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Feeling Worse to Feel Better: Pain-Offset Relief Simultaneously Stimulates Positive Affect and Reduces Negative Affect

Joseph C. Franklin, Kent M. Lee, Eleanor K. Hanna, and Mitchell J. Prinstein
University of North Carolina at Chapel Hill

Abstract

Although pain itself induces negative affect, the removal (or offset) of pain induces a powerful state of relief. Despite being implicated in a wide range of psychological and behavioral phenomena, relief remains a poorly understood emotion. In particular, some theorists associate relief with increased positive affect, whereas others associate relief with diminished negative affect. In the present study, we examined the affective nature of relief in a pain-offset paradigm with psychophysiological measures that were specific to negative valence (startle eyeblink reactivity) and positive valence (startle postauricular reactivity). Results revealed that pain offset simultaneously stimulates positive affect and diminishes negative affect for at least several seconds. Results also indicated that pain intensity differentially affects the positive and negative valence aspects of relief. These findings clarify the affective nature of relief and provide insight into why people engage in both normal and abnormal behaviors associated with relief.

Keywords

startle reflex, emotions, psychopathology

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Relief is among the most common emotional experiences. When someone finds lost keys, keeps a job after a series of layoffs, scratches an itch, steps into an air-conditioned room on a hot day, finishes a tough semester at school, or takes medication for back pain, he or she may describe feeling relieved. Although relief may occur across a variety of events, there are likely some commonalities to all experiences of relief. One such commonality may be affective valence, which is the positive or negative tone of an affective state (see Barrett & Bliss-Moreau, 2009). For example, anger may occur in response to a wide range of events, but all experiences of anger are constructed in part from negative affective valence. Most emotions have clear associations with affective valence—whether positive (e.g., happiness, joy, satisfaction), negative (anger, fear, sadness), or neutral (e.g., surprise, arousal, stillness; see Barrett & Bliss-Moreau, 2009). In contrast, the affective-valence component of relief remains obscure. Some researchers have associated relief with the experience of negative valence diminishing toward neutral valence (e.g., Franklin et al., 2010; Selby & Joiner, 2009), whereas others have associated relief with the experience of increasing positive valence (e.g., Leknes, Lee, Berna, Andersson, & Tracey, 2011; Levenson, 2011).

Knowledge about the affective-valence component of relief would provide insight into both normal behaviors (e.g., scratching; Davidson, Zhang, Khasabov, Simone, & Giesler, 2009) and abnormal behaviors (e.g., self-injury; Selby & Joiner, 2009) associated with this common emotional experience. Many relief behaviors are thought to be governed by negative reinforcement (e.g., Chapman, Gratz, & Brown, 2006), but evidence suggests that relief may also be strongly associated with positive reinforcement (Krumhuber & Scherer, 2011; Leknes, Brooks, Wiech, & Tracey, 2008; Sauter & Scott, 2007). Prior research has been unable to disentangle these fundamental issues.

According to some theoretical perspectives, relief may be one of the few basic positive emotions (Levenson, 2011). This idea is supported by evidence from vocal, facial-expression, and brain-imaging studies (Krumhuber & Scherer, 2011; Leknes et al., 2011; Sauter & Scott, 2007). There is also consistent evidence that the removal of pain (i.e., pain offset)

Corresponding Author:
Joseph C. Franklin, University of North Carolina at Chapel Hill, Department of Psychology, CB #3270 Davie Hall, Chapel Hill, NC 27599
E-mail: franjc1@gmail.com

generates increased self-reported pleasantness (Leknes et al., 2008) and increased neural activity in a brain area that has been associated with reward, the nucleus accumbens (Becerra & Borsook, 2008; Leknes et al., 2011; Seymour et al., 2005). However, these findings are inconsistent with evidence that pain offset reduces self-reported positive affect (Bresin, Gordon, Bender, Gordon, & Joiner, 2010). These findings also appear to be at odds with evidence that fruit flies still show pain-offset-relief learning after being neurogenetically modified to be resistant to reward learning (Yarali & Gerber, 2010).

