation, etc.) (Armstrong & Olatunji, 2012). Therefore, this systematic review is focused mainly on overt components of visual attentional biases in the context of pain.

This overview underscores substantial heterogeneity between studies in relation to participant groups and their assessment, use of pain manipulations, viewing paradigms, and operationalisations of attention. It is unclear how these variables affect the presence and magnitude of attentional biases. As such, we present a systematic review of evidence regarding associations between overt components of visual attention and the experience (induced or otherwise) or anticipation of pain. Although included studies were not limited to samples diagnosed with pain conditions or those who reported ongoing pain experiences, our primary focus was upon differences in visual attention towards pain-related stimuli among people with current pain experiences compared to pain-free controls. The review also examined the extent to which pain-related moderators such as fear of pain, pain catastrophising, and pain-related threat, are associated with eye movements on visual stimuli.

Among healthy individuals, these processes might precede and contribute to the emergence of chronic pain problems so research on pain-free groups is worthy of review. Finally, limitations within this literature were considered to provide foundations for future research designed to elucidate the role of attentional biases in pain experiences as well as the development and refinement of psychological interventions for pain.

Methods

Search strategy

The initial search included all available English-language journal articles and dissertations up to 27 December 2019 that investigated visual attentional processes quantified in terms of eye movements associated with the experience (induced or otherwise) or anticipation of pain. A literature search was performed within three electronic databases (ProQuest, PubMed, Web of Science), using title and abstract searches for the following keyword combinations: (*pain*) AND (*eye-tracking* OR *eye tracking* OR *gaze behavio*r* OR *EMs* OR *eye movement** OR *fixation*) AND (*attention* bias** OR *selective attention* OR *vigilance* OR *hypervigilance* OR *avoidance* OR *maintenance* OR *disengagement*). An updated search was conducted to retrieve records published between the end date of the initial search and 2 May 2020.

Eligibility criteria

There were two primary eligibility criteria for the review: (1) eye-tracking had to be used and attention to visual stimuli had to be quantified; and (2) attentional biases had to be studied within the context of pain (i.e., among people with chronic pain, people exposed to experimentally-induced pain or under the threat of experiencing pain, and healthy people who displayed quantifiable individual differences in pain-related experience or anticipation such as fear of pain or pain catastrophising). Based on these two criteria, studies did not have to include pain-related stimuli so long as attention to visual stimuli was quantified by eye movement indices and the second criterion was satisfied. For example, although Giel et al. (2018) presented only happy, sad, and neutral faces to participants, the sample comprised a

group with chronic pain and healthy controls and the authors quantified attention to these

images using eye movement indices. Therefore, this study was included in the review.

Data screening

The search flow is illustrated in Figure A1 (Moher et al., 2009). The initial search retrieved

960 articles, of which 402 were duplicates. The first and second authors (F.C. & H.S.)

independently screened titles and abstracts of the remaining 558 articles according to the

eligibility criteria. Both authors screened all papers and disagreements were resolved through

discussion and consensus. Interrater reliability was good (kappa = .893). Five hundred

twenty-five papers were deemed irrelevant to the review. After reading full-text versions of

the remaining 33 papers, ten articles were excluded for the following reasons: eye-tracking

technology was not involved (n = 4) (Schoth et al., 2018; Schoth, Beaney, et al., 2019;

Schoth, Ma, et al., 2015; Trost et al., 2016), status as a commentary (n = 2) (Sharpe, 2014;

Van Ryckeghem & Vervoort, 2016) or review article (n = 1) (Todd et al., 2015), eye-tracking

was used as a manipulation check instead of an outcome measure of attention (n = 1)

(Vervoort, Trost, Sütterlin, Caes, & Moors, 2014), psychometric properties of eye-tracking

such as test-retest reliability were examined rather than group comparisons or correlations

with pain indices (n = 1) (Skinner et al., 2018), and attention to visual stimuli was not

quantified (n = 1) (Schmidt et al., 2018). In addition to the 23 relevant articles retrieved from

the initial search, the updated search led to the discovery of one new article published after

the initial search that also met the inclusion criteria (Pilch et al., 2020). The final review

involved 24 papers.

Data extraction and synthesis

The first and second authors independently extracted then combined the following data from

studies: (1) sample characteristics (sample size, proportion of females, mean age); (2)

grouping/manipulation (e.g., diagnosis-control comparison, experimental pain stimulation,

threat manipulation, etc.), (3) stimulus presentation paradigm (task, presentation duration),

(4) stimulus characteristics (type, valence of stimuli), (5) eye movement indices (e.g., fixation count, fixation duration, etc.) and (6) data from analyses of between-group comparisons (e.g., clinical or self-reported pain versus pain-free controls), between-stimulus comparisons (e.g., pain-related versus neutral stimuli), between-manipulation differences (e.g., high- versus low-threat), or associations between eye movement indices and continuous pain-related indices (e.g., fear of pain, pain catastrophising). There was 100% agreement between raters in the coding of all extracted data.

Across reviewed studies, we synthesised evidence regarding (1) eye movement differences between groups with ongoing pain and controls, (2) eye movement differences between stimulus valences, (3) relations between experimentally-induced pain or experimentally-manipulated threat and eye movements, and (4) relations between eye movements and individual differences in pain experience or anticipation (e.g., fear of pain, pain catastrophising). These data were synthesised and reported separately for initial orienting (i.e., first fixation proportion, first fixation latency), followed by attentional engagement (i.e., total fixation/visit count) and attentional maintenance (i.e., first fixation/visit duration, average fixation/visit duration, total gaze duration).

To allow for more robust comparisons between studies, we extracted effect sizes of main findings reported in each study. For studies that reported effect sizes, we extracted the Cohen's *d* and converted all other calculations (e.g., *r*, eta-squared, etc.) to Cohen's *d* (Cohen, 1988; Rosenthal, 1994). For studies that only reported means and standard deviations or standard errors, we computed the Cohen's *d* for group comparisons (Lakens, 2013). Other studies did not report statistics that were necessary for the calculation of effect sizes. Effect sizes for Cohen's *d* values of 0.80, 0.50, and 0.20, respectively, were considered to be large, moderate and small in magnitude (Kotrlik & Williams, 2003; Vacha-Haase & Thompson, 2004). All findings identified as significant had *p* values lower than .05.

Results

Descriptive statistics and methodological quality

Study characteristics are reported in Table A1. Twenty-four studies were included in the final review. Thirteen studies reported on participants with chronic pain (n = 486). Two of these studies used the same chronic pain sample but adopted different tasks (Fashler & Katz, 2014, 2016). Seven studies reported on participants experiencing or anticipating experimentally-induced pain or threat (n = 552). Four studies reported on healthy people and examined relations between gaze behaviour and individual differences in pain experience or anticipation (e.g., fear of pain, pain catastrophising; n = 209). In terms of stimulus presentation paradigms, 12 studies used dot-probe tasks with presentation durations ranging from 500-4000ms, 13 studies used free-viewing tasks in which participants viewed one or multiple stimuli simultaneously with presentation durations ranging from 1000-8000ms, and one study used a visual search task. For visual stimuli, seven studies used words, 12 used face images and eight used scene images. Most studies examined initial orienting (k = 20) and attentional maintenance (k = 23), while less than half examined attentional engagement (k = 10).

Methodological quality was assessed according to a framework adapted from CONSORT criteria (Moher et al., 2010) by Crombez et al. (2013). On average, 95% of studies fulfilled the external validity criteria and 79% fulfilled the internal validity criteria, which were improved compared to previous meta-analyses of reaction time paradigms (Crombez et al., 2013; Todd et al., 2018). One possible reason is that the introduction of eye-tracking enables researchers to account for participants' engagement with the task. However, relevance of pain-related information to participants remains to be an area in need of improvement as only 58% of studies provided such descriptions.

Initial orienting

Initial orienting has been quantified most often by first fixation proportion and first fixation latency. First fixation proportion is typically calculated by the percentage of first fixations

that fall within an ROI, while first fixation latency indicates the average time taken to first fixate on an ROI.

First fixation proportion

Six studies compared first fixation proportion between participants with and without chronic pain. Two studies provided evidence that people with chronic headache had more first fixations on painful face expressions than did pain-free controls ($d = 0.79$-0.93) (Liossi et al., 2014; Schoth, Godwin, et al., 2015) but four others revealed no group differences (Giel et al., 2018; Mahmoodi-Aghdam et al., 2017; Mazidi et al., 2019; Yang et al., 2013).

Eight studies conducted between-stimulus comparisons of first fixation proportion within chronic pain samples, with five indicating that participants made significantly more first fixations on pain-related stimuli than neutral stimuli ($d = 0.47$-2.00) (Jackson et al., 2018b, 2019; Liossi et al., 2014; Mahmoodi-Aghdam et al., 2017; Schoth, Godwin, et al., 2015). Five studies indicated that first fixations on pain stimuli were more common among healthy participants ($d = 0.11$-2.00) (Heathcote et al., 2017; Jackson et al., 2018a; Ling et al., 2019; Mahmoodi-Aghdam et al., 2017; Pilch et al., 2020). In contrast, one study based on healthy adults found a lower first fixation proportion on pained faces than neutral faces (Priebe et al., 2015), but this exception cannot be explained by differences in study characteristics. One other study found a first fixation proportion bias towards positively-valenced (happy) faces compared to neutral faces in groups with and without chronic pain ($d = 1.44$) (Giel et al., 2018).

Regarding pain-related moderators, four studies compared participants high and low in fear of pain. One study provided evidence for an initial orienting bias (i.e., more first fixations) towards sensory pain words in healthy adults with high fear of pain compared to those with low fear of pain (Yang et al., 2012) but three other studies found no fear of pain effects on orienting (Jackson et al., 2018b; Sharpe et al., 2017; Yang et al., 2013). In six studies that investigated effects of threat on first fixation proportion, three found that first

fixation proportion on pain-related stimuli was reduced by the threat of pain ($d = 0.26$-0.84) (Jackson et al., 2018a, 2018b; Sharpe et al., 2017), while one found a complementary effect ($d = 0.32$) (Ling et al., 2019), and two others found no effect (Schoth, Wu, et al., 2019; Todd, Sharpe, Colagiuri, et al., 2016).

