The Effect of Pain Resilience on Pain Experience: Does Stimulus Matter?

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This dissertation titled
The Effect of Pain Resilience on Pain Experience: Does Stimulus Matter?

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ABSTRACT

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Psychological research on pain has primarily focused on factors that confer vulnerability to pain-related outcomes; however, the past fifteen years have seen an increase in studies investigating factors that confer resilience to pain outcomes. One such factor is pain resilience, one's ability to maintain behavioral engagement and regulate emotions as well as cognitions despite intense or prolonged pain. A weakness in not only the pain resilience literature, but pain research in general, has been the lack of rationale behind the selection of experimental pain stimuli. These pain stimuli can activate different nociceptive fibers, meaning that stimuli are not interchangeable. The present study examined the relationship between pain resilience and reported pain during three pain stimuli that stimulate different combinations of nociceptors: pinprick (primarily A δ fibers), cold water immersion (A δ and C fibers), and ischemic tourniquet (primarily C fibers). Results indicated that individuals with high pain resilience reported lower cold water immersion pain ratings over time than those with low pain resilience; however, there was no relationship between pain resilience and either pinprick or ischemic tourniquet pain ratings. Pain resilience was also more closely related to pain ratings than a generic resilience measure. This study provides further support for the use of multiple pain stimuli for pain assessment given their unique characteristics, further support for the use of a pain-specific measure of resilience, and concludes that outcome variables aside

from pain ratings may provide additional insight into the role of resilience on pain adaptation.

DEDICATION

For my wife Clare, without whom this would not have been possible

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INTRODUCTION

Traditionally, research on psychosocial factors that influence pain experience has focused on constructs that negatively influence pain perception; that is, characteristics about an individual that make them more vulnerable to negative pain outcomes. Recently, there has been a push towards investigating factors that confer resilience against negative outcomes (Sturgeon & Zautra, 2010, 2013). Research on these constructs began in chronic pain research, but numerous studies have investigated the role of resilience factors in experimental pain settings. Pain resilience, defined as one's ability to maintain behavioral engagement and regulate emotions as well as cognitions despite intense or prolonged pain (Ankawi, Slepian, Himawan, & France, 2017), is one such construct.

The relationship between pain resilience and experimental pain has been investigated in two studies. The initial validation study of the Pain Resilience Scale found that, relative to those with lower resilience, individuals with higher pain resilience reported lower pain throughout an ischemic tourniquet task and habituated better to pain over time (Slepian, Ankawi, Himawan, & France, 2016). Additionally, the study demonstrated that the Pain Resilience Scale was a better predictor of pain habituation than the Connor-Davidson Resilience Scale, providing support for the use of a measure of pain-specific resilience rather than general resilience when looking at acute pain outcomes. Ankawi and colleagues (2015) also investigated the relationship between Pain Resilience Scale scores and pain ratings, with this study utilizing repeated heat pain threshold and tolerance testing. No significant relationship was observed for heat pain threshold; however, a significant positive relationship was found between pain resilience

and heat pain tolerance exhibited on the last trial. Ankawi and colleagues (2015) also demonstrated that this relationship was stronger for pain-specific resilience as compared to general resilience. Although the effect of pain resilience was restricted to the last trial, it was argued that this was consistent with the notion that resilience resources are more likely to be important when pain is repeated or increasingly intense, which is consistent with previous findings regarding general resilience and pain habituation (Smith et al., 2009).

In addition to the perceived intensity of stimulation, another important feature that may highlight individual differences in coping is the nature of the pain itself.

Experimental pain reviews have detailed the physical and psychological responses associated with different stimuli (Neziri et al., 2011; Olesen, Andresen, Staahl, & Drewes, 2012; Rainville, Feine, Bushnell, & Duncan, 1992; Reddy, Naidu, Rani, & Rao, 2012). Generally, the physical differences between painful stimuli are described in terms of the nociceptive fibers that are most activated; specifically, A δ and C fibers, which carry nociceptive signals to the spinal cord. A δ fibers are thinly myelinated neurons that transmit these signals at up to 30 m/s and are associated with sharp pain. C fibers are thinner, unmyelinated neurons that transmit considerably more slowly and are associated with throbbing and chronic pain (Melzack & Wall, 1965). Although nociceptive stimuli can activate both types of neurons, certain stimuli elicit a stronger response from particular fibers (Olesen et al., 2012; Reddy et al., 2012). From a psychological perspective, it is also important to understand the affective nature of different pain stimuli. Price describes pain stimuli in terms of the ratio of unpleasantness of pain to

intensity of pain, with a ratio > 1 being more unpleasant than intense, and a ratio < 1 being the opposite (Price, 2000). Brief pain stimuli, such as pinpricks, typically have a ratio of < 1 , whereas prolonged pain stimuli typically have a ratio > 1 (Price, 2000; Rainville et al., 1992). Interestingly, there appears to be a relationship between pain intensity/unpleasantness ratings and the nociceptors associated with the stimulus. Pain stimuli that would be considered more intense than unpleasant activate more A δ fibers than C fibers, but pain stimuli that target C fibers (either predominately or equally with A δ fibers) are described as more unpleasant. Researchers can therefore assure that their findings are as comprehensive as possible by including at least one of each of the following types of stimuli: one that primarily activates A δ fibers, one that primarily activates C fibers, and one that activates both fibers equally (Cruz-Almeida & Fillingim, 2014; Geber et al., 2009, 2011; Rolke, Baron, et al., 2006).

Accordingly, the present study aimed to investigate if the relationship between pain-specific resilience and pain outcomes differs across stimuli. To accomplish this goal, three different painful stimuli were tested: mechanical pinprick, which primarily activates A δ fibers; ischemic tourniquet, which primarily activates C fibers; and cold water immersion, which activates both equally. It was hypothesized that pain-specific resilience (i.e., Pain Resilience Scale scores) would be related to cold water immersion and ischemic tourniquet pain, but not pinprick pain. This hypothesis was based on findings by Slepian and colleagues (2016) and Ankawi and colleagues (2015), in which this relationship was found for stimuli that primarily activate C fibers (i.e., ischemic tourniquet) or both A δ and C fibers (i.e., heat pain tolerance), but not for stimuli that

primarily activate A δ fibers (i.e., heat pain threshold). In addition, the present study also sought to investigate the strength of this relationship for a pain-specific resilience measure as compared to a measure of general resilience as well as individual resilience-related constructs of positive affect, dispositional optimism and hope. It was hypothesized that pain-specific resilience would be more closely related to pain ratings than either general resilience or individual resilience-related constructs.

METHODS

Participants

Participants (N = 100) for this study included 40 male and 60 female undergraduate students recruited using Ohio University's online SONA system. The sample was 88% White, 5% Black, 4% Asian, and 3% multiracial, with a mean age of 19.4 years (SD = 1.2). Participants were excluded from participation if they reported pre-existing pain conditions or hypertension.

Instruments

Participants completed a battery of measures prior to undergoing pain stimuli. The questionnaires assessed demographic information and constructs related to pain vulnerability and pain resilience. Participants also used measures to rate their pain after each pain stimulus. Descriptive statistics for each measure can be found in Table 1. Each measure and additional psychometric information can be found in Appendix A.

Table 1. Mean scores and standard deviation per item for each measure

	Full Sample	Men	Women
Pain resilience	2.65 (0.55)	2.76 (0.55)	2.57 (0.55)
General resilience	4.84 (0.58)	4.81 (0.62)	4.87 (0.55)
Positive Affect*	2.88 (0.71)	3.13 (0.73)	2.71 (0.64)
Optimism	1.50 (0.70)	1.43 (0.58)	1.55 (0.55)
Hope -Agency	6.45 (0.88)	6.28 (0.95)	6.58 (0.83)
Hope -Pathways	6.25 (0.90)	6.48 (0.90)	6.13 (0.88)
Pain catastrophizing	0.90 (0.52)	0.77 (0.51)	1.08 (0.52)

*p < 0.05 between genders

Note: Values shown are the average score per item.

Demographics and Health Status

A brief questionnaire was used to assess demographic information and health status. Participants reported their age, sex, race/ethnicity, and relevant medical history.