Multiple studies have found that relief is associated with diminished negative affective valence. Two studies have found that pain offset reduces self-reported negative affect (Bresin & Gordon, 2013; Bresin et al., 2010). Similarly, Bastian, Jetten, and Fasoli (2011) found that self-reported guilt was reduced after pain offset. In contrast, two other studies found that pain offset does not reduce self-reported negative affect (Andreatta, Muhlberger, Yarali, Gerber, & Pauli, 2010; Franklin et al., 2010). However, these latter two studies did find that pain offset reduces startle eyeblink reactivity—a psychophysiological measure of negative affective valence (Lang, Bradley, & Cuthbert, 1990).

It is clear from this burgeoning literature that relief is a desired emotional state, but the affective-valence component of relief remains obscure. This is due in part to three key methodological limitations of the few empirical studies on relief. First, positive and negative affective valence were simultaneously measured in only one relief study, which found support only for self-reported reduced negative valence (Bresin et al., 2010). Second, self-reports are often limited by a lack of insight into thoughts and feelings (Nisbett & Wilson, 1977), and this may be especially true for phenomena, such as relief (see Andreatta et al., 2010; Franklin et al., 2010), that may include changes in both positive and negative valence. Third, it is difficult to make valence-specific conclusions with brain-scanning measures because there is a substantial overlap in the neural correlates of positive and negative affect (see Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012). For example, the amygdala has traditionally been associated with fear, but it is also associated with positive affect and nonaffective processes (e.g., Morrison & Salzman, 2010); similarly, the nucleus accumbens has been associated with both reward and threat (e.g., Faure, Reynolds, Richard, & Berridge, 2008).

The primary purpose of the present study was to disentangle the positive and negative affective-valence components of relief. This was accomplished by measuring well-validated psychophysiological indices of negative affective valence (startle eyeblink reactivity; see Lang et al., 1990) and positive affective valence (startle postauricular reactivity; see Benning, Patrick, & Lang, 2004; Johnson, Valle-Inclán, Geary, & Hackley, 2012) after pain offset. Overcoming the limitations of self-report data, these measures do not require insight into feelings; overcoming the limitations of brain scanning, these measures are valence specific. We used a pain-offset paradigm because most prior relief studies have involved pain offset, it allowed for effective stimulus control, and it facilitated relief measurement across a large number of trials.

The second purpose of the present study was to examine the effects of pain intensity on pain-offset relief. Consistent with the opponent-process theory (Solomon, 1980), findings from Leknes et al. (2008) showed that more intense pain generated more self-reported relief after pain offset in humans. In contrast, Yarali et al. (2008) found that more intense pain substantially inhibited pain-relief learning in fruit flies. We aimed to clarify this discrepancy by investigating intensity effects in humans with psychophysiological measures of affective valence. The third purpose of the present study was to examine the temporal characteristics of pain-offset relief. Some studies suggest that pain-offset relief may persist for at least a few minutes if it is not interrupted (Franklin et al., 2010; Tanimoto, Heisenberg, & Gerber, 2004), but at least one study suggests that this effect may disappear after 14 s (Andreatta et al., 2010). To investigate this, we measured startle 3.5 s, 6 s, and 14 s after pain offset.

In this paradigm, safety conditioning is a potential alternative explanation for diminished eyeblink and increased postauricular reactivity across conditions. Specifically, over several trials, participants may learn that pain offset signals the lack of pain (i.e., safety) for several seconds. Previous studies have shown that safety cues are associated with reduced startle eyeblink reactivity (Gazendam & Kindt, 2012; Grillon & Charney, 2011; Lang et al., 2011). To investigate this potential alternative explanation, we also investigated pain-offset relief on a trial-by-trial basis across all conditions. If pain-offset relief is an automatic, unlearned phenomenon rather than a learned safety phenomenon, then relief should exist on initial trials and should not get stronger across trials.