In sum, between-group comparisons revealed that a unique orienting bias towards pain-related stimuli indexed by first fixation proportion may be evident only among people with chronic headache, but not heterogeneous chronic pain complaints. Furthermore, people with and without chronic pain may have a shared tendency to initially orient towards pain-related stimuli compared to neutral stimuli. Although the number of effect sizes is small, first fixation proportion biases might also be evident for positively-valenced stimuli. Although pain-related fear does not seem to affect first fixation proportions toward pain, effects of pain-related threat may vary across stimulus categories and threat manipulation paradigms.

First fixation latency

Five studies compared first fixation latency between those with and without chronic pain; one study found faster initial fixations on painful activity images among chronic back pain patients compared to controls ($d = 0.70$) (Franklin et al., 2019), while four others revealed null effects (Mahmoodi-Aghdam et al., 2017; Mazidi et al., 2019; Schoth, Godwin, et al., 2015; Yang et al., 2013).

In terms of between-stimulus comparisons within chronic pain groups, findings varied across paradigms. In particular, people with chronic pain had faster initial fixations on pained faces than neutral faces in a visual search task ($d = 1.12$) (Schoth et al., 2015), but had slower initial fixations on injury scenes than neutral scenes when image pairs signalled potential painful stimulation ($d = 0.46$) (Jackson et al., 2018b). In studies using dot-probe tasks in chronic pain samples, one study found evidence for faster initial fixations on painful activity images than neutral images ($d = 0.70$) (Franklin et al., 2019) while three others found no evidence of such biases (Jackson et al., 2018b; Mazidi et al., 2019; Yang et al., 2013).

Patterns displayed by healthy participants were also inconsistent; three studies found these groups initially fixate more slowly on pain-related images than neutral images (d = 0.57-0.70) (Mahmoodi-Aghdam et al., 2017; Schoth, Wu, et al., 2019), two studies observed faster first fixations on pain-related images (d = 0.26-1.12) (Jackson et al., 2018a; Schoth, Godwin, et al., 2015), and five studies reported no such biases (Mazidi et al., 2019; Sharpe et al., 2017; Sun et al., 2016; Todd, Sharpe, Colagiuri, et al., 2016; Yang et al., 2013). In addition, first fixation latency differences between stimulus valences may not be unique to pain-related stimuli, as groups with and without chronic pain have both been found to fixate more rapidly on happy faces than neutral faces (d = 0.53) (Schoth et al., 2015).

Regarding pain-related moderators, seven studies examined the role of fear of pain in first fixation latencies. One study found healthy people with higher fear of pain fixated more quickly on sensory pain words than less pain-fearful cohorts during a dot-probe task (d = 0.21) (Yang et al., 2012). However, six studies comprising chronic pain or healthy samples did not find an association between fear of pain and this particular index (Jackson et al., 2018b, 2018a; Schoth, Wu, et al., 2019; Sharpe et al., 2017; Todd, Sharpe, Colagiuri, et al., 2016; Yang et al., 2013). In relation to moderating effects of pain catastrophising, one study found that low catastrophising healthy participants had shorter first fixation latencies for pained faces than neutral faces during free-viewing, with initial fixation latencies becoming increasing faster with increasing levels of pain expression in images (Vervoort et al., 2013). In studies featuring manipulations of pain expectations and somatosensory stimulation, first fixation latencies were not affected by thermal pain prior to a dot-probe task (Sun et al., 2016), possible electric pain following stimulus presentations (Jackson et al., 2018a, 2018b), or pain-related threatening instructions (Schoth, Wu, et al., 2019; Sharpe et al., 2017; Sun et al., 2016; Todd, Sharpe, Colagiuri, et al., 2016).

In summary, first fixation latencies did not appear to differentiate people with and without chronic pain, with the exception of one study with chronic back pain patients.

Regarding between-stimulus comparisons of first fixation latencies, mixed results were observed. Although differences in study characteristics may explain these discrepancies, a conclusion or hypothesis may seem premature due to the limited number of effect sizes available for direct comparison. In terms of pain-related moderators, rather consistent null effects have been found for relations between first fixation latencies and fear of pain, experimentally-induced pain, and pain-related threat. Only one study examined the effect of pain catastrophising on first fixation latencies and therefore results may be inconclusive.

Attentional engagement

Attentional engagement is typically quantified by the total number of fixations and visits that fall within a particular ROI throughout stimulus presentation.

Total fixation/visit count

In between-group comparisons of total fixation counts, only one study found evidence that people with chronic pain had more fixations on sensory pain words than did pain-free controls in a dot-probe task ($d = 0.48$) (Fashler & Katz, 2014); four other investigations using other types of stimuli revealed null effects (Fashler & Katz, 2016; Franklin et al., 2019; Mahmoodi-Aghdam et al., 2017; Mazidi et al., 2019). Between-stimulus comparisons of total fixation counts in four chronic pain samples found more fixations on pain-related stimuli in the presence of neutral stimuli ($d = 1.54$-2.73) (Fashler & Katz, 2014, 2016; Franklin et al., 2019; Jackson et al., 2018b; Mahmoodi-Aghdam et al., 2017). This bias in number of fixations on pain-related stimuli presented with neutral stimuli extended to three healthy adult samples ($d = 0.47$-2.73) (Fashler & Katz, 2014, 2016; Jackson et al., 2018a; Mahmoodi-Aghdam et al., 2017). However, one other study that presented individual scene images indicated healthy adults had fewer fixations on injury scenes than neutral scenes ($d = 0.36$) (Schoth, Wu, et al., 2019).

In the few studies that have assessed total visit counts, it is also consistent that there is no difference between chronic pain samples and healthy groups (Fashler & Katz, 2014, 2016;

Liossi et al., 2014). In terms of between-stimulus comparisons, evidence varied across paradigms. More specifically, increased number of visits for pain-related stimuli compared to neutral stimuli has been found in people with and without chronic pain when performing dot-probe tasks with words or scene images (d = 1.11-1.66) (Fashler & Katz, 2014, 2016) while visits to neutral stimuli predominated in a free-viewing task with face images (d = 0.26-0.57) (Liossi et al., 2014).

In terms of pain-related moderators, anticipation of potential electric pain following the offset of injury images increased total fixation counts on injury images in healthy adults (d = 0.53) (Jackson et al., 2018a), but not in chronic pain patients (Jackson et al., 2018b).

Overall, a majority of studies found no difference in attentional engagement for pain-related stimuli between people with and without chronic pain. Between-stimulus comparisons of total fixation counts have revealed relatively consistent results, suggesting a general bias towards pain-related compared to neutral stimuli in groups with and without chronic pain. However, whether there is a similar effect for total visit counts remained to be determined. Pain-related threats may increase total fixation counts on injury images among healthy adults but not those with ongoing pain but this pattern is best viewed as a hypothesis since the number of effect sizes to date is small.

Attentional maintenance

Attentional maintenance in early phases of stimulus presentation has been quantified in terms of first fixation duration and first visit duration. Attentional maintenance during the entire stimulus presentation phase has been quantified by average fixation duration, average visit duration and total gaze duration. While average fixation/visit duration is calculated by taking the mean of all fixations/visits that occur on an ROI, total gaze duration is calculated by summing the duration of all fixations within an ROI. Some studies have also quantified total gaze duration into multiple time segments by dividing the whole presentation period into different phases.

First fixation/visit duration

In studies comparing first fixation durations on pain-related stimuli between chronic pain samples and healthy controls, none has found a difference (Liossi et al., 2014; Mahmoodi-Aghdam et al., 2017; Mazidi et al., 2019; Yang et al., 2013). Similarly, most studies have found no significant difference in first fixation durations on pain-related versus neutral stimuli in people with and without chronic pain (Liossi et al., 2014; Mahmoodi-Aghdam et al., 2017; Mazidi et al., 2019; Sharpe et al., 2017; Sun et al., 2016; Todd, Sharpe, Colagiuri, et al., 2016; Vervoort et al., 2013; Yang et al., 2012, 2013). Only one study found that pain-free adults had longer first fixation durations on pained than neutral faces ($d = 0.06$) (Pilch et al., 2020). Of note, however, the samples, viewing paradigms, and stimuli adopted were similar between Pilch et al. (2020) and Vervoort et al. (2013), yet inconsistent results were revealed regarding this index.

Moreover, first fixation durations on pain-related stimuli are not influenced by fear of pain (Sharpe et al., 2017; Yang et al., 2012, 2013), pain-related threatening instructions on a separate task (Sharpe et al., 2017; Sun et al., 2016; Todd, Sharpe, Colagiuri, et al., 2016), or experimental thermal pain prior to a dot-probe task (Sun et al., 2016). However, in two studies of pain-free participants that featured pain-related images signalling possible electric pain versus neutral images signalling its absence, first fixation durations for pain-related images were significantly longer ($d = 0.47$-0.58) (Jackson et al., 2018a; Ling et al., 2019).

Only two studies have examined first visit durations so results are inconclusive. One study found samples with and without chronic pain both had shorter first visit durations for painful activity images than neutral images ($d = 0.94$) (Mahmoodi-Aghdam et al., 2017). In another study with healthy participants, first visit durations for injury images were increased by thermal pain prior to a dot-probe task ($d = 0.80$) but then diminished by additional pain-related threatening instructions ($d = 0.63$) (Sun et al., 2016).

In sum, a majority of studies did not find significant effects of chronic pain or fear of pain on first fixation/visit durations. There is also limited evidence suggesting pain-related stimuli elicit longer first fixation/visit durations than neutral stimuli do. Although select research suggests experimentally-manipulated pain experiences and expectations might have stronger impact on these indices, clear conclusions are not apparent because results have been mixed and the number of effect sizes to date have been limited.

Average fixation/visit duration

Between-group comparisons showed that average fixation duration was not affected by chronic pain (Fashler & Katz, 2014, 2016; Liossi et al., 2014), fear of pain (Yang et al., 2012), or pain-related threat (Schoth, Wu, et al., 2019), though one study reported chronic back pain patients had longer fixations on painful activity images compared to healthy controls ($d = 0.90$) (Franklin et al., 2019). Between-stimulus comparisons of average fixation durations showed mixed results. One study found samples with and without chronic headaches had longer fixations for happy faces than pained faces ($d = 0.27$) (Liossi et al., 2014), while another study found a chronic back pain sample had longer fixations upon painful activity images than neutral images ($d = 0.80$) (Franklin et al., 2019). Finally, research based on healthy participants found longer average fixation durations for facial expressions than other parts of injury scene images ($d = 1.42$) (Schoth, Wu, et al., 2019).