Pain Resilience Factors

The Pain Resilience Scale was used to measure one's ability to maintain behavioral engagement and regulate emotions as well as cognitions despite prolonged or intense pain (Slepian et al., 2016). The Pain Resilience Scale is a 14 item measure that asks participants to rate how often they have specific thoughts about pain on a scale from 0 ("Not at all") to 4 ("all the time"). Scores were analyzed as the average rating per item for a theoretical range of 0-4. The Pain Resilience Scale has demonstrated strong internal consistency (Cronbach's $\alpha = 0.93$) and acceptable test-retest reliability over a one-month interval (Slepian et al., 2016).

The Connor-Davidson Resilience Scale was used to assess general resilience, a psychological construct describing one's ability to thrive in the face of adversity (Connor & Davidson, 2003). Participants are presented with 25 statements and asked to rate how true each statement has been for them over the past month on a scale from 1 ("Not at all true") to 5 ("True nearly all the time"). Scores were analyzed as the average rating per item for a theoretical range of 1-5. The Connor-Davidson Resilience Scale has demonstrated strong internal consistency (Cronbach's $\alpha = 0.89$) and high test-retest reliability ($r = 0.87$) (Connor & Davidson, 2003).

The Positive and Negative Affect Schedule was used to measure state-level positive affect, the degree to which the participant is experiencing positive emotions at

the present moment (Watson, Clark, & Tellegen, 1988). Each item on this 20 item measure is a single word, and participants rate the degree to which the word describes how they feel from 1 (“very slightly or not at all”) to 5 (“extremely”). Half of the items correspond to positive affect, and half to negative affect. Scores were analyzed as the average rating per item for a theoretical range of 1-5. This measure has demonstrated acceptable internal consistency (Cronbach’s $\alpha = 0.84-0.90$) and reliability ($r = 0.39-0.71$) over an eight week retesting interval (Watson et al., 1988).

The Life Orientation Test-Revised was used to assess dispositional optimism, a tendency to have positive expectations about the future (Scheier, Carver, & Bridges, 1994). This 10 item measure asks participants to rate the extent to which they agree with a statement on a scale from 0 (“strongly disagree”) to 4 (“strongly agree”). Of the ten items, only six are scored, with half of them being reverse-scored. Scores were analyzed as the average rating per item for a theoretical range of 0-4. The Life Orientation Test-Revised has demonstrated acceptable internal consistency (Cronbach’s $\alpha = 0.70$) and test-retest reliability over four month ($r = 0.68$), 12 month ($r = 0.60$), 24 month ($r = 0.56$), and 28 month ($r = 0.79$) intervals (Scheier et al., 1994).

The Adult Trait Hope Scale was used to assess trait-level hope, a mental set that one can take actions to achieve their desired goals (Snyder et al., 1991). Participants are asked to rate how truthfully 12 items describe them on a scale from 1 (“Definitely false”) to 4 (“Definitely true”). This measure consists of two subscales: Agency, one’s sense of determination in meeting their goals, and Pathways, one’s sense of being able to generate plans for successful goal completion. Each subscale is made up of four items, with four

more being filler items that are not included in scoring. Scores were analyzed as the average rating per item for a theoretical range of 1-4. The measure has demonstrated acceptable internal consistency for the full scale (Cronbach's $\alpha = 0.74-0.84$) and subscales (Agency: Cronbach's $\alpha = 0.71-0.76$; Pathways: Cronbach's $\alpha = 0.63-0.80$), as well as high test-retest reliability after three week ($r = 0.85$), eight week ($r = 0.73$), and ten week ($r = 0.76-0.82$) intervals (Snyder et al., 1991).

Pain Vulnerability

The Pain Catastrophizing Scale is a 13 item measure that assesses pain catastrophizing by asking participants to rate the degree to which they experience certain thoughts from 0 ("Not at all") to 4 ("all the time") while in pain (Sullivan, Bishop, & Pivik, 1995). Scores were analyzed as the average rating per item for a theoretical range of 0-4. The Pain Catastrophizing Scale has demonstrated a high degree of internal consistency (Cronbach's $\alpha = 0.87$) and acceptable test-retest reliability over six week ($r = 0.75$) and ten week ($r = 0.70$) intervals.

Pain Ratings

For each pain stimulus, participants continuously rated their pain from 0 ("no pain") to 100 ("worst pain imaginable") before, during, and immediately following each task. This was done using a physical device which manipulated an on-screen slider. If a participant rated their pain as 100 during a pain task, the stimulus was immediately discontinued and they entered a rest period.

After each task, participants completed two additional pain measures. The first was a two-item Numerical Rating Scale assessing pain intensity and unpleasantness.

Participants rated the pain intensity and unpleasantness of each task on a scale from 0 (no pain/no unpleasantness) to 10 (worst pain imaginable/as unpleasant as I can imagine). These items were analyzed individually. Participants also completed the Short Form McGill Pain Questionnaire 2, a 22-item measure that asks participants to rate the quality of pain (e.g., throbbing, stabbing) on a scale from 0 (“none”) to 10 (“worst possible”). Scores were analyzed as the average rating per item for a theoretical range of 0-10. This measure has high internal consistency (Cronbach’s $\alpha = 0.91-0.96$) (Dworkin et al., 2009; Lovejoy, Turk, & Morasco, 2012).

Pain Stimuli

Pinprick

The Neuropen (Owen Mumford, Marietta, GA) is a mechanical pinprick device that was developed for clinical use to assess pain perception in individuals with neuropathy. Disposable semi-sharp lancets are calibrated to deliver 40g of force to the skin, which elicits a painful sensation without piercing the skin. This type of painful mechanical stimulation has been shown to predominantly activate from A δ nerve fibers (Olesen et al., 2012).

Cold Water Immersion

Water was kept at 4° Celsius using a Wine Well Chiller (Milford, CT) that is 11 inches in diameter and 10 inches deep (see Figure 1). An electrical pump kept water circulating to ensure a consistent temperature throughout the immersion. Cold water immersion has been shown to activate both the A δ and C nerve fibers when intensity reaches a painful level (Olesen et al., 2012).

Figure 1. Wine Well Chiller cold water bath

Tourniquet Ischemia

Prior to tourniquet ischemia, participants engaged in forearm muscle activation using a Lafayette hand dynamometer (Model 76618; Lafayette Instrument Company, Lafayette, Indiana). The dynamometer has a squeezable handle and a pressure gauge that provides real-time feedback regarding the amount of pressure applied to the handle. In the present study, this exercise was used to induce exercise hyperemia and the release of metabolic byproducts related to forearm muscle activity.

Following dynamometer compression, a Hokanson Rapid Cuff Inflator (Model E20, D.E. Hokanson, Inc, Bellevue, WA) was used in conjunction with a Hokanson Air Source (Model AG101) to fill a blood pressure cuff (Model SC-10, D.E. Hokanson, Inc)

fitted over the bicep of the exercised arm to 200 mmHg in under 0.3 seconds. The resulting occlusion of blood flow and associated muscle ischemia has been shown to activate predominately C nerve fibers when intensity reaches a painful level (MacIver & Tanelian, 1992).

Procedure

Participants completed a single session lasting up to one hour. Participants were asked to abstain from exercise, nicotine, caffeine, and alcohol for four hours leading up to the study. They were also instructed not to take any pain medication the day of the study. Participants who failed to comply with these restrictions were rescheduled for another day, if they wished. Several participants were rescheduled and successfully completed the study, although the exact number of rescheduled participants was not recorded. After completing the consent process, participants completed a battery of measures and watched a thirty second video that demonstrated the three pain tasks. Participants were then randomly assigned to one of three pain stimulus sequences based on a Latin square design to counterbalance stimuli across patients. The three sequences were: 1) pinprick/cold water immersion/ischemic tourniquet, 2) cold water immersion/ischemic tourniquet/pinprick, and 3) ischemic tourniquet/pinprick/cold water immersion. For each pain stimulus, participants were told that the stimulus would be discontinued if they indicated that their pain was 100 on a scale from 0 (“no pain”) to 100 (“worst pain imaginable”). The procedure for each pain stimulus is detailed below.

Pinprick

Three overlapping adhesive rings were placed on the participant's left medial forearm as targets for Neuropen stimulation (see Figure 2). Next, the participant's arm was stimulated once, after which they rated the intensity and unpleasantness of the stimulation. After this rating, participants completed the 90 second pinprick task. For the first 30 seconds, participants rated their pain using the continuous digital sliding scale (with anchors of 0 "no pain" and 100 "worst pain imaginable") while no stimulation occurred. For the second 30 second period, the researcher stimulated the participant's forearm at a rate of one pinprick per second unless the participant provided a rating of "100" and chose to discontinue (no participant discontinued the pinprick task). Ten pinpricks were administered into each target area to minimize the potential for skin irritation. For the final 30 second period, participants continued rating their pain with no pinprick stimulation. Immediately following the pinprick task, participants retrospectively rated their pain during the task using the Numerical Rating Scale and the Short Form McGill Pain Questionnaire 2. Participants who had another pain stimulus after the pinprick task were given a five minute rest period before beginning the next task.