Method

Participants

Participants were 40 (26 male, 14 female) introductory psychology students who participated to fulfill a partial research requirement. Their ages ranged from 18 to 28 years (M = 19.21, SD = 1.65). Participants self-identified as European American (75%), African American (10%), Latino American (5%), Asian American (2.5%), and other ethnicity (7.5%).

Psychophysiological measures

Startle stimuli. All startle methods were created and performed in accordance with recommended guidelines (Benning et al., 2004; Blumenthal et al., 2005). Startle stimuli consisted of 100 dB(A) broadband noises (20Hz–20kHz) with a near-instantaneous rise-and-fall time delivered to participants through headphones. Startle was quantified by measuring the electromyographic (EMG) activity from surface recording electrodes, processed and sampled at 1000 Hz by a Biopac (Goleta, CA) MP150 workstation, relayed through a band-pass filter at 28 to 500 Hz, and smoothed with a five-sample boxcar filter (cf. Blumenthal et al., 2005).

Startle eyeblink reactivity. Startle eyeblink is a protective reflex that occurs in response to a sufficiently sudden and intense stimulus. Because it is a defensive reflex, startle eyeblink reactivity is potentiated by unpleasant stimuli and diminished by pleasant stimuli (see Lang et al., 1990). Eyeblink reactivity was quantified as the EMG activity of the orbicularis oculi muscle (see Blumenthal et al., 2005). Startle eyeblink reactivity has been used in hundreds of studies as a measure of negative affective valence to examine affective abnormalities in a variety of disorders (e.g., Vaidyanathan, Patrick, & Cuthbert, 2009).

Startle postauricular reactivity. Startle postauricular reactivity was measured simultaneously with startle eyeblink reactivity (cf. Benning et al., 2004). The postauricular muscle is located behind the ear and shows a pattern of startle modulation that is opposite to that of eyeblink (Benning et al., 2004). This muscle is used by most infant mammals to pull back the ear during nursing, but it is largely vestigial in humans (Johnson et al., 2012). However, in humans, the postauricular muscle can still be primed by pleasant stimuli (especially those related to food, nursing, or reward; see Sandt et al., 2009; Johnson et al., 2012). When an intense stimulus, such as a startling sound, is presented, the motor units of the postauricular muscle are synchronized in response to the stimulus; this in turn generates a sudden spike in activity that is larger the more primed the muscle is (i.e., during pleasant affective states; see Johnson et al., 2012). Particular advantages of startle postauricular reactivity include its specificity to positive valence and its ability to be modulated by stimulus valence regardless of stimulus arousal (Gable & Harmon-Jones, 2009).

Pain stimuli

Pain was induced with 200-ms electrocutaneous stimulations (i.e., shocks) delivered at 150 Hz via two electrodes attached to the left bicep. Following the methods of Andreatta et al. (2010), we adjusted stimulus intensity for each participant until they rated the shocks as a 30 on a scale from 0 (*no pain*) to 100 (*worst pain imaginable*). This level was assessed twice to ensure the validity of the ratings. The maximum voltage was 200 V. The average voltage level rated a 30 was 90 V (SD = 33 V), which was the voltage of the shocks in the high-intensity conditions. Voltage in the low-intensity conditions was half that of the voltage in the high-intensity conditions. Participants were not informed that there would be lower-intensity shock stimuli.

Procedure

Startle habituation. Startle reactivity tends to decrease across the first few stimuli, potentially adding error variance to results. Therefore, following evidence that startle reactivity reaches an asymptote by 13 trials (Lane, Franklin, & Curran, 2013), we included an initial block of 13 startle-only trials. These data were not relevant to the present analyses.

Experimental block. The experimental block consisted of 64 total trials. There were eight different trials types. The first consisted of shock-only trials with no startle stimuli (these trials yielded no data for analysis). The second type was startle-only trials with no shock stimuli. In the third through fifth trial types, low-intensity shocks were followed by a startle stimulus at 3.5 s, 6 s, or 14 s, respectively; in the sixth through eighth trial types, high-intensity shocks were followed by a startle stimulus at 3.5 s, 6 s, or 14 s, respectively. There were eight trials of each type; trials were presented in a random order with an intertrial interval that varied from 18 s to 25 s.