Two studies involving the same sample used average visit durations as a bias index. Results indicated that people with chronic pain had longer mean visits for sensory-pain words ($d = 0.87$) and injury scenes ($d = 0.74$) than neutral alternatives (Fashler & Katz, 2014, 2016). For healthy controls, between-stimulus differences in visit durations were evident for injury scene images ($d = 0.74$) but not pain words (Fashler & Katz, 2014, 2016).

To summarise, average durations of fixations and visits might not be associated with chronic pain, fear of pain, or pain-related threat. However, longer mean fixations on painful activity images among chronic back pain patients compared to healthy controls suggested that

there may be pain-site-specific effects. Nonetheless, it is not clear whether there are between-stimulus differences in chronic pain samples and controls given that few studies have adopted these two indices and results, to date, have been mixed.

Total gaze duration

In studies using words, facial expressions, and daily activity images as visual stimuli, no chronic pain versus control group differences in total gaze durations have been found (Giel et al., 2018; Mahmoodi-Aghdam et al., 2017; Mazidi et al., 2019; Yang et al., 2013), even when this index was divided into multiple time segments (Fashler & Katz, 2014; Mazidi et al., 2019). However, one study presenting injury images for 2000ms suggested people with chronic pain had longer gaze durations on injury images during the 1000-2000ms segment compared to healthy controls ($d = 0.48$) (Fashler & Katz, 2016). A recent longitudinal study with a chronic pain sample found that although the total gaze duration on injury images was not associated with pain or interference at baseline, it significantly predicted elevations in pain and interference assessed at 6-month follow-up (Jackson et al., 2019). This finding suggests that even though total gaze durations may not differentiate chronic pain groups from healthy cohorts, longer gaze durations toward pain cues might instead predict later functioning in people with chronic pain.

Regarding between-stimulus comparisons of total gaze duration, some studies have suggested people with chronic pain have longer total gaze durations for pain-related stimuli than neutral stimuli ($d = 0.40$-2.40) (Jackson et al., 2018b, 2019; J. Lee et al., 2019), but others did not (J. Lee et al., 2018, 2019; Mahmoodi-Aghdam et al., 2017; Mazidi et al., 2019; Yang et al., 2013). Similarly, within healthy samples, some studies found longer total gaze durations for pain-related stimuli than neutral stimuli ($d = 0.43$-1.40) (Heathcote et al., 2017; Jackson et al., 2018a; Ling et al., 2019; Pilch et al., 2020), but others found no stimulus type differences (Mahmoodi-Aghdam et al., 2017; Mazidi et al., 2019; Sharpe et al., 2017; Sun et al., 2016; Todd, Sharpe, Colagiuri, et al., 2016; Vervoort et al., 2013; Yang et al., 2012,

2013). Methodological factors such as differences in stimulus presentation paradigm, presentation duration, and stimulus category did not appear to account for discrepancies.

When analysing gaze duration within different time segments, select research has found people with and without chronic pain initially display prolonged gaze on neutral stimuli compared to pain-related stimuli (i.e., 0-500ms; $d = 0.77$) (Fashler & Katz, 2016) and subsequently maintain gaze for more time on pain-related stimuli (i.e., 500-3000ms; $d = 0.53$-0.97) (Fashler & Katz, 2014, 2016; J. Lee et al., 2018). However, one other study reported longer gaze maintenance on pain-related stimuli than neutral stimuli during 0-1000ms but not during 1000-2000ms among healthy adults (Priebe et al., 2015). Finally, there is evidence that chronic pain samples and control groups spend more time viewing happy faces compared to (1) neutral faces during presentation durations of 3000ms ($d = 1.69$) (Giel et al., 2018), and (2) pained faces during 1000-1500ms ($d = 0.31$) (Mazidi et al., 2019).

In terms of pain-related moderators, most studies have found fear of pain has no effect on overall gaze durations during entire presentation intervals (Jackson et al., 2018a, 2018b, 2019; Sharpe et al., 2017; Todd, Sharpe, Colagiuri, et al., 2016; Yang et al., 2012, 2013), though one study found gaze durations for sensory-pain words of more pain-fearful healthy participants were reduced during the first 250ms of 1500ms presentation intervals ($d = 1.09$) (Todd, Sharpe, Colagiuri, et al., 2016). In studies examining the role of pain catastrophising, results have been mixed. Some authors have found higher pain catastrophising levels are related to longer total gaze durations on pain-related stimuli ($d = 0.74$-0.81) (J. Lee et al., 2018, 2019), while others have found positive relations of pain catastrophising with gaze durations on happy faces during the first 250ms of 1500ms presentation intervals ($d = 1.15$) (Todd, Sharpe, Colagiuri, et al., 2016) or no catastrophising-gaze duration associations (Heathcote et al., 2017; Jackson et al., 2019; Todd, Sharpe, Colagiuri, et al., 2016). Some researchers have suggested that relations of catastrophising with attentional maintenance are moderated by pain intensity and attention control, such that the tendency to catastrophise

about pain increases total gaze durations for both pained and neutral faces among cohorts who experience more intense pain (Vervoort et al., 2013), and increases total gaze durations for happy faces among persons with higher attention control (Mazidi et al., 2019).

In studies featuring experimentally-manipulated threats and pain experiences, there is evidence that total gaze duration upon injury images and pained faces that signal potential pain are longer (d = 0.46-0.86) than total gaze durations on images that signal the absence of potential pain (Jackson et al., 2018a, 2018b; Ling et al., 2019). Conversely, under conditions of low threat, participants gaze longer at happy faces than pained faces (Todd, Sharpe, Colagiuri, et al., 2016). Finally, some studies revealed no effects of pain-related threats or experimentally-induced pain on gaze durations (Sharpe et al., 2017; Sun et al., 2016).

In summary, total gaze durations on pain-related stimuli did not differ between chronic pain samples and healthy samples, except when injury images were used and time segments were defined. Initial longitudinal research suggests total gaze durations on injury images compared to neutral images predict later functioning in persons with chronic pain. However, evidence from between-stimulus comparisons within chronic pain samples and healthy groups has been mixed. Although its exact role is still unclear, pain catastrophising was more strongly associated with total gaze durations than fear of pain was. In addition, several studies indicated that threat manipulations based on pain cues that signal possible impending pain may prolong total gaze duration on pain-related stimuli, though null effects have been found when threat manipulations diverged from this approach.

Discussion

Main findings

The current review synthesised results of 24 eye-tracking studies on pain-related attentional biases in initial orienting, attentional engagement, and attentional maintenance. Regarding between-group comparisons (i.e., chronic pain vs. pain-free) of gaze biases, a majority of studies found no significant group differences in eye movements on visual stimuli, regardless

of the eye movement indices used. Instead, findings favoured general biases towards pain-related stimuli wherein chronic pain samples and pain-free controls both have more first fixations and total fixations on pain-related compared to neutral stimuli. Between-stimulus comparisons of other eye movement indices revealed either consistent null effects (i.e., first fixation duration) or mixed findings where syntheses may be premature (i.e., first fixation latency, total visit count, first visit duration, average fixation/visit duration, total gaze duration). Moreover, between-stimulus effects might not be specific to pain-related stimuli as some research has suggested a universal bias towards positive compared to neutral stimuli.

Nonetheless, overall null effects revealed by between-group comparisons may be influenced by several factors. In particular, chronic pain samples in most studies reported heterogeneous primary pain sites; only a few studies examined gaze biases in patients with specific subtypes of chronic pain. To elaborate, higher first fixation proportions for pained faces were only found among chronic headache patients compared to controls (Liossi et al., 2014; Schoth, Godwin, et al., 2015). Similarly, faster first fixations and longer mean fixations for pain-related movement images were only found among chronic back pain patients compared to controls (Franklin et al., 2019). These differences were not evident in studies of other types of chronic pain or in studies with heterogenous chronic pain samples. There may be an interaction between chronic pain subtypes and stimulus categories which might explain these findings (e.g., face stimuli may be more salient to those with headache or facial pain than those with lower extremity pain). Future studies should examine whether gaze biases differ between subtypes of chronic pain.

A related explanation for overall null effects in between-group comparisons might be the similarity in meaning that pain-related stimuli have across these groups. More precisely, stimuli such as sensory pain words, pained faces, and injury scenes may elicit similar responses in people with and without chronic pain because these stimuli are clearly related to pain experiences. In contrast, daily activity images that depict ambiguous movements (e.g.,

bending/lifting) might be more pain-provoking for people with chronic pain than healthy controls who do not associate such movements with pain. Ambiguous stimuli of this type might give rise to between-group differences because people with chronic pain interpret such stimuli in a different manner than pain-free cohorts do. Indeed, the only two studies that adopted daily activity images in this review both found pain status differences in eye movements (Franklin et al., 2019; Mahmoodi-Aghdam et al., 2017).

In terms of pain-related moderators, fear of pain had only isolated effects on eye movements; most studies failed to establish an association between this construct and gaze behaviours. In contrast, the tendency to catastrophise about pain was more strongly associated with pain-related attentional biases, although precise conditions under which catastrophising is related to gaze biases remain to be determined.

Finally, research examining effects of pain-related threat on eye movements was marked by methodological heterogeneity, particularly in various ways in which threat has been manipulated. Some studies manipulated threat by giving participants threatening or reassuring information about an upcoming cold pressor task prior to assessing gaze biases on an unrelated dot-probe task (Todd, Sharpe, Colagiuri, et al., 2016), some gave participants different information regarding the seriousness of injuries depicted in images (Schoth, Wu, et al., 2019), and some others used within-subjects designs wherein the presence of injury images signalled possible subsequent painful stimulation (i.e., high-threat task) or its absence (i.e., low-threat task) following image pairs offset (Ling et al., 2019). Of particular relevance is the threat interpretation model which suggests that there is a positive association between threat and initial vigilance, and a nonlinear relation between threat and attentional maintenance (Todd et al., 2015). More specifically, the nonlinear relation suggests that individuals can disengage easily from pain-related stimuli in low threat contexts, have difficulty disengaging from pain-related stimuli under moderately threatening conditions, and avoid pain-stimuli altogether when threat levels are sufficiently high (Todd et al., 2015).