Figure 2.

Neuropen and placement of rings for pinprick stimulus

Cold water immersion

The cold water immersion task lasted for a total of six minutes. For the first two minutes, participants provided continuous ratings of pain in their right hand using the continuous digital sliding scale (with anchors of 0 “no pain” and 100 “worst pain imaginable”). After two minutes, they submerged their right hand and forearm into the cold water with their fingers spread out until the palm of their hand touched the bottom of the bucket while continuing to provide pain ratings. Immersion continued for up to two minutes, unless the participant provided a rating of “100” and chose to discontinue (37 of the 99 participants analyzed discontinued this task before two minutes). After two minutes of cold water immersion, or earlier if the participant chose to discontinue prematurely, they removed their hand and continued to provide pain ratings for two more

minutes. Afterwards, they provided retrospective ratings of their pain experience during the cold water immersion task using the Short-Form McGill Pain Questionnaire 2 and Numerical Rating Scales. Participants who had another pain task to complete after the cold water immersion task completed a five minute rest period before beginning the next task.

Tourniquet Ischemia

The tourniquet ischemia task lasted for a total of nine minutes and fifteen seconds. Before beginning the task, a blood pressure cuff fitted around the participant's left bicep. For the first two minutes, participants provided continuous ratings of pain in their left arm using the continuous digital sliding scale (with anchors of 0 "no pain" and 100 "worst pain imaginable"). After the two minute rating period, participants compressed a hand dynamometer with their left hand using maximal effort to determine their maximum contraction value. For the next two minutes, participants compressed the hand dynamometer to 50% of their maximum voluntary contraction every two seconds. At the end of the two minutes, participants raised their left hand over their head for 15 seconds to allow for exsanguination. After 15 seconds passed, the blood pressure cuff was inflated to 200 mmHg to occlude blood flow to the arm, at which point participants were instructed to lower their arm. For the next five minutes, participants provided continuous ratings of pain in their left arm using a digital scale ranging from 0-100 (with anchors of 0 "no pain" and 100 "worst pain imaginable"). The cuff was immediately deflated if the participant rated their pain as 100 (four of the 99 analyzed participants chose to discontinue before five minutes). Immediately following deflation of the cuff,

participants continued to provide ratings of their pain using the 0-100 scale for two minutes. After the two minutes elapsed, participants provided retrospective ratings of their overall arm pain experience during the application of the tourniquet using the Short-Form McGill Pain Questionnaire 2 and Numerical Rating Scales. Participants who had another pain task after the ischemic tourniquet completed a ten minute rest before beginning the next task; this rest period was longer to compensate for the length of this pain induction relative to the other pain stimuli.

After completion of all three pain tasks, participants were debriefed on the purpose of the study and given the opportunity to ask questions. Once all questions were answered, participants were dismissed and provided with research credit as compensation for their participation.

DATA REDUCTION AND ANALYSES

To test the proposed hypotheses of this study, both retrospective and continuous ratings of pain were analyzed. Participants rated their pain continuously before, during, and after each pain stimulus. The present analyses focused on the pain ratings during each pain stimulus; findings from the pre- and post-stimulus ratings can be found in Appendix B.

The relationship between pain resilience and continuous ratings of pain by stimulus were analyzed using mixed models. Prior to these analyses, one participant who did not follow the directions to provide continuous pain ratings was removed from the data (i.e., he kept the pain rating scale at zero until after the pain task, at which point he moved the slider to indicate how painful he found the task). Scores on the Pain Catastrophizing Scale and Pain Resilience Scale were centered at their means. Continuous ratings of pain were averaged for each second of exposure to the stimulus. Three-level mixed models were created with pain ratings at every time point nested within each participant. Intercept was entered as a random slope. Sex, pain catastrophizing, pain resilience, order of stimuli, and time were entered into the first block; interactions between time and pain resilience, time and stimulus, and pain resilience and stimulus were entered into the second block; and the interaction between time, pain, and stimulus was entered into the third block. Order was dropped from the final model because it had no significant effect on pain outcomes. Linear, logarithmic, quadratic, and cubic unconditional growth curves were fitted to the model to identify the best fit to the pain ratings, as determined by the Akaike Information Criteria (AIC) and

Schwarz's Bayesian Criteria (BIC). Lower numbers represent a better fit, with decreases of 3 representing meaningful change and decreases of 10 considered strongly meaningful (Burnham & Anderson, 2002; Kass & Raftery, 1995). The cubic growth curve did not consistently converge and was unstable (i.e., it gave different coefficients each time it was run). For this reason, it was not considered for analysis. The quadratic growth curve (AIC = 307,436.8; BIC = 307,669.8) provided a significantly better fit than the logarithmic (AIC = 316,574.1; BIC = 316,765.4) and linear (AIC = 318,144.2; BIC = 318,299.5) growth curves and was therefore selected for analysis.

The relationship between pain resilience and retrospective pain ratings was analyzed using repeated measures ANCOVAs for within-participants differences. Three ANCOVAs were conducted with pain resilience as a continuous predictor variable and stimulus as the repeated measure: one for pain intensity (per Visual Analog Scale), one for pain unpleasantness (per Visual Analog Scale), and one for total score on the McGill Pain Questionnaire.

RESULTS

Relationship Between Pain Resilience and Continuous Pain Ratings

Using the quadratic mixed model described above, interactions between predictors were analyzed to assess the first hypothesis that pain-specific resilience (i.e., Pain Resilience Scale Scores) would be related to ischemic tourniquet and cold immersion pain, but not pinprick pain (see Table 2). There was a second level interaction between stimulus and pain resilience on pain, as well as a third level interaction between stimulus, pain resilience, and time on pain. To further investigate these interactions, two-level quadratic mixed models were created for pinprick and cold water immersion, with pain ratings at every time point nested within each participant. Sex, pain catastrophizing, pain resilience, and time were entered into the first level, and the interactions between time and pain resilience were entered into the second level. Because the quadratic model for the ischemic task did not converge, a follow-up analysis of the interaction was conducted using a linear model was created with the same parameters. The graphs are based on estimated pain ratings; because of this the graphs do not start at 0 (i.e., pain ratings for pinprick and ischemic tourniquet pain begin above 0, whereas pain ratings for cold water immersion begin below zero). For ease of interpretation, the cold water immersion pain ratings have been centered so that the lowest value is 0.

Table 2. Tests of fixed effects for the quadratic growth curve model predicting differences in pain between stimuli over time.

Fixed Effect	df Numerator	df Denominator	F
Intercept	1	110	6.14*
Time	1	352	468.46***
Time ²	1	40,527	72.69***
Stimulus	2	41,059	762.88***
Pain resilience	1	108	0.05
Pain catastrophizing	1	98	0.71
Sex	1	98	4.00*
Stimulus x Time	2	41,052	4283.21***
Stimulus x Time ²	2	41,049	2041.75***
Stimulus x Pain resilience	2	41,044	3.55*
Time x Pain resilience	1	352	5.89*
Time ² x Pain resilience	1	40,527	3.95*
Stimulus x Time x Pain resilience	2	41,043	111.44***
Stimulus x Time ² x Pain resilience	2	41,045	71.86***

* $p < 0.05$, 2-tailed

*** $p < 0.001$, 2-tailed

Results of the follow-up analysis for the pinprick task are presented in Table 3 and the relationship between pain resilience and pinprick pain ratings is illustrated in Figure 3 with pain resilience fixed at one standard deviation above and below the mean. As shown in Table 3, a significant main effect of time reflected increasing pinprick pain ratings increased over time (see Figure 3). None of the other main effects or interactions were significant.

Table 3. Tests of fixed effects for the quadratic growth curve model predicting changes in pain over time for the pinprick task.

Fixed Effect	df Numerator	df Denominator	F
Intercept	1	122	38.65***
Time	1	99	70.06***
Time ²	1	99	22.01***
Pain resilience	1	102	0.62
Pain catastrophizing	1	99	0.85
Sex	1	99	0.13
Time x Pain resilience	1	99	1.50
Time ² x Pain resilience	1	99	1.58

*** $p < 0.001$, 2-tailed

Figure 3. Estimated pain ratings for high pain resilience (+ 1 SD) and low pain resilience (- 1SD) for the pinprick task. Error bars represent the standard error of the mean.