Data-analysis plan

Startle scoring. Following established guidelines (Blumenthal et al., 2005), we quantified startle eyeblink magnitude as the difference between the peak and the foot of the largest response within a window of 20 ms to 100 ms after the onset of the startle stimulus. Also following established guidelines (Benning et al., 2004), we quantified startle postauricular magnitude as the difference between the maximum voltage within a window of 5 ms and 35 ms after the onset of the startle stimulus and the average voltage 50 ms before the startle stimulus. For both measures, responses were averaged within each condition for each participant.

Analyses. Analyses were identical for eyeblink and postauricular data. We conducted a within-participants analysis of variance (ANOVA) across all seven conditions that included a startle stimulus. For any significant effect, we then examined differences between each condition. We were primarily interested in differences between the startle-only conditions and the other conditions, but other comparisons were also made. To examine the safety-conditioning hypothesis, we investigated trial order, which resulted in eight conditions—one for each of the eight trials per condition (data were collapsed across conditions). We then calculated the difference between each condition and the corresponding startle-only condition (e.g., the first startle-only trial was compared with the first shock trial). We conducted a within-participants ANOVA on these difference scores to examine potential trial-order effects for both eyeblink and postauricular trials.

Results

Demographic factors were not significantly associated with startle eyeblink—gender: $F(1, 36) = 1.78$, $p = .19$; ethnicity: $F(4, 33) = 0.29$, $p = .89$—or postauricular reactivity—gender: $F(1, 38) = 0.16$, $p = .70$; ethnicity: $F(4, 35) = 1.29$, $p = .29$. Eyeblink data for 2 participants were excluded as outliers because they were more than 3 standard deviations from the mean.

Despite being measured at the same time and displaying inverse patterns with affective stimuli, startle eyeblink and postauricular reactivity showed only a small inverse correlation (e.g., $r = -.11$; Sandt, Sloan, & Johnson, 2009). Similarly, of the 49 correlations between the seven eyeblink conditions and the seven postauricular conditions in the present study, none reached significance (average $r = -.07$). This suggests that these measures are independent and that positive and negative affect are two separate dimensions (cf. Cacioppo & Berntson, 1994).

Startle postauricular reactivity

A within-participants ANOVA revealed a significant effect of condition on startle postauricular reactivity, $F(6, 234) = 4.27$, $p < .001$. Post hoc tests showed that, compared with the startle-only condition, all other conditions displayed significantly elevated postauricular reactivity (all *p*s < .05; see Fig. 1). The effect sizes for these comparisons were moderate (Cohen's d = 0.38–0.57). This indicated that pain offset significantly increased positive affect. Follow-up post hoc tests also indicated that the 3.5-s high-intensity shock condition evidenced significantly higher postauricular reactivity than the 3.5-s low-intensity shock condition and the 14-s high-intensity shock condition (*p*s < .05). Overall, the pattern of data suggested that increased positive affect tended to be greatest after higher-intensity shocks and at shorter intervals.

Inconsistent with the safety-learning hypothesis, results from a within-participants ANOVA showed that there were no significant trial-order effects on startle postauricular reactivity, $F(7, 273) = 0.19$, $p = .99$. Furthermore, as Figure 2 shows, pain offset elevated startle postauricular activity on initial trials, and this effect diminished nonsignificantly across later trials.