In the current review, the positive relation between threat and initial vigilance was supported by only one study, wherein participants had more first fixations on pained faces when stimuli predicted impending pain versus nonpainful touch (Ling et al., 2019); other studies revealed either non-significant effects (Schoth, Wu, et al., 2019; Todd, Sharpe, Colagiuri, et al., 2016) or fewer first fixations on pain-related stimuli (Jackson et al., 2018a, 2018b; Sharpe et al., 2017). One hypothesis explaining this pattern is that associations between threat and initial vigilance may be stimulus-specific. More precisely, threat might increase first fixation proportions for painful facial expressions (Ling et al., 2019) as a reflection of facilitated pain empathy (Decety, 2010; Decety & Jackson, 2004) but reduce initial fixations toward affective-pain words (Sharpe et al., 2017) and injury depictions (Jackson et al., 2018a, 2018b) which generate potential inhibition.

In comparison, certain threat manipulation paradigms have produced replicable results regarding relations between threat and attentional maintenance. In studies that manipulated the threat value of pain-related images themselves (i.e., the presence of pain-related images signalled subsequent potential painful stimulation or its absence following image pair offsets), pained face and injury scene images that signalled potential pain were related to longer first fixation and overall gaze durations (Jackson et al., 2018b, 2018a; Ling et al., 2019). These studies used within-subjects designs where participants served as their own controls and were exposed to both lower- and higher-threat contexts. Importantly, these results were consistent with the moderate versus lower threat predictions from the threat interpretation model (Todd et al., 2015). Conversely, studies featuring between-group designs where participants were exposed to threatening/reassuring information about an upcoming experimental pain task that was unrelated to the viewing task have not observed consistent patterns of bias in maintenance of gaze (Sharpe et al., 2017; Todd, Sharpe, Colagiuri, et al., 2016). Although additional studies are needed, it is possible that manipulating the personal

threat value of stimuli used in viewing tasks produces relatively consistent biases in maintenance of gaze towards more threatening images.

The overall lack of differences between chronic pain cohorts versus controls are somewhat inconsistent with previous meta-analyses of reaction time investigations that reported consistent attentional biases towards sensory pain words in people with chronic pain relative to controls (Crombez et al., 2013; Roelofs et al., 2002; Schoth et al., 2012; Todd et al., 2018), albeit group differences for pain-related pictures were not observed. In the present review, only two studies examined gaze biases toward word stimuli in chronic pain cohorts versus controls. Fashler & Katz (2014) found that participants with chronic pain had more total fixations on English-language sensory pain words than did controls. Yang et al. (2013) found no group difference in eye movements towards Chinese sensory pain words. Therefore, a comparison with previous syntheses of reaction time research is difficult and may be misleading. Relatedly, it has been suggested by previous synthesis that people with chronic pain attend to sensory pain and affective pain words differently (Crombez et al., 2013; Todd et al., 2018). However, only two eye-tracking studies with healthy participants have adopted affective pain words and the findings were inconsistent (Sharpe et al., 2017; Todd, Sharpe, Colagiuri, et al., 2016). It is therefore unfeasible to compare our results with previous meta-analytic findings before more studies with both types of word stimuli are conducted. Nevertheless, our conclusion that fear of pain has no impact on eye movements is consistent with Crombez et al. (2013) who also found no effect of pain-related fear on attentional biases.

In summary, a majority of studies included in this review suggested groups with chronic pain and pain-free controls display no significant differences on pain-related gaze bias indexes. Rather, our findings revealed a universal bias towards pain where both of these groups have more first fixations and total fixations on pain-related compared to neutral stimuli. Between-stimulus comparisons of other indices have revealed null effects or mixed findings. Nonetheless, there is preliminary evidence suggesting pain-related gaze biases may

be more pronounced in certain subtypes of chronic pain and studies featuring more ambiguous stimuli (e.g., physical movements) that have potentially different meanings and implications for groups with chronic pain relative to pain-free controls. These two hypotheses should be tested in future work. Moreover, although attentional biases were not reliably associated with the presence or absence of current chronic pain, longer total gaze durations toward injury rather than neutral images have been found to predict severity of pain and disability among adults with chronic pain six months later (Jackson et al., 2019). Similar longitudinal eye-tracking studies may be a fruitful line for future research. Regarding pain-related moderators, fear of pain had no impact on pain-related gaze biases in a majority of studies. Conversely, pain catastrophising had stronger associations with gaze behaviour, though the small number of effect sizes, to date, preclude us from drawing broad conclusions from this literature. Finally, although results regarding relations between threat and gaze biases are not yet conclusive, hypotheses that emerge from these data include contentions that initial, threat-related vigilance varies as a function of pain stimulus type and within-subject designs featuring "impending pain" manipulations (Ling et al., 2019) generate comparatively consistent maintenance biases reflecting prolonged gaze towards cues that signal potential pain for participants rather than its absence.

Limitations and future directions

Eye-tracking has been considered to have advantages over reaction time measures because it can assess the dynamic course of visual attention during stimulus presentations and generate potentially more reliable data (Skinner et al., 2018). However, synthesising results of current literature on eye-tracking and pain revealed a tentative, mixed pattern of findings that may be explained by heterogeneous methodologies and small numbers of studies available for direct comparison. A critique of studies completed to date can provide a base for recommendations regarding future research directions in this field.

Eye movement analyses

One potential limitation of current eye movement analyses concerns the reliability of indices that quantify early stages of attentional bias (e.g., first fixation proportion, first fixation latency, first fixation/visit duration). A recent psychometric study suggested that reliabilities of orienting indices are poor, especially for between-group comparisons (Skinner et al., 2018). This concern might contribute to conclusions that orienting indices have typically had non-significant results when comparing people with and without chronic pain as well as mixed findings regarding effects of threat expectancies and pain stimulation on early attentional indices. In contrast, indices that quantify eye movements within longer trial durations (e.g., total gaze durations) might produce more reliable results and may be appropriate for both discriminative (between-group) and evaluative (within-group) testing (Skinner et al., 2018). Indeed, a recent longitudinal study found that while total gaze duration predicted elevations in pain and interference among people with chronic pain at a six-month follow-up, first fixation proportion did not (Jackson et al., 2019). Relatedly, Skinner et al.'s (2018) suggestion that outcome measures with longer exposure times have increased reliability may have a bearing on inconsistent findings based on the division of total gaze duration into multiple time segments (e.g., total gaze duration during 1000-1500ms). Although the reliability of total fixation counts was not assessed in Skinner et al.'s (2018) paper, results revealed by this index have been relatively consistent. Therefore, it may be helpful for future studies use eye movement indices that quantify overall attention over the entire duration of each trial. Indexes from event-related potentials such as N2 posterior contralateral amplitudes provide a neural marker of early attention allocation that has potential utility as an alternative measure of pain-related orienting biases (Wang et al., 2020).

Another problem concerns the conceptualisation of certain eye movement indices. We treated fixation/visit counts as measures of attentional engagement but some studies have conceptualised these indices as measures of attentional maintenance. Although higher fixation counts and overall dwell times on pain stimuli during a trial often correlate with one

another, fixation/visit count data appear to reflect disengagement followed by re-engagement

of eye movements upon the same stimulus that does not necessarily reflect a pattern of

continuous, uninterrupted dwelling on a particular stimulus category. Instead, higher

fixation/visit count might reflect a more erratic style of scanning (more rapid visual shifts

between attentional capture and escape), while lower fixation/visit count might reflect

relatively static gaze tendencies (Yang et al., 2012). In light of these distinctions, future

studies should consider differences between attentional engagement and attentional

maintenance to reduce ambiguity in understanding and interpretations of particular gaze

indexes.

Similarly, total gaze duration does not necessarily reflect stable maintenance of gaze

towards stimuli of interest. For example, some people may have frequent, short visits upon

pain-related images (rapid shifts between disengagement and re-engagement), while others

who have an equivalent overall total gaze duration may display less frequent, longer visits

(prolonged maintenance/disengagement difficulty). This example illustrates how attentional

biases reflecting longer overall gaze durations toward pain-related stimuli can comprise

heterogenous patterns of underlying gaze behaviour that cannot be captured by the general

index. Therefore, future studies that assess total gaze durations upon pain-related stimuli

should explore differences between possible subgroups such as those that are characterised by

infrequent visits of longer durations versus frequent visits of comparatively brief durations.

Moreover, while eye movement analyses in all included studies relied on indices

assumed to reflect attentional allocation for visual information across time, the manner in

which researchers quantified these indices was somewhat arbitrary. First, studies frequently

predefined ROIs and calculated indices based on fixations that occurred within these regions.

For instance, some studies presenting competing stimuli in each trial defined the whole

rectangular images of pain-related stimuli as ROIs and compared fixations within these

regions to those that fell in other ROIs where stimuli with different valences were shown

(Vervoort et al., 2013). In studies where individual stimuli were presented in each trial

(Schoth, Wu, et al., 2019), researchers predefined sub-ROIs within these images (e.g., an ROI

encompassing the whole face of the injured person in scene images). However, there is no

universal standard for defining the location, size or shape of ROIs. For example, some studies

adopted oval-shaped ROIs surrounding face stimuli (Schoth, Godwin, et al., 2015), while

others used rectangular ROIs (Vervoort et al., 2013). Another concern with predefining ROIs

is the possibility that potentially important information not included in ROIs is discarded.

This problem is particularly relevant in studies where individual stimuli are presented and

sub-ROIs are predefined. For example, Schoth et al. (2019) defined facial expressions in

injury scene images as ROIs, while ignoring other important information such as body sites

where injuries occurred. Similarly, predefining time segments (e.g., 0-500ms) also suffers

from a lack of consensus regarding optimal durations of time segments. For instance,

researchers have divided presentation durations of 2000ms into four equal segments (i.e., 0-

500ms, 500-1000ms, 1000-1500ms, 1500-2000ms) (Priebe et al., 2015), shorter segments for

early stages of attention (i.e., 0-250ms) (Todd et al., 2016), and longer segments for later

stages of attention (i.e., 1000-2000ms) (Fashler & Katz, 2014). Inconsistent criteria for

predefining spatial and temporal parameters might contribute to variable results between

reviewed studies. Although it is beyond the scope of this paper to provide optimal criteria for

predefining ROIs and time segments, researchers should clearly report their rationales for

selecting these parameters, ideally in an a priori manner.