Results of the follow-up analysis for the cold water immersion are presented in Table 4 and the relationship between pain resilience and pinprick pain ratings is illustrated in Figure 4 with pain resilience fixed at one standard deviation above and below the mean. It should be noted that the values for pain ratings for this graph end above 100. This is because the values for these graphs are based on estimates from the slope from the mixed model. These slopes are based on the data from all participants,

Table 4. Tests of fixed effects for the quadratic growth curve model predicting changes in pain over time for the cold water immersion.

Fixed Effect	df Numerator	df Denominator	F
Intercept	1	106	7.72**
Time	1	89	131.83***
Time ²	1	38	3.46
Pain resilience	1	103	0.00
Pain catastrophizing	1	100	0.11
Sex	1	100	0.05
Time x Pain resilience	1	93	0.41
Time ² x Pain resilience	1	39	8.53**

**p < 0.01, 2-tailed

***p < 0.001, 2-tailed

Figure 4. Estimated pain ratings for high and low pain resilience for the cold water immersion. Error bars represent the standard error of the mean.

including those who ended the task before the 120 second mark; this means that their slope would project pain above 100 when extended past their end time. These extreme slopes would also cause a starting pain below 0. Only the cold water immersion task was affected by this because of the relatively high discontinuation rate compared to the other tasks (i.e., 37 participants discontinued the cold water immersion, compared to zero for the pinprick task and four for the ischemic tourniquet). As shown in Table 3, a significant main effect of time reflected increasing cold water immersion pain ratings over time (See Figure 4). There was also a significant interaction between pain resilience and time which, as shown in Figure 4, indicates that individuals with high pain resilience reported

less pain over time than individuals with low pain resilience. None of the other main effects or interactions was significant.

Results of the follow-up analysis for the ischemic tourniquet are presented in Table 5. The relationship between pain resilience and ischemic tourniquet pain ratings is illustrated in Figure 5, with pain resilience fixed at one standard deviation above and below the mean. As shown in Table 5, a significant main effect of time reflected increasing ischemic tourniquet pain ratings over time (see Figure 5). There were also significant main effects observed for pain catastrophizing and sex, with pain catastrophizing being positively related to pain ratings and men reporting lower pain than women.

Table 5. Tests of fixed effects for the linear growth curve model predicting changes in pain over time for the ischemic tourniquet task.

Fixed Effect	df Numerator	df Denominator	F
Intercept	1	104	106.41***
Time	1	95	26.03***
Pain resilience	1	101	1.35
Pain catastrophizing	1	99	8.86**
Sex	1	99	18.29***
Time x Pain resilience	1	95	0.38

**p < 0.01, 2-tailed

***p < 0.001, 2-tailed

Figure 5. Estimated pain ratings for high and low pain resilience for the ischemic tourniquet task. Error bars represent the standard error of the mean.

Pain Resilience Compared to General Resilience

To investigate the second hypothesis, that pain ratings would be more closely related to pain-specific resilience than general resilience, two conditional growth curve models were created; the one described above, containing the Pain Resilience Scale, and one in which the Connor-Davidson Resilience Scale replaced the Pain Resilience Scale. The AIC and BIC were compared to determine which model was a better fit to the data. As shown in Table 6, the model containing the Pain Resilience Scale was a better fit to

the data than the model containing the Connor-Davidson Resilience Scale as indicated by lower AIC and BIC values.

Table 6. AIC and BIC values for conditional growth curve models containing resilience scores.

Factor	AIC	BIC
Pain resilience	307,436.8	307,669.8
General resilience	308,639.2	308,846.3
Optimism	308,476.1	308,683.2
Hope (Pathways)	308,441.2	308,648.3
Hope (Agency)	308,688.1	308,895.2
Positive affect	305,109.9	305,316.8

Pain Resilience Compared to Resilience Factors of Positive Affect, Optimism, and Hope

To investigate the third hypothesis, that pain ratings would be more closely related to pain-specific resilience than positive affect, dispositional optimism, or hope, conditional growth curve models were created; the one described above, containing the Pain Resilience Scale, and four others in which the Pain Resilience Scale was replaced by one of the following: optimism (Life Orientation Test-Revised), hope pathways (subscale of the Adult Hope Scale), hope agency (subscale of the Adult Hope Scale), and positive affect (subscale of the Positive and Negative Affect Schedule). The AIC and BIC of each model were compared to the model containing the Pain Resilience Scale to determine which model provided the better fit to the data. As shown in Table 6, lower AIC and BIC values indicate that the model containing the Pain Resilience Scale was a better fit to the data than the models containing optimism, hope pathways, or hope agency. However, the

model containing positive affect was a better fit to the data than the model containing the Pain Resilience Scale as indicated by lower AIC and BIC values.

Relationship Between Pain Resilience and Retrospective Pain Ratings

Three repeated-measures ANOVAs were conducted to analyze the relationship between pain resilience and pain ratings across stimuli. Pain resilience was entered as a covariate and stimulus was the repeated measure. As shown in Table 7, no significant interactions between stimulus and pain resilience were found for pain intensity, $F(2, 97) = 1.79$, $p = 0.17$, $\eta_p^2 = 0.04$, pain unpleasantness, $F(2, 97) = 2.06$, $p = 0.13$, $\eta_p^2 = 0.04$, or total scores on the McGill Pain Questionnaire, $F(2, 97) = 0.98$, $p = 0.38$, $\eta_p^2 = 0.02$.

Table 7. Effects of stimulus and pain resilience on retrospective pain ratings.

Pain intensity	F
Stimulus	9.11***
Pain resilience	1.24
Stimulus*Pain resilience	1.74
Pain unpleasantness	
Stimulus	11.84***
Pain resilience	0.45
Stimulus*Pain resilience	2.15
McGill Pain Questionnaire	
Stimulus	3.22*
Pain resilience	0.01
Stimulus*Pain resilience	0.60

* $p < 0.05$, 2-tailed

*** $p < 0.001$, 2-tailed

DISCUSSION

The findings from the mixed model analyses support the hypothesis that the relationship between pain resilience and pain ratings is influenced by the type of stimulus. Post-hoc analyses found that higher pain resilience was associated with lower pain over time during the cold water immersion task, and that there was no relationship between pain resilience and pain for the pinprick or ischemic tourniquet tasks. The lack of a relationship for the pinprick task was consistent with the stimulus-specific hypotheses; however, a relationship was expected for the ischemic tourniquet given that it primarily stimulates C fibers. That said, although the findings for the specific stimuli did not fully align with the hypotheses in that pain resilience was related to cold water pain but not ischemic pain, these findings nonetheless support the notion that the relationship between pain resilience and pain differs across stimuli.

There are a few possible explanations why the hypothesized relationship between pain resilience and ischemic tourniquet pain was not observed. The first such explanation is that pain resilience is a resource that is only tapped into when facing high degrees of pain. This explanation is consistent with the definition of pain resilience, which suggests that it is a measure of coping during “intense or prolonged pain” (Ankawi et al., 2017). This would explain why the relationship of pain resilience on pain over time was only significant for the cold water immersion task, as this stimulus had the highest pain intensity and unpleasantness ratings. Another potential explanation is that the stimulus-specific hypotheses were based on theory, rather than attempted replication of existing studies. Stimuli were chosen based on the nociceptive fibers they primarily stimulate,

with the hypothesis that pain resilience would be a predictor of pain ratings in stimuli that activated C fibers (i.e., throbbing, unpleasant pain) but not stimuli that primarily activated A δ fibers (i.e., sharp, intense pain). Lending some support that the correct nociceptors were stimulated, the ratios of intensity to unpleasantness based on retrospective ratings were consistent with expectations, with the pinprick task having the highest ratio of intensity to unpleasantness (0.93) and the ischemic tourniquet having the lowest (0.87). That said, Price (2000) suggested that intense stimuli would have a ratio greater than one, which the pinprick task did not achieve. There was also no way to physically verify to what degree each type of nociceptor was stimulated during each stimulus, meaning that the targeted nociceptors may not have stimulated in the theorized manner. Given that the only significant relationship between pain resilience and pain ratings was found during the cold water immersion, which theoretically stimulates both types of nociceptors and has an intensity to unpleasantness ratio that falls between the other two stimuli (0.89), it is possible that this relationship is independent of the type of nociceptor stimulated. Indeed, there are other ways to categorize pain stimuli, such as type of tissue stimulated (e.g., skin, muscle, viscera) (Arendt-Nielsen & Curatolo, 2013), quality of pain (e.g., freezing, burning, crushing) (Dworkin et al., 2009), or mechanism of pain (e.g., mechanical, thermal, electrical, chemical) (Neziri et al., 2011; Reddy et al., 2012). Further, there are subjective differences between the stimuli that are difficult to account for statistically; for example, participants may have experienced anxiety as their arm became pale during the ischemic tourniquet task, or participants may have an aversion to cold temperatures.