Startle eyeblink reactivity

A within-participants ANOVA indicated a significant effect of condition on startle eyeblink reactivity, $F(6, 222) = 5.06$, $p < .001$. Post hoc tests revealed that, compared with eyeblink reactivity in the startle-only condition, eyeblink reactivity across all three low-intensity shock conditions was significantly diminished (*p*s < .05), but only significantly reduced in the 6-s high-intensity shock condition ($p < .05$; see Fig. 3). Effect sizes for comparisons between the startle-only and high-intensity shock conditions were small (Cohen's d = 0.00–0.27), but effect sizes were moderate for comparisons with the low-intensity shock conditions (Cohen's d = 0.39–0.59). Follow-up post hoc tests also showed that eyeblink reactivity in the 3.5-s low-intensity shock condition was significantly diminished compared with eyeblink reactivity in all other conditions, with the exception of the 6-s low-intensity shock condition (*p*s < .05). Similarly, the 6-s low-intensity shock condition was significantly diminished compared with the 3.5-s and 14-s high-intensity shock conditions (*p*s < .01).

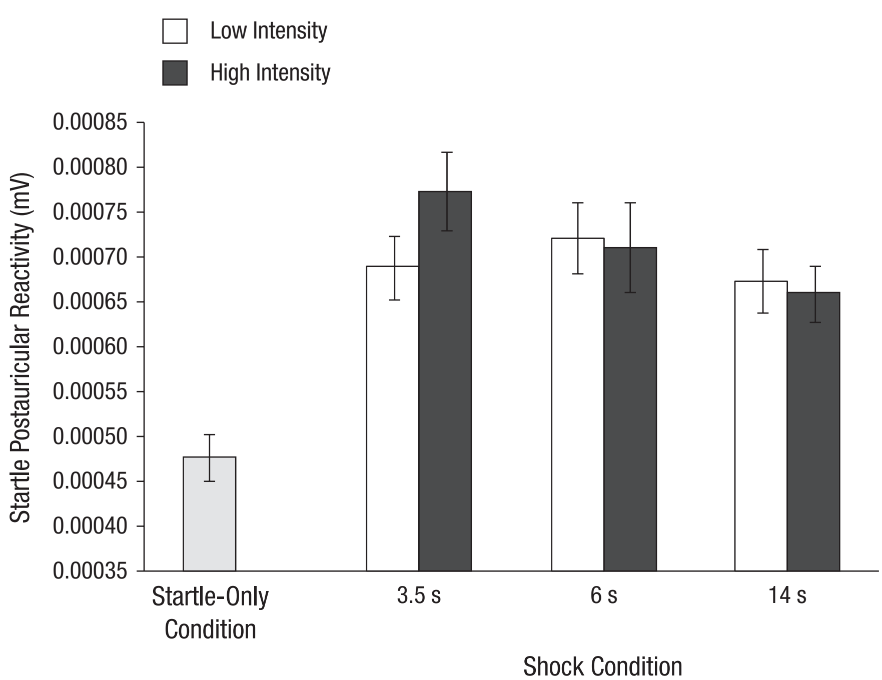

Fig. 1. Startle postauricular reactivity as a function of condition and shock intensity. For the shock conditions, the times indicate how many seconds before the startle the shock was delivered. Error bars indicate ±1 *SEM*.

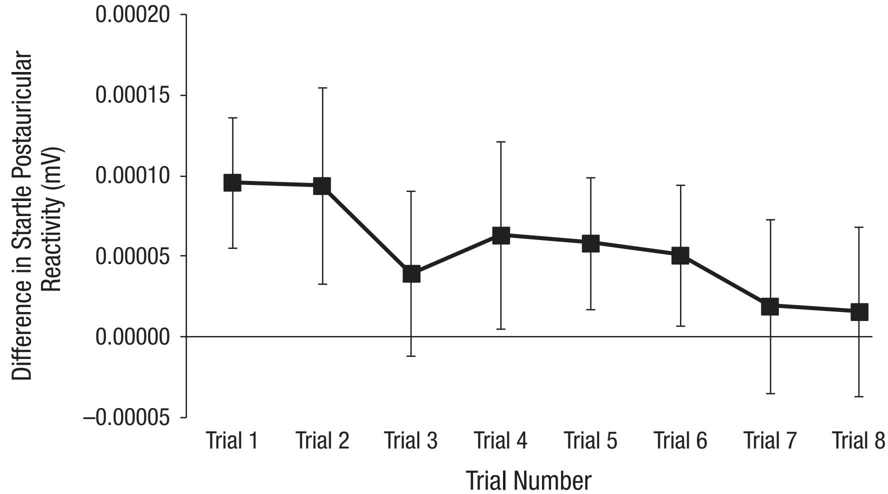

Fig. 2. Difference in startle postauricular reactivity between the startle-plus-shock conditions (collapsed) and the startle-only condition as a function of trial number. Error bars indicate ±1 *SEM*.