 An additional concern with conventional eye movement analyses is that individual

and subgroup differences in gaze patterns are frequently neglected. Most studies are based on

the assumption that all people with chronic pain allocate their attention in similar ways and

warrant inclusion within a single group. However, it is plausible that chronic pain samples

include subgroups that display stable patterns of vigilance towards versus avoidance of pain-

related stimuli (Fashler & Katz, 2014) as a result of differences in learning history rather than

typically assessed moderators such as fear of pain or pain catastrophising (Vlaeyen, 2015).

Thus, relying on group-based aggregate statistics might mask different patterns of biases that

are explained by distinct mechanisms. Future work in this area should therefore consider

individual differences in eye movement patterns as variables of interest rather than noise.

Complementing conventional eye movement analysis approaches with more advanced

approaches to operationalising gaze behaviour may address some of the aforementioned

challenges and provide novel insights. For example, Caldara and Miellet (2011) developed a

data-driven heatmap-based solution (i.e., iMap) that does not require predefining ROIs. iMap

generates fixation density maps for each individual and each visual stimulus that can then be

averaged into group fixation maps, thus allowing for between- and within-subjects

comparisons (Lao et al., 2017). Another recently developed method uses hidden Markov

models to analyse eye movement data (i.e., EMHMM) (Chuk et al., 2014). In brief, EMHMM

is a data-driven machine-learning approach that summarises individuals' gaze patterns with

personalised ROIs and transition probabilities among them. These individual patterns can be

categorised into different pattern subgroups via a clustering algorithm (Coviello et al., 2012),

and the extent to which one adopts a certain pattern can then be quantified. In previous

studies using this technique, an analytic pattern (focusing on the eye region) and a holistic

pattern (focusing on the face centre) were found in the general population in face viewing

tasks (Chuk et al., 2014), while a focused pattern (focusing on foreground) and an explorative

pattern (more frequent shifts between foreground and background) were found in scene

viewing tasks (Hsiao et al., 2019). This approach may be highly applicable to pain research,

because face and scene images have also been used frequently in this field. Future

investigations should adopt novel approaches based on gaze pattern subgrouping to clarify

the nature and implications of pain-related attentional biases more fully.

Sample characteristics

There is clearly a lack of eye-tracking research that focuses on paediatric samples in the current literature. Only one study included in this review assessed children (Heathcote et al., 2017). However, chronic pain is common among children and adolescents, with median prevalence rates for different chronic pain subtypes ranging from 10% to 40% (King et al., 2011). Pain becomes more prevalent as children become adolescents and youths who report persistent pain are more likely to become adults with chronic pain (Kamper et al., 2016). Following Lau and colleagues (2018), there is a need to study pain-related cognitive biases in younger age groups because pain-related attention biases may start to emerge and stabilise during childhood and adolescence.

Relatedly, none of the reviewed studies assessed older adults, a group at higher risk of chronic, debilitating pain and poorer treatment responses (Gibson & Lussier, 2012; Schofield, 2007; Tsang et al., 2008). To our knowledge, studies of older adults have been limited to examining effects of pain on broader cognitive functioning based on the premise that age-related cognitive declines worsen pain experiences (Moriarty et al., 2011). Future studies comparing older versus younger adults may clarify age differences in patterns of visual attention for pain-related information and attention as a factor that accounts for age group differences in pain perception and disability.

Underlying the need for research on younger and older age groups, 14 of 23 studies included in this review evaluated undergraduate student samples that comprised more women than men. Other studies recruited adults with wider age ranges, but most had a mean age of less than 50 years. Though investigating pain-related attentional processes in younger adults is important, this group is potentially more highly educated, socioeconomically more advantaged, less impaired and more unlikely to be taking medications, and less representative of the population affected by persistent pain problems (Yang et al., 2013). As such, findings from this review may not be readily generalisable to the population suffering from pain problems including acute pain, different subtypes of chronic pain, and pain reported by

people with other health conditions such as cancer. The scope of future studies should be

extended to more gender-diverse samples and to those who are less educated, of lower

socioeconomic status, and more severely impaired by pain.

Nearly half of the included studies did not report whether participants were screened

for current/past psychiatric illnesses. Screening mental illnesses is important because chronic

pain that is comorbid with mental disorders, including depression (H.-J. Lee et al., 2018;

Miller & Cano, 2009) and anxiety disorders (e.g., PTSD) may exacerbate disturbances

(Gallagher & Verma, 1999; Leo, 2005; Li, 2015) and influence attentional processes in a

manner that differs from chronic pain without comorbidity. In one included study, Giel et al.

(2018) investigated attentional biases in chronic pain patients, healthy controls, and pain-free

individuals who were matched to the chronic pain group according to depressive symptoms.

In this sample, nearly 40% of chronic pain patients met criteria for at least one mental

disorder, primarily those related to mood and/or anxiety. Giel et al. (2018) reported several

similarities in information processing of emotionally-valenced information between chronic

pain patients and those with depressive symptoms. Although the authors did not compare

attentional processes between pain patients with and without comorbid disorders, their results

reinforced evidence of substantial overlaps between chronic pain and depression, and

heterogeneity in chronic pain comorbidities. Future studies should include screening criteria

for history and presence of psychiatric disorders in order to consider or rule out effects that

are driven by symptoms that are not a direct reflection of pain alone. Inclusion of self-report

measures of depressive and anxious symptoms within assessment protocols may also help to

disentangle links of emotional disturbances versus pain status with gaze bias tendencies.

Ecological validity and personal relevance

Dear et al. (2011) assessed attentional biases using a word-based and a picture-based dot-

probe tasks and found an effect only for idiosyncratically chosen pictorial stimuli. This result

suggested that both ecological validity and personal relevance are important considerations in the design of attentional bias research.

Pain-related word stimuli (Yang et al., 2012), painful expression images (Vervoort et al., 2013), pictures depicting injuries during daily situations (Sun et al., 2016), and daily activity pictures that might be perceived as painful by people with chronic pain (Mahmoodi-Aghdam et al., 2017) have all been used to assess pain-related attention biases. Word stimuli can control for confounding factors (e.g., novelty, complexity) and have elicited pain-related attentional differences between chronic pain cohorts and pain-free controls in select studies (Fashler & Katz, 2014; Yang et al., 2013). However, word stimuli may not approximate real-life situations in which pain is experienced.

Although an increasing number of eye-tracking studies have used pictorial stimuli in recent years, presentations of these stimuli can have poor ecological validity. Typically, two or more competing images of different valences are presented simultaneously in laboratory task trials, yet these presentations seldom resemble scenarios that occur in everyday life. It is also unclear how the presence of a neutral stimulus influences visual processing of a complementary pain-related stimulus (Schoth, Wu, et al., 2019). In contrast, few studies have presented individual stimuli within eye-tracking paradigms so our current knowledge of pain-related attentional biases might be limited to evidence reflecting selective attention to pain-related stimuli in the presence of competing stimuli with other valences. Processing biases related to single image presentations are less well understood in the attention bias literature and warrant consideration.

Other ways to improve ecological validity include using dynamic stimuli such as videos and novel technologies such as eye-tracking in immersive virtual environments instead of static stimuli. Dynamic stimuli have emerged in attentional bias research on affective disorders (e.g., social anxiety) (Weeks et al., 2013; Wieser et al., 2009). More recent studies have recorded participants' eye movements during webcam conversation with

confederates (Howell et al., 2016), or while viewing virtual bodies in immersive virtual reality scenarios (Porras-Garcia et al., 2019). The incorporation of these strategies within eye-tracking studies of pain may provide additional insights that cannot be garnered by the reliance on static images.

In terms of personal relevance, pain-related visual stimuli alone may be irrelevant to participants since these stimuli usually depict other people experiencing pain. In the current review, nearly half of the studies did not describe whether or how pain stimuli used in assessments of attention were sufficiently salient to participants. Stimulus relevance assessments should be incorporated within future studies. Following from impending pain research on reaction time, one approach to increasing the personal relevance of painful images has been to inform participants that the presence of such images signals the potential delivery of painful somatosensory stimulation to one's extremities (Jackson et al., 2018a; Ling et al., 2019). Another strategy was to tell participants that painful facial expressions they viewed were from other participants who had undergone a painful laboratory task that participants were about to undergo themselves (Heathcote et al., 2017). Future investigations that incorporate strategies to increase the personal relevance of experimental pain stimuli for participants may improve the internal validity of this field.

Attentional biases as a risk factor and cause of pain responses

Previous eye-tracking studies focused primarily on associations between the presence or absence of current pain or related experiences (e.g., pain catastrophising) and gaze biases. Cross-sectional designs, common within this field, have constrained the scope of research questions that can be investigated. Several studies have featured designs that allowed investigators to evaluate the impact of pain-related attentional biases from a viewing task on subsequent laboratory pain responses (Sharpe et al., 2017). One recent longitudinal eye-tracking study also assessed the impact of pain-related gaze biases at baseline on changes in adjustment to chronic pain six months later (Jackson et al., 2019). Future prospective

investigations should be undertaken to clarify the predictive validity of gaze biases from

laboratory tasks on responses to laboratory pain and risk for the development and

maintenance of persistent, disabling pain.

This field would also benefit from intervention research that examines whether and

how gaze biases change following pain treatments and the impact of reductions in pain-

related gaze biases on pain relief. There has been a growing literature investigating

attentional bias modification training in the context of pain. Presumably, training participants

to shift attention away from threats is related to better pain outcomes. However, results from

reaction time paradigms have been inconsistent in relation to effects of training on changes in

attentional biases and pain intensity (Heathcote et al., 2018; Schoth, Georgallis, & Liossi,

2013; Van Ryckeghem, Van Damme, & Vervoort, 2018). One study has incorporated eye-

tracking technology within an attention bias modification protocol (Todd, Sharpe, &

Colagiuri, 2016), though the intervention did not affect gaze biases. Further studies are

warranted because such investigations offer another opportunity to explore causal hypotheses

regarding the nature of attentional processes that contribute to pain and its relief.

Attentional biases are unlikely to be the sole contributor to pain and pain-related

beliefs. The development and exacerbation of pain is a multifaceted process that involves

attention as well as interpretation and memory (Crombez et al., 2015; Todd et al., 2015; Van

Ryckeghem et al., 2019). To date, most eye-tracking studies investigate attentional biases in

isolation of other cognitive processes. However, as suggested by the recent threat

interpretation model (Todd et al., 2015), the presence of attentional biases is dependent on

pain experiences as well as interpretations of pain as salient or threatening. Van Ryckeghem

et al. (2019) also suggested that different forms of cognitive biases co-occur and interact with

each other. Hence, future studies should examine biases in attention, interpretation, and

memory in combination to foster an integrative view of how these processes are associated

with pain experience. In addition, there is emerging evidence showing that attention control is

an important moderator of the association between anxiety, pain catastrophising and attentional biases (Heathcote et al., 2017; Mazidi et al., 2019). Future studies that include measures of attention control may aid in explaining variability in findings between samples.