Another possibility is that pain ratings may not be an ideal outcome measure in the context of pain resilience testing. Pain resilience has been defined as one's ability to maintain behavioral engagement and regulate emotions as well as cognitions despite intense or prolonged pain (Ankawi et al., 2017). Per this definition, a resilient person is not necessarily expected to report lower pain. Rather, they would be expected to remain engaged in a task and more capably regulate their cognitions and emotions during a painful task, possibly contributing to better performance on that task. For example, Slepian and France (2017) demonstrated that pain resilience was positively related to persistence and performance on a stressful mental arithmetic when combined with concomitant heat pain exposure. In addition to measuring such behavioral outcomes, a continuous measure that taps into the affective dimension of pain (i.e., pain unpleasantness) may be a better outcome variable than pain intensity given the relationship between pain resilience and ability to regulate emotions and cognitions.

Further support for the use of behavioral and affective outcome variables can be found in the resilience and chronic pain literature. Behavioral outcomes that have been used in resilience research include engagement in physical activity (Bargiel-Matusiewicz & Krzyszkowska, 2009) and likelihood to utilize active coping strategies, such as carrying on with daily activities despite pain (Ramírez-Maestre, Esteve, & López, 2012). Affective outcomes include depression and other negative emotions (Berendes et al., 2010; Hsu, Lu, Tsou, & Lin, 2003; Kilic, Dorstyn, & Guiver, 2013; Strand et al., 2006; Viggers & Caltabiano, 2012; Zautra, Johnson, & Davis, 2005; Zautra, Smith, Affleck, & Tennen, 2001), anxiety (Kilic et al., 2013; Viggers & Caltabiano, 2012), stress (Kilic et

al., 2013; Viggers & Caltabiano, 2012; Wright et al., 2011), and quality of life (Ankawi et al., 2017). These findings suggest that using pain ratings as the sole outcome variable likely provides an incomplete picture of pain adaptation.

Unlike the findings for continuous ratings of pain, no difference was found between stimuli for the relationship between pain resilience and retrospective ratings of pain unpleasantness or intensity. A potential analytic explanation for the observed difference between the continuous and retrospective ratings is that the mixed modeling analysis is a much more powerful statistical test, and therefore a potentially small effect could still be significant. Perhaps more importantly, from a theoretical perspective the non-significant outcome for retrospective ratings may reflect the temporal dimension of pain resilience given that the construct measures one's ability to maintain behavioral engagement and cognitive-emotional regulation during intense or prolonged pain (Slepian et al., 2016). This definition, and the items on the Pain Resilience Scale, describe how one reacts while in pain (e.g., "I push through it," "I focus on positive thoughts"), not how one reacts following exposure to pain. This suggests that pain ratings during the painful experience may be more suited to capturing individual differences in resilience as compared to post-stimulus reflections. Further, as noted above, it is also possible that pain ratings may not be the ideal dependent variable to capture the key features of pain resilience.

Although there was only partial support for the stimulus-specific hypotheses, there was nonetheless support for a pain-specific resilience measure. Consistent with previous findings, pain resilience was more closely related to pain ratings over time than

general resilience, providing additional support for the use of a pain-specific measure over a general measure when investigating pain outcomes (Ankawi et al., 2017; Slepian et al., 2016). Similarly, pain resilience was more strongly related to pain ratings than both optimism and hope. Given that the Pain Resilience Scale considered optimism and hope during item development, this was expected, as the Pain Resilience Scale is measuring aspects of these psychosocial constructs in addition to others, making it a more complete measure (Slepian et al., 2016). Although positive affect was also accounted for during the development of the Pain Resilience Scale, positive affect provided the best fit to the data out of all the tested resilience resources. When considering the pain resilience literature, however, this is not unexpected. Negative relationships between positive affect and pain are consistently found in the experimental pain literature (Dunbar, Kaskatis, MacDonald, & Barra, 2012; Meagher, Arnau, & Rhudy, 2001; Van Laarhoven et al., 2012), whereas studies on pain resilience and experimental pain ratings have found both significant (Slepian et al., 2016) and non-significant (Ankawi et al., 2015) relationships.

Additionally, the Positive and Negative Affect Schedule is a measure of state-level positive affect, whereas the other measures all assessed trait-level factors. This is an important distinction, as a model of pain adaptation developed by Sturgeon and Zautra (2010, 2013) proposed that state-level resilience factors mediate the relationship between trait-level resilience factors and coping responses to pain. These coping responses, which are also influenced by pain vulnerability factors and the nature of the pain episode, predict how individuals react to pain psychologically, behaviorally, and socially. This suggests a more proximal relationship between pain coping and state-level positive affect

than trait-level resilience, which consequently means a more proximal relationship between state-level factors and reactions to pain. This notion is supported by the findings of a recent study on acute back pain recovery over a 3-month time period by Slepian and colleagues (under review). This study found that the effect of pain resilience (a trait-level factor) on pain, depressive symptoms, and perceived disability at 3-month follow-up was mediated by levels of pain self-efficacy (a state-level factor) at 1-month follow-up. The closer proximity of state-level factors may explain why positive affect is a stronger predictor of pain outcomes than pain resilience.

Limitations and Future Directions

The present study has a number of methodological strengths that add to the existing literature on the relationship between pain resilience and response to acute experimental pain (e.g., investigating the effects of stimulus difference on interactions between pain and pain stimulus; use of both concurrent and retrospective pain ratings; comparisons of the effects of multiple resilience factors on pain ratings); nonetheless, the findings must be interpreted with the consideration of some limitations. One limitation is that participants self-selected into this study, meaning individuals with particularly low pain tolerance or high fear of pain may have been less likely to participate. Although participant demographics in the present study are similar to those in the initial validation of the Pain Resilience Scale (i.e., both samples were recruited using Ohio University's online participant recruitment system, were similar in age, and were majority female), these samples differed in regards to resilience and vulnerability to pain (Slepian et al., 2016). Participants in the present study endorsed higher average scores on the Pain

Resilience Scale ($M = 37.1$, $SD = 7.7$) and lower scores on the Pain Catastrophizing Scale ($M = 11.6$, $SD = 6.8$) relative to the average scores from the initial validation of the Pain Resilience Scale (Pain Resilience Scale: $M = 33.3$ - 34.8 , $SD = 11.1$ - 11.9 ; Pain Catastrophizing Scale: $M = 15.4$, $SD = 9.0$). One potential explanation for the higher resilience and lower vulnerability in the present study's sample is that the present study's description stated that participants would undergo painful stimulation, whereas the validation study was conducted online and required no laboratory testing; hence, less resilient participants may have elected not to participate in the present study.

As stated above, another potential limitation is that pain ratings were the only outcome variable. Future studies should extend the methodology used by Slepian and France (Slepian & France, 2017) to investigate task persistence and other behavioral outcomes across stimuli. For example, one way to look at the role of pain resilience would be to use completion rates or duration (if there are high discontinuation rates) of the pain stimulus as the outcome variable. This would require selection of a stimulus with a high enough discontinuation rate to make comparisons valid. Cold water immersion would be an ideal stimulus for this type of outcome variable as 37% of the present sample discontinued this stimulus before the full exposure time.

A third limitation to this study is the varying length of the stimuli. The pinprick stimulus was 30 seconds; the cold water immersion, up to 120 seconds; and the ischemic tourniquet task, up to 300 seconds. Although these temporal differences indicate that caution is needed when comparing the effect of pain resilience across stimuli, it should be

noted that this limitation does not apply to the interpretation of within-stimulus analyses of pain resilience influences on pain ratings over time.