Taken together, this pattern of data showed that pain offset reduced negative affect and that this effect tended to be strongest after lower-intensity shocks and at shorter intervals.

Inconsistent with the safety-learning hypothesis, the results of a within-participants ANOVA showed that there were no significant trial-order effects on startle eyeblink reactivity, $F(7, 238) = 1.21$, $p = .30$. Furthermore, as Figure 4 shows, pain offset reduced startle eyeblink reactivity on initial trials, and this effect diminished nonsignificantly across later trials.

Discussion

Relief is a common emotional experience that plays a role in a wide range of psychological processes. Despite its ubiquity,

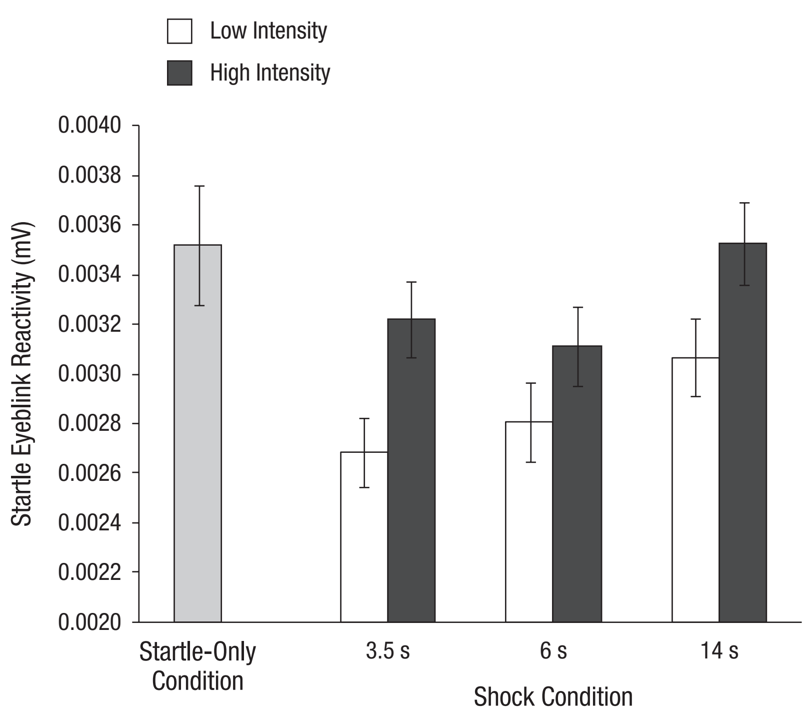

Fig. 3. Startle eyeblink reactivity as a function of condition and shock intensity. For the shock conditions, the times indicate how many seconds before the startle the shock was delivered. Error bars indicate ±1 *SEM*.