Furthermore, recent theoretical models suggest that cognitive processes should be considered in tandem with motivational and contextual factors (Crombez et al., 2012; Tabor et al., 2020; Van Ryckeghem et al., 2019). More specifically, cognitive biases are dynamic phenomena that can be influenced by the presence of pain-relevant goals (e.g., controlling pain) or competing goals (e.g., performing valued daily activities) as well as contextual variables such as the presence of safety cues and significant others (Crombez et al., 2012; Tabor et al., 2020; Van Ryckeghem et al., 2019). Indeed, a study included in this review found that gaze biases towards injury images were diminished when participants were motivated to avoid negative outcomes (i.e., pain stimulation) by maximising their speed and accuracy in a dot-probe task (Sun et al., 2016). Several studies indicated within-person gaze biases can be altered by the threat value of painful visual cues (Jackson et al., 2018b, 2018a; Ling et al., 2019). Additionally, a recent study found that gaze maintenance on facial expressions of pain can be influenced by different perspectives adopted by observers (e.g., self-perspective: imagining oneself to be in the pain sufferer's situations; other-perspective: consider feelings of the depicted person) (Pilch et al., 2020).

Finally, cognitive biases should be considered within a person's broader learning history. In particular, people with chronic pain may acquire heightened expectations for pain and reduced discriminative acuity of bodily sensations through associative learning processes that emerge during painful events (Zaman et al., 2015). Through these associative processes, interpretations of harmless, neutral stimuli can be altered to predict pain (Madden et al., 2016). Heightened expectations of pain might then affect attentional processing of people with ongoing pain so that they become hypervigilant toward or avoidant of cues that are now perceived as pain-related (Vlaeyen, 2015). The extent to which attentional biases are learned

through painful experiences and the impact of attention on learning during painful experiences are important foci for future research.

Conclusion

This systematic review examined pain-related biases in initial orienting, attentional engagement, and attentional maintenance from eye-tracking studies of pain. Overall results provided limited evidence for gaze biases within chronic pain samples having heterogeneous pain complaints compared to pain-free controls, though there is initial evidence for stronger pain-related gaze biases in homogeneous chronic pain subtypes (e.g., chronic headache) and ambiguous stimuli such as images of physical movements whose meanings are more salient for persons with chronic pain. In contrast, a majority of studies suggested that chronic pain samples and pain-free controls both display more first fixations and total fixations upon pain-related stimuli than neutral stimuli. Fear of pain had only isolated associations with gaze biases while relations of pain catastrophising and experimental pain with pain-related gaze biases were inconsistent and difficult to synthesise. Although there was some evidence indicating pain-related gaze biases are influenced by threat, effects might be context-specific and dependent on the nature of pain-related images used and threat manipulation paradigms adopted. Future studies based on more sophisticated, rigorous analyses of eye movement data, more diverse samples, paradigms with increased ecological validity and a broader conceptual scope that considers interactions between multiple cognitive processes can help to advance the field.

References

Armstrong, T., & Olatunji, B. O. (2012). Eye tracking of attention in the affective disorders:

A meta-analytic review and synthesis. *Clinical Psychology Review*, *32*, 704–723.

https://doi.org/10.1016/j.cpr.2012.09.004

Caldara, R., & Miellet, S. (2011). iMap: A novel method for statistical fixation mapping of

eye movement data. *Behavior Research Methods*, *43*, 864–878.

https://doi.org/10.3758/s13428-011-0092-x

Chen, N. T. M., & Clarke, P. J. F. (2017). Gaze-Based Assessments of Vigilance and

Avoidance in Social Anxiety: a Review. *Current Psychiatry Reports*, *19*, 59.

https://doi.org/10.1007/s11920-017-0808-4

Chuk, T., Chan, A. B., & Hsiao, J. H. (2014). Understanding eye movements in face

recognition using hidden Markov models. *Journal of Vision*, *14*(11), 1–14.

https://doi.org/10.1167/14.11.8

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*. Erlbaum.

Coviello, E., Chan, A. B., & Lanckriet, G. R. G. (2012). Clustering hidden Markov models

with variational HEM. *Journal of Machine Learning Research*, *1*, 1–44.

http://arxiv.org/abs/1210.6707

Crombez, G., Eccleston, C., Van Damme, S., Vlaeyen, J. W. S., & Karoly, P. (2012). Fear-

avoidance model of chronic pain: The next generation. *Clinical Journal of Pain*, *28*(6),

475–483. https://doi.org/10.1097/AJP.0b013e3182385392

Crombez, G., Heathcote, L. C., & Fox, E. (2015). The puzzle of attentional bias to pain. *Pain*,

156(9), 1581–1582. https://doi.org/10.1097/j.pain.0000000000000255

Crombez, G., Van Ryckeghem, D. M. L., Eccleston, C., & Van Damme, S. (2013).

Attentional bias to pain-related information: A meta-analysis. *Pain*, *154*, 497–510.

https://doi.org/10.1016/j.pain.2012.11.013

Dear, B. F., Sharpe, L., Nicholas, M. K., & Refshauge, K. (2011). Pain-related attentional

biases: The importance of the personal relevance and ecological validity of stimuli. *Journal of Pain*, *12*(6), 625–632. https://doi.org/10.1016/j.jpain.2010.11.010

Decety, J. (2010). The neurodevelopment of empathy in humans. *Developmental Neuroscience*, *32*, 257–267. https://doi.org/10.1159/000317771

Decety, J., & Jackson, P. L. (2004). The functional architecture of human empathy. *Behavioral and Cognitive Neuroscience Reviews*, *3*(2), 71–100. https://doi.org/10.1177/1534582304267187

Dehghani, M., Sharpe, L., & Nicholas, M. K. (2003). Selective attention to pain-related information in chronic musculoskeletal pain patients. *Pain*, *105*, 37–46. https://doi.org/10.1016/S0304-3959(03)00224-0

Eccleston, C., & Crombez, G. (1999). Pain Demands Attention: A Cognitive-Affective Model of the Interruptive Function of Pain. *Psychological Bulletin*, *125*(3), 356–366. https://doi.org/10.1109/METAMAT.2006.334934

Fashler, S. R., & Katz, J. (2014). More than meets the eye: Visual attention biases in individuals reporting chronic pain. *Journal of Pain Research*, *7*, 557–570. https://doi.org/10.2147/JPR.S67431

Fashler, S. R., & Katz, J. (2016). Keeping an eye on pain: Investigating visual attention biases in individuals with chronic pain using eye-tracking methodology. *Journal of Pain Research*, *9*, 551–561. https://doi.org/10.2147/JPR.S104268

Franklin, Z., Holmes, P., & Fowler, N. (2019). Eye Gaze Markers Indicate Visual Attention to Threatening Images in Individuals with Chronic Back Pain. *Journal of Clinical Medicine*, *8*(1), 31. https://doi.org/10.3390/jcm8010031

Gallagher, R. M., & Verma, S. (1999). Managing pain and comorbid depression: A public health challenge. *Seminars in Clinical Neuropsychiatry*, *4*(3), 203–220.

Gibson, S. J., & Lussier, D. (2012). Prevalence and Relevance of Pain in Older Persons. *Pain Medicine*, *13*, S23–S26.

Giel, K. E., Paganini, S., Schank, I., Enck, P., Zipfel, S., & Junne, F. (2018). Processing of

emotional faces in patients with chronic pain disorder: An eye-tracking study. *Frontiers*

in Psychiatry, *9*, 63. https://doi.org/10.3389/fpsyt.2018.00063

Haggman, S. P., Sharpe, L., Nicholas, M. K., & Refshauge, K. M. (2010). Attentional Biases

Toward Sensory Pain Words in Acute and Chronic Pain Patients. *Journal of Pain*,

11(11), 1136–1145. https://doi.org/10.1016/j.jpain.2010.02.017

Heathcote, L. C., Jacobs, K., Van Ryckeghem, D. M. L., Fisher, E., Eccleston, C., Fox, E., &

Lau, J. Y. F. (2018). Attention bias modification training for adolescents with chronic

pain: a randomized placebo-controlled trial. *Pain*, *159*(2), 239–251.

https://doi.org/10.1097/j.pain.0000000000001084

Heathcote, L. C., Lau, J. Y. F., Mueller, S. C., Eccleston, C., Fox, E., Bosmans, M., &

Vervoort, T. (2017). Child attention to pain and pain tolerance are dependent upon

anxiety and attention control: An eye-tracking study. *European Journal of Pain*, *21*,

250–263. https://doi.org/10.1002/ejp.920

Howell, A. N., Zibulsky, D. A., Srivastav, A., & Weeks, J. W. (2016). Relations among

Social Anxiety, Eye Contact Avoidance, State Anxiety, and Perception of Interaction

Performance during a Live Conversation. *Cognitive Behaviour Therapy*, *45*(2), 111–

122. https://doi.org/10.1080/16506073.2015.1111932

Hsiao, J. H., Chan, K. Y., Du, Y., & Chan, A. B. (2019). Understanding Individual

Differences in Eye Movement Pattern During Scene Perception through Co-Clustering

of Hidden Markov Models. *COGSCI'19 - Creativity + Cognition + Computation:*

Proceedings of the 41st Annual Meeting of the Cognitive Science Society, 3283.

Jackson, T., Su, L., & Wang, Y. (2018a). Effects of higher versus lower threat contexts on

pain-related attention biases: An eye-tracking study. *European Journal of Pain*, *22*,

1113–1123. https://doi.org/10.1016/j.jpain.2018.01.011

Jackson, T., Su, L., & Wang, Y. (2018b). Effects of Higher Versus Lower Threat Contexts on

Pain-Related Visual Attention Biases: An Eye-Tracking Study of Chronic Pain. *Journal of Pain*, *19*(6), 649–659. https://doi.org/10.1016/j.jpain.2018.01.011

Jackson, T., Yang, Z., & Su, L. (2019). Pain-related gaze biases and later functioning among adults with chronic pain: a longitudinal eye-tracking study. *Pain*, *160*(10), 2221–2228. https://doi.org/10.1097/j.pain.0000000000001614

Kamper, S. J., Henschke, N., Hestbaek, L., Dunn, K. M., & Williams, C. M. (2016). Musculokeletal pain in children and adolescents. *Brazilian Journal of Physical Therapy*, *20*(3), 275–284.