Conclusion

This study is the first to compare the effects of pain resilience on individual differences in pain responses to different types of noxious stimuli, and provides additional evidence of the benefit of using multiple noxious stimuli to target different nociceptive fibers (Cruz-Almeida & Fillingim, 2014; Geber et al., 2011; Rolke, Magerl, et al., 2006). Specifically, given that the hypotheses regarding the relationship between pain resilience and pain ratings across tasks was only partially supported, assessment using multiple stimuli is important to continue to establish the specific features of nociceptive stimuli that differentiate the sensory, cognitive, and affective reactions of those with high versus low pain resilience. The null findings in retrospective ratings in this study, the null relationship between pain resilience and pain ratings for the ischemic tourniquet task, and the use of other outcome variables in the pain resilience literature suggest that other outcomes, especially behavioral outcomes, are also needed to fully address the relationship between pain resilience and acute experimental pain responses. Finally, the present study provides further evidence that pain resilience is a better predictor of pain ratings than general resilience, and preliminary evidence that state-level positive affect has a stronger influence on pain ratings than trait-level resilience factors.

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APPENDIX A

Questionnaires, Measures, and Additional Psychometrics

Demographics and Health Status

Session Date: _____

Participant Number: _____

Sex: M   F

Age (years): _____

Race: Please choose a category (or categories) that best describes your racial background:

_____ American Indian/Alaskan native

_____ Black or African American

_____ Asian

_____ White

_____ Native Hawaiian/Other Pacific Islander

_____ Other (_____)

Ethnicity: Please choose a category that best describes your ethnicity:

_____ Hispanic or Latino

_____ Not Hispanic or Latino

Has a doctor ever told you that you have a chronic or ongoing

medical concern? For example, chronic pain, high blood pressure,   Yes   No

diabetes, asthma, etc.

Pain Resilience Scale

Pain Resilience Scale

Directions: We are interested in the different ways that people respond to intense or prolonged pain (toothache, muscle strain, headache). Using a 0 ("Not at all") to 4 ("All the time") scale, please rate how much each of the following items describe how you respond when faced with intense or prolonged pain.

	When faced with intense or prolonged pain	Not at all	To a slight degree	To a moderate degree	To a great degree	All the time
1.	I get back out there	①	①	②	③	④
2.	I still work to accomplish my goals	①	①	②	③	④
3.	I push through it	①	①	②	③	④
4.	I try to continue working	①	①	②	③	④
5.	I like to stay active	①	①	②	③	④
6.	I focus on positive thoughts	①	①	②	③	④
7.	I keep a positive attitude	①	①	②	③	④
8.	It doesn't affect my happiness	①	①	②	③	④
9.	I still find joy in my life	①	①	②	③	④
10.	I keep a hopeful attitude	①	①	②	③	④
11.	I don't let it get me down	①	①	②	③	④
12.	I don't let it upset me	①	①	②	③	④
13.	I avoid negative thoughts	①	①	②	③	④
14.	I try to stay relaxed	①	①	②	③	④

Connor-Davidson Resilience Scale

For each item, please select the response that best indicates how much you agree with the following statements as they apply to you over the last month. If a particular situation has not occurred recently, answer according to how you think you would have felt.

	Not at all true	Rarely true	Sometimes true	Often true	True nearly all the time
I am able to adapt when changes occur,	☐	☐	☐	☐	☐
I have at least one close and secure relationship that helps me when I am stressed,	☐	☐	☐	☐	☐
When there are no clear solutions to my problems, sometimes fate or God can help.	☐	☐	☐	☐	☐
I can deal with whatever comes my way.	☐	☐	☐	☐	☐
Past successes give me confidence in dealing with new challenges and difficulties,	☐	☐	☐	☐	☐
I try to see the humorous side of things when I am faced with problems,	☐	☐	☐	☐	☐
Having to cope with stress can make me stronger,	☐	☐	☐	☐	☐
I tend to bounce back after illness, injury, or other hardships,	☐	☐	☐	☐	☐
Good or bad, I believe that most things happen for a reason,	☐	☐	☐	☐	☐
I give my best effort no matter what the outcome may be,	☐	☐	☐	☐	☐
I believe that I can achieve my goals, even if there are obstacles,	☐	☐	☐	☐	☐
Even when things look hopeless, I don't give up.	☐	☐	☐	☐	☐
During times of stress/crisis, I know where to turn for help.	☐	☐	☐	☐	☐
Under pressure, I stay focused and think clearly,	☐	☐	☐	☐	☐
I prefer to take the lead in solving problems rather than letting others make all the decisions.	☐	☐	☐	☐	☐
I am not easily discouraged by failure,	☐	☐	☐	☐	☐
I think of myself as a strong person when dealing with life's challenges and difficulties.	☐	☐	☐	☐	☐

I can make unpopular or
difficult decisions that affect
other people, if it is necessary.

I am able to handle
unpleasant or painful feelings
like sadness, fear, and anger.

In dealing with life's problems,
sometimes you have to act on
a hunch without knowing why.

I have a strong sense of
purpose in life.

I feel in control of my life.

I like challenges

I work to attain my goals no
matter what roadblocks I
encounter along the way.

I take pride in my
achievements.

Positive and Negative Affect Schedule

This scale consists of a number of words that describe different feelings and emotions. Read each item and then list the number from the scale below next to each word. Indicate to what extent you feel this way right now, that is, at the present moment.

1	2	3	4	5
Very Slightly or Not at All	A Little	Moderately	Quite a Bit	Extremely

_____ 1. Interested _____ 2. Distressed _____ 3. Excited _____ 4. Upset _____ 5. Strong _____ 6. Guilty _____ 7. Scared _____ 8. Hostile _____ 9. Enthusiastic _____ 10. Proud	_____ 11. Irritable _____ 12. Alert _____ 13. Ashamed _____ 14. Inspired _____ 15. Nervous _____ 16. Determined _____ 17. Attentive _____ 18. Jittery _____ 19. Active _____ 20. Afraid

Life Orientation Test- Revised

Using the scale below as a guide, indicate how much you agree with each statement below.

0 = Strongly Disagree

1 = Disagree

2 = Neutral

3 = Agree

4 = Strongly Agree

1. In uncertain times, I usually expect the best. _____
2. It's easy for me to relax. _____
3. If something can go wrong for me it will. _____
4. I am always optimistic about my future. _____
5. I enjoy my friends a lot. _____
6. It's important for me to keep busy. _____
7. I hardly ever expect things to go my way. _____
8. I don't get upset too easily. _____
9. I rarely count on good things happening to me. _____
10. Overall, I expect more good things to happen to me than bad. _____

Adult Hope Scale

The Adult Hope Scale

Directions: Read each item carefully. Using the scale shown, please select the number that best describes YOU and put that number in the blank provided.

- 1 = Definitely false
- 2 = Mostly false
- 3 = Somewhat false
- 4 = Slightly false
- 5 = Slightly true
- 6 = Somewhat true
- 7 = Mostly true
- 8 = Definitely true

1. _____ I can think of many ways to get out of a jam.
2. _____ I energetically pursue my goals.
3. _____ I feel tired most of the time.
4. _____ There are lots of ways around any problem.
5. _____ I am easily downed in an argument.
6. _____ I can think of many ways to get the things in life that are important to me.
7. _____ I worry about my health.
8. _____ Even when others get discouraged, I know I can find a way to solve the problem.
9. _____ My past experiences have prepared me well for my future.
10. _____ I've been pretty successful in life.
11. _____ I usually find myself worrying about something.
12. _____ I meet the goals that I set for myself.

Pain Catastrophizing Scale

Everyone experiences painful situations at some point in their lives. Such experiences may include headaches, tooth pain, joint or muscle pain. People are often exposed to situations that may cause pain such as illness, injury, dental procedures or surgery.

We are interested in the types of thoughts and feelings that you have when you are in pain. Listed below are thirteen statements describing different thoughts and feelings that may be associated with pain. Using the following scale, please indicate the degree to which you have these thoughts and feelings when you are experiencing pain.

0 – not at all   1 – to a slight degree   2 – to a moderate degree   3 – to a great degree   4 – all the time

---

When I'm in pain ...

- ☐ I worry all the time about whether the pain will end.
- ☐ I feel I can't go on.
- ☐ It's terrible and I think it's never going to get any better.
- ☐ It's awful and I feel that it overwhelms me.
- ☐ I feel I can't stand it anymore.
- ☐ I become afraid that the pain will get worse.
- ☐ I keep thinking of other painful events.
- ☐ I anxiously want the pain to go away.
- ☐ I can't seem to keep it out of my mind.
- ☐ I keep thinking about how much it hurts.
- ☐ I keep thinking about how badly I want the pain to stop.
- ☐ There's nothing I can do to reduce the intensity of the pain.
- ☐ I wonder whether something serious may happen.