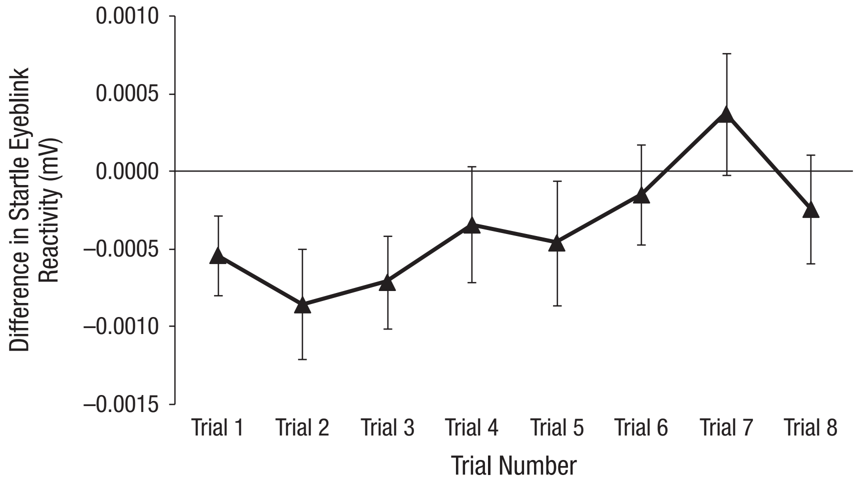

Fig. 4. Difference in startle eyeblink reactivity between the startle-plus-shock conditions (collapsed) and the startle-only condition as a function of trial number. Error bars indicate ±1 *SEM*.

relief has received surprisingly little empirical attention. In the present study, we advanced knowledge on this phenomenon by disentangling the effects of pain-offset relief on positive and negative affective valence, examining the effect of pain intensity on relief, and investigating the time course of relief.

Results revealed that pain-offset relief simultaneously diminished negative valence and stimulated positive valence (see Figs. 1 and 3). Theory and prior studies have associated relief primarily with increased positive valence (e.g., Leknes et al., 2011; Levenson, 2011) or diminished negative valence (e.g., Franklin et al., 2010; Selby & Joiner, 2009). The present data supported both of these perspectives and clarified that neither perspective alone encapsulates the affective-valence component of relief. Most emotions have been traditionally conceptualized within a single aspect of affective valence (e.g., joy and positive valence); however, the present results suggest that relief is most effectively conceptualized in terms of both positive and negative affective valence. It is possible that relief is unique in this regard, but it is more likely that many emotions have both positive and negative affective components. Beyond self-report studies, few investigations have examined multiple dimensions of affective valence when studying emotions. The present findings suggest that simultaneously measuring startle eyeblink and postauricular reactivity may be helpful for such investigations.

Behaviorally, the present results suggest that relief is associated with both positive and negative reinforcement. This finding may have important implications for behaviors associated with pain-offset relief, such as nonsuicidal self-injury (e.g., cutting or burning oneself in the absence of suicidal intent; Nock, 2010). Although self-report evidence suggests that nonsuicidal self-injury is associated with both positive and negative reinforcement (Nock & Prinstein, 2005), treatments for this dangerous behavior primarily target negative reinforcement (e.g., Chapman et al., 2006). The present results suggest that pain-offset relief may help to explain why nonsuicidal self-injury is associated with both positive and negative reinforcement, and they suggest that treatments may also benefit from targeting positive reinforcement.

Trial-by-trial results did not support the alternative explanation that the present paradigm induced safety conditioning (e.g., Gazendam & Kindt, 2012; Grillon & Charney, 2011; Lang et al., 2011) rather than pain-offset relief. This explanation would predict that relief is weak or nonexistent on initial trials and strongest on later trials as safety conditioning becomes stronger (cf. Gazendam & Kindt, 2012). Contradicting this hypothesis, our results showed that relief was strongest on initial trials and diminished nonsignificantly for both startle eyeblink and postauricular reactivity across later trials (see Figs. 2 and 4). This finding is consistent with evidence that pain offset generates relief after a single administration of a painful stimulus (Bastian et al., 2011; Bresin & Gordon, 2013; Franklin et al., 2010). These findings also indicate that pain-offset relief is an automatic, unconditioned response rather than a learned response.