Khatibi, A., Dehghani, M., Sharpe, L., Asmundson, G. J. G., & Pouretemad, H. (2009). Selective attention towards painful faces among chronic pain patients: Evidence from a modified version of the dot-probe. *Pain*, *142*, 42–47. https://doi.org/10.1016/j.pain.2008.11.020

King, S., Chambers, C. T., Huguet, A., MacNevin, R. C., McGrath, P. J., Parker, L., & MacDonald, A. J. (2011). The epidemiology of chronic pain in children and adolescents revisited: A systematic review. *Pain*, *152*, 2729–2738. https://doi.org/10.1016/j.pain.2011.07.016

Kotrlik, J. W., & Williams, H. A. (2003). The Incorporation of effect size in information technology, learning, and performance research. *Information Technology, Learning, and Performance Journal*, *21*(1), 1–7. https://doi.org/10.1.1.331.4489

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, 863. https://doi.org/10.3389/fpsyg.2013.00863

Lao, J., Miellet, S., Pernet, C., Sokhn, N., & Caldara, R. (2017). iMap4: An open source toolbox for the statistical fixation mapping of eye movement data with linear mixed modeling. *Behavior Research Methods*, *49*, 559–575. https://doi.org/10.3758/s13428-016-0737-x

Lau, J. Y. F., Heathcote, L. C., Beale, S., Gray, S., Jacobs, K., Wilkinson, N., & Crombez, G. (2018). Cognitive Biases in Children and Adolescents With Chronic Pain: A Review of Findings and a Call for Developmental Research. *Journal of Pain*, *19*(6), 589–598. https://doi.org/10.1016/j.jpain.2018.01.005

Lee, H.-J., Choi, E. J., Nahm, F. S., Yoon, I. Y., & Lee, P. B. (2018). Prevalence of unrecognized depression in patients with chronic pain without a history of psychiatric diseases. *The Korean Journal of Pain*, *31*(2), 116–124.

Lee, J., Beom, J., Choi, S., Lee, S., Wachholtz, A., & Lee, J. H. (2019). Chronic pain patients' gaze patterns toward pain-related information: Comparison between pictorial and linguistic stimuli. *Medicina*, *55*, 530. https://doi.org/10.3390/medicina55090530

Lee, J., Kim, S. H., Shin, S. K., Wachholtz, A., & Lee, J. H. (2018). Attentional Engagement for Pain-Related Information among Individuals with Chronic Pain: The Role of Pain Catastrophizing. *Pain Research and Management*, 6038406. https://doi.org/10.1155/2018/6038406

Leo, R. J. (2005). Chronic pain and comorbid depression. *Current Treatment Options in Neurology*, *7*(5), 403–412. https://doi.org/10.1007/s11940-005-0032-0

Li, J. X. (2015). Pain and depression comorbidity: A preclinical perspective. *Behavioural Brain Research*, *276*, 92–98. https://doi.org/10.1016/j.bbr.2014.04.042

Ling, Y., Yang, Z., & Jackson, T. (2019). Visual attention to pain cues for impending touch versus impending pain: An eye tracking study. *European Journal of Pain*, *23*, 1527–1537. https://doi.org/10.1002/ejp.1428

Liossi, C., Schoth, D. E., Bradley, B. P., & Mogg, K. (2009). Time-course of attentional bias for pain-related cues in chronic daily headache sufferers. *European Journal of Pain*, *13*, 963–969. https://doi.org/10.1016/j.ejpain.2008.11.007

Liossi, C., Schoth, D. E., Godwin, H. J., & Liversedge, S. P. (2014). Using eye movements to investigate selective attention in chronic daily headache. *Pain*, *155*, 503–510.

https://doi.org/10.1016/j.pain.2013.11.014

Madden, V. J., Bellan, V., Russek, L. N., Camfferman, D., Vlaeyen, J. W. S., & Moseley, G.

L. (2016). Pain by Association? Experimental Modulation of Human Pain Thresholds

Using Classical Conditioning. *Journal of Pain*, *17*(10), 1105–1115.

https://doi.org/10.1016/j.jpain.2016.06.012

Mahmoodi-Aghdam, M., Dehghani, M., Ahmadi, M., Banaraki, A. K., & Khatibi, A. (2017).

Chronic Pain and Selective Attention to Pain Arousing Daily Activity Pictures:

Evidence From an Eye Tracking Study. *Basic and Clinical Neuroscience*, *8*(6), 467–

478.

Mazidi, M., Dehghani, M., Sharpe, L., Dolatshahi, B., Ranjbar, S., & Khatibi, A. (2019).

Time course of attentional bias to painful facial expressions and the moderating role of

attentional control: an eye-tracking study. *British Journal of Pain*, 1–12.

https://doi.org/10.1177/2049463719866877

Miller, L. R., & Cano, A. (2009). Comorbid Chronic Pain and Depression: Who Is at Risk?

Journal of Pain, *10*(6), 619–627. https://doi.org/10.1016/j.jpain.2008.12.007

Moher, D., Hopewell, S., Schulz, K. F., Montori, V., Gøtzsche, P. C., Devereaux, P. J.,

Elbourne, D., Egger, M., & Altman, D. G. (2010). CONSORT 2010 explanation and

elaboration: updated guidelines for reporting parallel group randomised trials. *The BMJ*,

340, c869. https://doi.org/10.1016/j.ijsu.2011.10.001

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2009). Preferred

reporting items for systematic reviews and meta-analyses: The PRISMA statement.

Journal of Clinical Epidemiology, *62*, 1006–1012.

https://doi.org/10.3736/jcim20090918

Moriarty, O., Mcguire, B. E., & Finn, D. P. (2011). The effect of pain on cognitive function:

A review of clinical and preclinical research. *Progress in Neurobiology*, *93*, 385–404.

https://doi.org/10.1016/j.pneurobio.2011.01.002

Nahin, R. L. (2015). Estimates of Pain Prevalence and Severity in Adults: United States, 2012. *Journal of Pain*, *16*(8), 769–780. https://doi.org/10.1016/j.jpain.2015.05.002

Pilch, M., O'Hora, D., Jennings, C., Caes, L., McGuire, B. E., Kainz, V., & Vervoort, T. (2020). Perspective-taking influences attentional deployment towards facial expressions of pain. *Pain*, *00*(00), 1–11. https://doi.org/10.1097/j.pain.0000000000001827

Porras-Garcia, B., Ferrer-Garcia, M., Ghita, A., Moreno, M., López-Jiménez, L., Vallvé-Romeu, A., Serrano-Troncoso, E., & Gutiérrez-Maldonado, J. (2019). The influence of gender and body dissatisfaction on body-related attentional bias: An eye-tracking and virtual reality study. *International Journal of Eating Disorders*, *52*(10), 1181–1190. https://doi.org/10.1002/eat.23136

Priebe, J. A., Messingschlager, M., & Lautenbacher, S. (2015). Gaze behaviour when monitoring pain faces: An eye-tracking study. *European Journal of Pain*, *19*, 817–825. https://doi.org/10.1002/ejp.608

Roelofs, J., Peters, M. L., Fassaert, T., & Vlaeyen, J. W. S. (2005). The Role of Fear of Movement and Injury in Selective Attentional Processing in Patients with Chronic Low Back Pain: A Dot-Probe Evaluation. *The Journal of Pain*, *6*(5), 294–300.

Roelofs, J., Peters, M. L., Zeegers, M. P. A., & Vlaeyen, J. W. S. (2002). The modified Stroop paradigm as a measure of selective attention towards pain-related stimuli among chronic pain patients: A meta-analysis. *European Journal of Pain*, *6*, 273–281. https://doi.org/10.1053/eujp.2002.0337

Rosenthal, R. (1994). Parametric measures of effect size. In H. Cooper & L. V. Hedges (Eds.), *The Handbook of Research Synthesis*. Sage.

Schmidt, K., Gamer, M., Forkmann, K., & Bingel, U. (2018). Pain Affects Visual Orientation: an Eye-Tracking Study. *Journal of Pain*, *19*(2), 135–145. https://doi.org/10.1016/j.jpain.2017.09.005

Schofield, D. P. (2007). Pain in Older Adults: Epidemiology, Impact and Barriers to

Management. *Reviews in Pain*, *1*(1), 12–14.

Schoth, D. E., Beaney, R., Broadbent, P., Zhang, J., & Liossi, C. (2019). Attentional,

interpretation and memory biases for sensory-pain words in individuals with chronic

headache. *British Journal of Pain*, *13*(1), 22–31.

https://doi.org/10.1177/2049463718789445

Schoth, D. E., Georgallis, T., & Liossi, C. (2013). Attentional Bias Modification in People

with Chronic Pain: A Proof of Concept Study. *Cognitive Behaviour Therapy*, *42*(3),

233–243. https://doi.org/10.1080/16506073.2013.777105

Schoth, D. E., Godwin, H. J., Liversedge, S. P., & Liossi, C. (2015). Eye movements during

visual search for emotional faces in individuals with chronic headache. *European

Journal of Pain*, *19*, 722–732. https://doi.org/10.1002/ejp.595

Schoth, D. E., Ma, Y., & Liossi, C. (2015). Exploring Attentional Bias for Real-World, Pain-

related Information in Chronic Musculoskeletal Pain Using a Novel Change Detection

Paradigm. *Clinical Journal of Pain*, *31*(8), 680–688.

https://doi.org/10.1097/AJP.0000000000000149

Schoth, D. E., Nunes, V. D., & Liossi, C. (2012). Attentional bias towards pain-related

information in chronic pain; a meta-analysis of visual-probe investigations. *Clinical

Psychology Review*, *32*, 13–25. https://doi.org/10.1016/j.cpr.2011.09.004

Schoth, D. E., Parry, L., & Liossi, C. (2018). Combined cognitive biases for pain and

disability information in individuals with chronic headache: A preliminary investigation.