Numerical Rating Scale of Pain Intensity and Pain Unpleasantness

There are two aspects of pain which we are interested in measuring: the intensity, how strong the pain feels, and the unpleasantness, how unpleasant or disturbing the pain is for you. The distinction between the two aspects of pain might be made clearer if you think of listening to a sound, such as a radio. As the volume of the sound increases, I can ask you how loud it sounds or how unpleasant it is to hear it. The intensity of pain is like loudness; the unpleasantness of pain depends not only on intensity but also on other factors which may affect you. There are scales for measuring each of these two aspects of pain. Although some pain sensations may be equally intense and unpleasant, we would like you to judge the aspects independently.

How **intense** was the pain during the last pain task?

0   1   2   3   4   5   6   7   8   9   10

No pain

Worst pain

imaginable

How **unpleasant** was the pain during the last pain task?

0   1   2   3   4   5   6   7   8   9   10

Not unpleasant

As unpleasant as I

at all

can imagine

[illegible]

Additional Psychometrics

The Pain Resilience Scale was used to measure one's ability to maintain behavioral engagement and regulate emotions as well as cognitions despite prolonged or intense pain (Slepian et al., 2016). The Pain Resilience Scale is a 14 item measure that asks participants to rate how often they have specific thoughts about pain on a scale from 0 ("Not at all") to 4 ("all the time"). It has two subscales that allow the researcher to look at specific domains of pain resilience; namely, the Cognitive/Affective Positivity subscale and the Behavioral Perseverance subscale. Items on the Cognitive/Affective Positivity subscale assess an individual's perceived ability to control their thoughts and emotions related to pain. An example item from this subscale is "I keep a positive attitude." Items on the Behavioral Perseverance subscale assess an individual's tendency to engage in particular behaviors when faced with prolonged pain. An example item from this subscale is "I push through it." It demonstrated strong internal consistency for the full scale ($\alpha = 0.93$) and for both subscales (Cognitive/Affective Positivity $\alpha = 0.91$; Behavioral Perseverance $\alpha = 0.87$). The Pain Resilience Scale also demonstrated acceptable test-retest reliability (ICC = 0.80) over a one-month interval in a sample of college students (Slepian et al., 2016). The Pain Resilience Scale has demonstrated convergent validity by way of significant positive relationships to other measures of resilience, such as the Connor-Davidson Resilience Scale ($r = 0.68$) and Brief Resilience Scale ($r = 0.45$), as well as a significant positive relationship with the Pain Self-Efficacy Questionnaire ($r = 0.62$). Further, the Pain Resilience Scale has shown to be a better predictor of ischemic tourniquet pain responses than the Connor-Davidson Resilience

Scale, a general measure of resilience that is described in more detail below (Slepian et al., 2016).

The Connor-Davidson Resilience Scale was used to assess general resilience, a psychological construct describing one's ability to thrive in the face of adversity (Connor & Davidson, 2003). Participants are presented with 25 statements and asked to rate how true each statement has been for them over the past month on a scale from 1 ("Not at all true") to 5 ("True nearly all the time"). The Connor-Davidson Resilience Scale has demonstrated strong internal consistency (Cronbach's $\alpha = 0.89$) and high test-retest reliability ($r = 0.87$) (Connor & Davidson, 2003). Convergent validity has been assessed by correlating the Connor-Davidson Resilience Scale with related constructs, and support has been demonstrated in the form of a significant positive relationship with the Kobasa Hardiness Scale, and negative relationships with the Perceived Stress Scale and Stress Vulnerability Scale (Connor & Davidson, 2003).

The Positive and Negative Affect Schedule was used to measure state-level positive affect, the degree to which the participant is experiencing positive emotions at the present moment (Watson et al., 1988). Each item on this 20 item measure is a single word, and participants rate the degree to which the word describes how they feel from 1 ("very slightly or not at all") to 5 ("extremely"). Half of the items correspond to positive affect, and half to negative affect. Convergent validity was demonstrated after finding positive relationships for negative affect and negative relationships for positive affect when correlated with measures of distress, depression, and anxiety. This measure has

demonstrated acceptable internal consistency (Cronbach's $\alpha = 0.84-0.90$) and reliability ($r = 0.39-0.71$) over an eight week retesting interval (Watson et al., 1988).

The Life Orientation Test-Revised was used to assess dispositional optimism, a tendency to have positive expectations about the future (Scheier et al., 1994). This 10 item measure asks participants to rate the extent to which they agree with a statement on a scale from 0 ("strongly disagree") to 4 ("strongly agree"). Of the ten items, only six are scored, with half of them being reverse-scored. Convergent validity was demonstrated by the scale's positive relationships with other psychosocial constructs, such as self-mastery and self-esteem, and negative relationships with negative constructs, such as neuroticism and trait anxiety. The measure also uniquely predicted outcomes such as depression, acceptance, and restraint after controlling for these constructs, suggesting that it is a distinct construct. The Life Orientation Test-Revised has demonstrated acceptable internal consistency (Cronbach's $\alpha = 0.70$) and test-retest reliability over four month ($r = 0.68$), 12 month ($r = 0.60$), 24 month ($r = 0.56$), and 28 month ($r = 0.79$) intervals (Scheier et al., 1994).

The Adult Trait Hope Scale was used to assess trait-level hope, a mental set that one can take actions to achieve their desired goals (Snyder et al., 1991). Participants are asked to rate how truthfully 12 items describe them on a scale from 1 ("Definitely false") to 4 ("Definitely true"). This measure consists of two subscales: Agency, one's sense of determination in meeting their goals, and Pathways, one's sense of being able to generate plans for successful goal completion. Each subscale is made up of four items, with four more being filler items that are not included in scoring. Convergent validity was

demonstrated by positive relationships between the Adult Trait Hope Scale and the Life Orientation Test, Burger-Cooper Life Experiences Survey, and the Rosenberg Self-Esteem Scale. The measure has demonstrated acceptable internal consistency for the full scale (Cronbach's $\alpha = 0.74-0.84$) and subscales (Agency: Cronbach's $\alpha = 0.71-0.76$; Pathways: Cronbach's $\alpha = 0.63-0.80$), as well as high test-retest reliability after three week ($r = 0.85$), eight week ($r = 0.73$), and ten week ($r = 0.76-0.82$) intervals (Snyder et al., 1991).

Pain Vulnerability

The Pain Catastrophizing Scale is a 13 item measure that assesses pain catastrophizing by asking participants to rate the degree to which they experience certain thoughts from 0 ("Not at all") to 4 ("all the time") while in pain (Sullivan et al., 1995). Convergent validity has been supported by significant positive correlations between the Pain Catastrophizing Scale and the Inventory of Negative Thoughts in Response to Pain (Osman et al., 1997). The Pain Catastrophizing Scale has demonstrated a high degree of internal consistency (Cronbach's $\alpha = 0.87$) and acceptable test-retest reliability over six week ($r = 0.75$) and ten week ($r = 0.70$) intervals.

Pain Ratings

For each pain stimulus, participants continuously rated their pain from 0 ("no pain") to 100 ("worst pain imaginable") before, during, and immediately following each task. This was done using a physical device which manipulated an on-screen slider. If a participant rated their pain as 100 during a pain task, the stimulus was immediately discontinued and they entered a rest period.