Results indicated that higher-intensity shocks generated slightly more positive valence than lower-intensity shocks. This effect on positive valence is consistent with the findings of Leknes et al. (2008), who showed that more intense pain generated greater self-reported relief. This effect is also consistent with the opponent-process theory (Solomon, 1980), which posits that a more intense primary process (e.g., pain) leads to a more intense opponent process (e.g., relief). Inconsistent with this theory, however, our results showed that more intense shocks did not lead to a greater reduction in negative valence. Similarly, Yarali et al. (2008) found that low-intensity shocks (i.e., up to 100 V) facilitated pain-relief learning, but high-intensity shocks (i.e., 150 V) completely inhibited it. It is unclear why this effect occurs. On the basis of the present results, it is possible to conclude that higher-intensity shocks generate a state of relief that is primarily composed of increased positive valence rather than diminished negative valence. This valence pattern could conceivably produce a self-reported state of greater relief (cf. Leknes et al., 2008) that is not associated with a substantial reduction in negative valence.

Results also revealed that the effects of pain offset appeared to last at least several seconds, though these effects began to dissipate somewhat after 14 s. This finding is consistent with results seen in prior studies that have found that pain-offset relief may persist for at least a few minutes (e.g., Franklin et al., 2010; Tanimoto et al., 2004). These general results appear somewhat inconsistent with the findings of Andreatta et al. (2010), who uncovered no evidence of pain-offset-relief conditioning after 14 s. However, Andreatta et al. (2010) employed shock intensities comparable with those in the present high-intensity shock condition and measured startle eyeblink. It is interesting that the analogous condition in the present study—the 14-s high-intensity shock eyeblink condition—was the only condition to show virtually no change compared with the startle-only condition (see Fig. 3). Accordingly, the present results appear to be consistent with the findings of Andreatta et al. (2010) but build on these findings by showing that pain-offset relief appears to be most persistent after lower-intensity shocks and for positive valence.

The present results should be interpreted in light of the limitations of the study, which may help to establish new directions for relief research. First, startle eyeblink and postauricular reactivity are among the best-validated psychophysiological measures of affective valence (Johnson et al., 2012; Lang et al., 1990), but they are not perfect measures. Measures of explicit and implicit emotion would provide important complements to these measures. We did not include implicit measures of emotion because such measures are performance based (e.g., Payne, Cheng, Govorun, & Stewart, 2005) and could not fit directly into a pain-offset-relief paradigm. We decided against including self-reported affect because we aimed to obtain an uninterrupted index of affect. We reasoned that processes engaged during self-report (e.g., thinking about affect, comparing affect in the present state with affect in a prior state, deciding how to rate affect, and reporting affect) may interrupt ongoing affect generated by pain offset. Given evidence that explicit, implicit, and psychophysiological measures often diverge (e.g., Andreatta et al., 2010; Franklin et al., 2010; Payne et al., 2005), future studies may gain a more complete picture of pain-offset effects by including a wider variety of measures.

Second, to test the generalizability of the present findings, future studies may benefit from including other types of pain induction, a wider range of pain intensities, and a greater variety of postshock measurement times. Similarly, future studies may also benefit from examining whether results from studies investigating pain-offset relief generalize to relief that is not generated by pain offset. Third, because we were primarily concerned with valence effects, the present study did not include a measure of physiological arousal. Combining the present results with those of Leknes et al. (2008), we might best describe pain-offset relief as diminished arousal, diminished negative valence, and increased positive valence. To provide a more complete account of each of these factors, future studies should include all three measures.

Fourth, although the present findings may have important implications for phenomena such as nonsuicidal self-injury and trichotillomania, we did not include participants who engaged in these behaviors. Against expectations, previous studies have found no differences in pain-offset relief between self-injurers and healthy control subjects (Bresin & Gordon, 2013; Franklin et al., 2010). Further suggesting that this is a fundamental phenomenon, pain-offset relief has even been demonstrated in several studies on fruit flies (e.g., Tanimoto et al., 2004; Yarali et al., 2008). Nevertheless, to empirically demonstrate that the present findings generalize to other populations, these findings must be replicated in other samples.

The present study provides new insights into the nature of pain-offset relief. These findings have important implications for both basic emotion research and applied research on phenomena associated with relief. It is hoped that future research will build on these findings to provide a more accurate account of relief and how it applies to a wide range of psychological phenomena.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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