Journal of Health Psychology, *23*(12), 1610–1621.

https://doi.org/10.1177/1359105316664136

Schoth, D. E., Wu, J., Zhang, J., Guo, X., & Liossi, C. (2019). Eye-movement behaviours

when viewing real-world pain-related images. *European Journal of Pain*, 1–12.

https://doi.org/10.1002/ejp.1363

Sharpe, L. (2014). Attentional biases in pain: More complex than originally thought? *Pain*,

155, 439–440. https://doi.org/10.1016/j.pain.2013.12.020

Sharpe, L., Brookes, M., Jones, E., Gittins, C., Wufong, E., & Nicholas, M. K. (2017). Threat and fear of pain induces attentional bias to pain words: An eye-tracking study. *European Journal of Pain*, *21*, 385–396. https://doi.org/10.1002/ejp.936

Skinner, I. W., Hübscher, M., Moseley, G. L., Lee, H., Wand, B. M., Traeger, A. C., Gustin, S. M., & McAuley, J. H. (2018). The reliability of eyetracking to assess attentional bias to threatening words in healthy individuals. *Behavior Research Methods*, *50*, 1778–1792. https://doi.org/10.3758/s13428-017-0946-y

Sun, Z. K., Wang, J. Y., & Luo, F. (2016). Experimental pain induces attentional bias that is modified by enhanced motivation: An eye tracking study. *European Journal of Pain*, *20*, 1266–1277. https://doi.org/10.1002/ejp.851

Tabor, A., Van Ryckeghem, D. M. L., & Hasenbring, M. I. (2020). Pain Unstuck: The Role of Action and Motivation. *Clinical Journal of Pain*, *36*(3), 143–149. https://doi.org/10.1097/AJP.0000000000000786

Todd, J., Sharpe, L., & Colagiuri, B. (2016). Attentional bias modification and pain: The role of sensory and affective stimuli. *Behaviour Research and Therapy*, *83*, 53–61. https://doi.org/10.1016/j.brat.2016.06.002

Todd, J., Sharpe, L., Colagiuri, B., & Khatibi, A. (2016). The effect of threat on cognitive biases and pain outcomes: An eye-tracking study. *European Journal of Pain*, *20*, 1357–1368. https://doi.org/10.1002/ejp.887

Todd, J., Sharpe, L., Johnson, A., Nicholson Perry, K., Colagiuri, B., & Dear, B. F. (2015). Towards a new model of attentional biases in the development, maintenance, and management of pain. *Pain*, *156*(9), 1589–1600. https://doi.org/10.1097/j.pain.0000000000000214

Todd, J., Van Ryckeghem, D. M. L., Sharpe, L., & Crombez, G. (2018). Attentional bias to pain-related information: a meta-analysis of dot-probe studies. *Health Psychology*

Review, *12*(4), 419–436. https://doi.org/10.1080/17437199.2018.1521729

Treede, R.-D., Rief, W., Barke, A., Aziz, Q., Bennett, M., Benoliel, R., Cohen, M., Evers, S., Finnerup, N., First, M., Giamberardino, M. A., Kaasa, S., Korwisi, B., Kosek, E., Lavand homme, P., Nicholas, M., Perrot, S., Scholz, J., Schug, S., … Wang, S.-J. (2019). Chronic pain as a symptom or a disease: the IASP Classification of Chronic Pain for the International Classification of Diseases (ICD-11). *Pain*, *160*(1), 19–27. https://doi.org/10.1097/j.pain.0000000000001390

Trost, Z., Van Ryckeghem, D. M. L., Scott, W., Guck, A., & Vervoort, T. (2016). The Effect of Perceived Injustice on Appraisals of Physical Activity: An Examination of the Mediating Role of Attention Bias to Pain in a Chronic Low Back Pain Sample. *Journal of Pain*, *17*(11), 1207–1216. https://doi.org/10.1016/j.jpain.2016.08.001

Tsang, A., Von Korff, M., Lee, S., Alonso, J., Karam, E., Angermeyer, M. C., Borges, G. L. G., Bromet, E. J., de Girolamo, G., de Graaf, R., Gureje, O., Lepine, J. P., Haro, J. M., Levinson, D., Oakley Browne, M. A., Posada-Villa, J., Seedat, S., & Watanabe, M. (2008). Common Chronic Pain Conditions in Developed and Developing Countries: Gender and Age Differences and Comorbidity With Depression-Anxiety Disorders. *Journal of Pain*, *9*(10), 883–891. https://doi.org/10.1016/j.jpain.2008.05.005

Vacha-Haase, T., & Thompson, B. (2004). How to estimate and interpret various effect sizes. *Journal of Counseling Psychology*, *51*(4), 473–481. https://doi.org/10.1037/0022-0167.51.4.473

Van Ryckeghem, D. M. L., Noel, M., Sharpe, L., Pincus, T., & Van Damme, S. (2019). Cognitive biases in pain: an integrated functional–contextual framework. *Pain*, *160*(7), 1489–1493.

Van Ryckeghem, D. M. L., Van Damme, S., & Vervoort, T. (2018). Does attention bias modification training impact on task performance in the context of pain: An experimental study in healthy participants. *PLoS ONE*, *13*(7), 1–16.

https://doi.org/10.1371/journal.pone.0200629

Van Ryckeghem, D. M. L., & Vervoort, T. (2016). Towards an integrative view of cognitive

biases in pain. *European Journal of Pain*, *20*, 1201–1202.

https://doi.org/10.1002/ejp.913

Vervoort, T., Trost, Z., Prkachin, K. M., & Mueller, S. C. (2013). Attentional processing of

other's facial display of pain: An eye tracking study. *Pain*, *154*, 836–844.

https://doi.org/10.1016/j.pain.2013.02.017

Vervoort, T., Trost, Z., Sütterlin, S., Caes, L., & Moors, A. (2014). Emotion regulatory

function of parent attention to child pain and associated implications for parental pain

control behaviour. *Pain*, *155*, 1453–1463. https://doi.org/10.1016/j.pain.2014.04.015

Vlaeyen, J. W. S. (2015). Learning to predict and control harmful events: chronic pain and

conditioning. *Pain*, *156*, S86–S93. https://doi.org/10.1097/j.pain.0000000000000107

Vlaeyen, J. W. S., & Linton, S. J. (2000). Fear-avoidance and its consequences in chronic

musculoskeletal pain: a state of the art. *Pain*, *85*, 317–332.

papers3://publication/uuid/327BB4B4-2761-41DB-903F-9BA66D0042CF

Wang, Y., Liu, Y., Gozli, D., Xiang, Y. T., & Jackson, T. (2020). The N2pc component as a

neural index of early attention allocation among adults with chronic musculoskeletal

pain. *European Journal of Pain*.

Weeks, J. W., Howell, A. N., & Goldin, P. R. (2013). Gaze avoidance in social anxiety

disorder. *Depression and Anxiety*, *30*, 749–756. https://doi.org/10.1002/da.22146

Weierich, M. R., Treat, T. A., & Hollingworth, A. (2008). Theories and measurement of

visual attentional processing in anxiety. *Cognition and Emotion*, *22*(6), 985–1018.

https://doi.org/10.1080/02699930701597601

Wieser, M. J., Pauli, P., Alpers, G. W., & Mühlberger, A. (2009). Is eye to eye contact really

threatening and avoided in social anxiety?-An eye-tracking and psychophysiology study.

Journal of Anxiety Disorders, *23*, 93–103. https://doi.org/10.1016/j.janxdis.2008.04.004

Williams, A. C. de C., & Craig, K. D. (2016). Updating the definition of pain. *Pain*, *157*,

    2420–2423. https://doi.org/10.1097/j.pain.0000000000000613

Yang, Z., Jackson, T., & Chen, H. (2013). Effects of chronic pain and pain-related fear on

    orienting and maintenance of attention: An eye movement study. *Journal of Pain*,

    14(10), 1148–1157. https://doi.org/10.1016/j.jpain.2013.04.017

Yang, Z., Jackson, T., Gao, X., & Chen, H. (2012). Identifying selective visual attention

    biases related to fear of pain by tracking eye movements within a dot-probe paradigm.

    Pain, *153*, 1742–1748. https://doi.org/10.1016/j.pain.2012.05.011

Zaman, J., Vlaeyen, J. W. S., Van Oudenhove, L., Wiech, K., & Van Diest, I. (2015).

    Associative fear learning and perceptual discrimination: A perceptual pathway in the

    development of chronic pain. *Neuroscience and Biobehavioral Reviews*, *51*, 118–125.

    https://doi.org/10.1016/j.neubiorev.2015.01.009

Figure

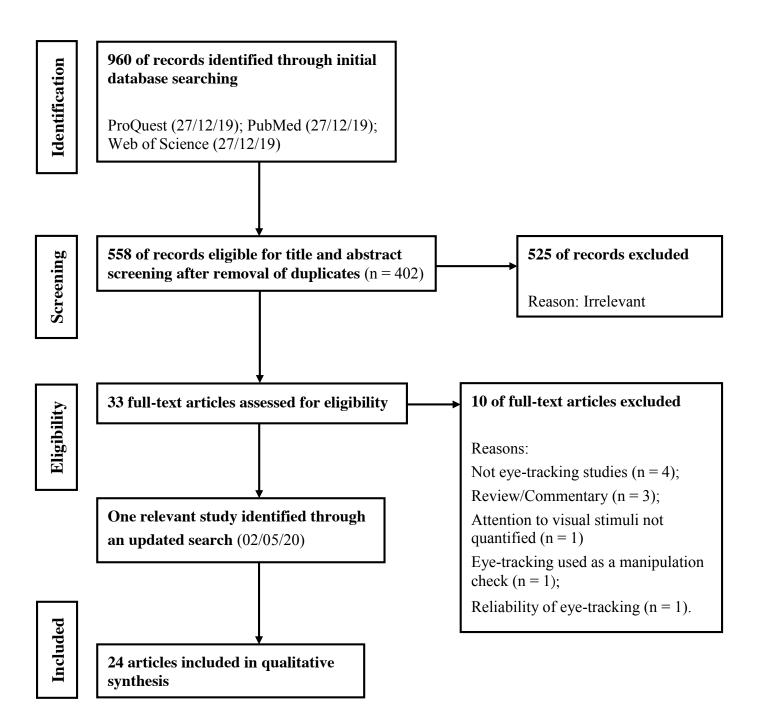*Figure 1* PRISMA 2009 Flow Diagram illustrating the search process (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009).

Table