After each task, participants completed two additional pain measures. The first was a two-item Numerical Rating Scale assessing pain intensity and unpleasantness. Participants rated the pain intensity and unpleasantness of each task on a scale from 0 (no pain/no unpleasantness) to 10 (worst pain imaginable/as unpleasant as I can imagine). Participants also completed the Short Form McGill Pain Questionnaire 2, a 22-item measure that asks participants to rate the quality of pain (e.g., throbbing, stabbing) on a scale from 0 (“none”) to 10 (“worst possible”). This measure has high internal consistency (Cronbach’s $\alpha = 0.91-0.96$) (Dworkin et al., 2009; Lovejoy et al., 2012). Convergent validity was confirmed by positive relationships between total scores on the Short Form McGill Pain Questionnaire 2 and scores on both the Brief Pain Inventory and Multidimensional Pain Inventory. Discriminant validity was supported by physical descriptors of pain having stronger correlations with the Pain Catastrophizing Scale (which better predicts physical functioning) than the Mental Component Summary (which better predicts mental functioning), and by affective descriptors having the opposite relationship (Dworkin et al., 2009)

APPENDIX B

Supplemental Analyses and Figures

Participants rated their pain before, during, and after each stimulus. The ratings before the stimulus were to ensure that there was no residual pain from previous stimuli. Most participants rated their pain at 0/100 for the entire duration of the pre-stimulus ratings. There were eight instances (for eight different participants) where pre-stimulus ratings averaged over 1/100; this could be due to mechanical issues (i.e., the scale appeared to be at 0/100 but was in the low single digits) or residual pain from a previous stimulus. These ratings ranged from an average of 1.08-4.86 over the pre-stimulus period, and were distributed as such: three before pinprick (i.e., after ischemic tourniquet), one before cold water immersion (i.e., after pinprick), and four before ischemic tourniquet (i.e., after cold water immersion). Due to the low pain intensity and low frequency (only 2.7% of stimuli had non-zero pre-stimulus ratings) this was not factored into the analyses of continuous ratings of pain during stimuli.

The relationship between pain resilience and continuous ratings of post-stimulus pain by stimulus were analyzed using mixed models. Prior to these analyses, one participant who did not follow the directions to provide continuous pain ratings was removed from the data (i.e., he kept the pain rating scale at zero until after the pain task, at which point he moved the slider to indicate how painful he found the task). Scores on the Pain Catastrophizing Scale and Pain Resilience Scale were fixed at their means. Continuous ratings of pain were averaged for each second of post-stimulus recovery. Three-level mixed models were created with pain ratings at every time point nested

within each participant. Sex, pain catastrophizing, pain resilience, order of stimuli, and time were entered into the first level; interactions between time and pain resilience, time and stimulus, and pain resilience and stimulus were entered into the second level; and the interaction between time, pain, and stimulus was entered into the third level. Order was dropped from the final model because it had no significant effect on pain outcomes.

Linear, logarithmic, quadratic, and cubic unconditional growth curves were fitted to the model to identify the best fit to the pain ratings, as determined by the Akaike Information Criteria (AIC) and Schwarz's Bayesian Criteria (BIC). Lower numbers represent a better fit, with decreases of 3 representing meaningful change and decreases of 10 considered strongly meaningful (Burnham & Anderson, 2002; Kass & Raftery, 1995). The cubic growth curve did not consistently converge and was unstable (i.e., it gave different coefficients each time it was run). For this reason, it was not considered for analysis. The quadratic growth curve (AIC = 215,484.1; BIC = 215,705.3) provided a significantly better fit than the logarithmic (AIC = 222,693.9; BIC = 222,841.4) and linear (AIC = 219,474.8; BIC = 219,658.3) growth curves and was therefore selected for analysis.

Using the quadratic mixed model, interactions between predictors were analyzed to determine if and how pain-specific resilience (i.e., Pain Resilience Scale Scores) was related to post-stimulus pain (see Supplemental Table 1). There was a second level interaction between stimulus and pain resilience on pain, as well as a third level interaction between stimulus, pain resilience, and time on pain. To further investigate these interactions, graphs were created for each stimulus with pain resilience fixed at one standard deviation above and below the mean. A two-level quadratic mixed model was

also created for each stimulus, with pain ratings at every time point nested within each participant. Sex, pain catastrophizing, pain resilience, and time were entered into the first level, and the interactions between time and pain resilience were entered into the second level.

Supplemental Table 1. Tests of fixed effects for the quadratic growth curve model predicting differences in pain during recovery between stimuli over time.

Fixed Effect	df Numerator	df Denominator	F
Intercept	1	125	501.67***
Time	1	194	226.25***
Time ²	1	7,048	105.57***
Stimulus	2	26,432	4,642.17***
Pain resilience	1	104	1.38
Pain catastrophizing	1	99	0.26
Sex	1	99	2.08
Stimulus x Time	2	26,432	264.49***
Stimulus x Time ²	2	26,432	43.58***
Stimulus x Pain resilience	2	26,432	227.45***
Time x Pain resilience	1	194	0.45
Time ² x Pain resilience	1	7,048	0.07
Stimulus x Time x Pain resilience	2	26,432	42.69***
Stimulus x Time ² x Pain resilience	2	26,432	13.02***

***p < 0.001, 2-tailed

Results of the follow-up analysis for the pinprick task are presented in Supplemental Table 2 and the relationship between pain resilience and recovery pain ratings is illustrated in Supplemental Figure 1 with pain resilience fixed at one standard deviation above and below the mean. As shown in Supplemental Table 2, a significant main effect was observed for time. As shown in Supplemental Figure 1, this reflects a

negative relationship such that recovery pain ratings decreased over time. None of the other main effects or interactions was significant.

Supplemental Table 2. Tests of fixed effects for the quadratic growth curve model predicting changes in pain over time during recovery after the pinprick task.

Fixed Effect	df Numerator	df Denominator	F
Intercept	1	118	110.99***
Time	1	99	76.81***
Time ²	1	99	65.94***
Pain resilience	1	101	0.27
Pain catastrophizing	1	99	0.01
Sex	1	99	1.77
Time x Pain resilience	1	99	0.02
Time ² x Pain resilience	1	99	0.00

***p < 0.001, 2-tailed

Supplemental Figure 1. Estimated pain ratings for high pain resilience (+ 1 SD) and low pain resilience (- 1SD) for recovery after the pinprick task. Error bars represent the standard error of the mean.

Results of the follow-up analysis for the cold water immersion are presented in Supplemental Table 3 and the relationship between pain resilience and recovery pain ratings is illustrated in Supplemental Figure 2 with pain resilience fixed at one standard deviation above and below the mean. It should be noted that the values for pain ratings for this graph start above 100. This is because the values for these graphs are based on estimates from the slope from the mixed model. These slopes are based on the data from all participants, with some rating a sharp decrease in pain after removing their hand from the cold water bath. Averaging these sharp slopes along with flatter slopes from other

participants led to a high y-intercept. Only the cold water immersion was affected by this because it had a higher rate of discontinuation (i.e., more participants started the recovery at 100 than for the other tasks); therefore, this task would have sharp decreases of larger amplitudes than As shown in Supplemental Table 3, significant main effects were observed for time and pain resilience. As shown in Supplemental Figure 2, this reflects a negative relationship for time such that recovery pain ratings decreased over time, and a negative relationship for pain resilience such that higher pain resilience was associated with lower pain.

Supplemental Table 3. Tests of fixed effects for the quadratic growth curve model predicting changes in pain over time during recovery after the cold water immersion.

Fixed Effect	df Numerator	df Denominator	F
Intercept	1	122	533.13***
Time	1	99	119.05***
Time ²	1	99	30.06***
Pain resilience	1	103	6.51*
Pain catastrophizing	1	99	0.14
Sex	1	99	0.94
Time x Pain resilience	1	99	2.45
Time ² x Pain resilience	1	99	1.47

**p < 0.01, 2-tailed

***p < 0.001, 2-tailed

Supplemental Figure 2. Estimated pain ratings for high pain resilience (+ 1 SD) and low pain resilience (- 1SD) for recovery after the cold water immersion task. Error bars represent the standard error of the mean.

Results of the follow-up analysis for the ischemic tourniquet task are presented in Supplemental Table 4 and the relationship between pain resilience and recovery pain ratings is illustrated in Supplemental Figure 3 with pain resilience fixed at one standard deviation above and below the mean. As shown in Supplemental Table 4, a significant main effect was observed for time. As shown in Supplemental Figure 3, this reflects a negative relationship such that recovery pain ratings decreased over time. None of the other main effects or interactions was significant.

Supplemental Table 4. Tests of fixed effects for the linear growth curve model predicting changes in pain over time for the ischemic tourniquet task.

Fixed Effect	df Numerator	df Denominator	F
Intercept	1	111	162.81***
Time	1	99	73.74***
Time ²	1	99	41.08***
Pain resilience	1	100	0.51
Pain catastrophizing	1	100	0.57
Sex	1	99	0.05
Time x Pain resilience	1	99	0.20
Time ² x Pain resilience	1	99	0.00

***p < 0.001, 2-tailed

Supplemental Figure 3. Estimated pain ratings for high pain resilience (+ 1 SD) and low pain resilience (- 1SD) for recovery after the ischemic tourniquet task. Error bars represent the standard error of the mean.

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