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Pain ratings reflect cognitive context: A range frequency model of pain perception

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ABSTRACT

When painful stimuli are evaluated at the time they are experienced, judgments are made not in isolation but with reference to other experienced stimuli. We tested a specific quantitative model of how such context effects occur. Participants experienced 3 blocks of 11 different pressure pain stimuli, and rated each stimulus on a 0–10 scale of intensity. Stimulus distribution was varied between participants. Study 1 found that that the rating of a stimulus of a particular pressure was higher in the context in which it ranked highest. Study 2 found that pain ratings were higher in a context where most stimuli were relatively intense, even when the mean stimulus was constant. It is suggested that pain judgments are relative, involve the same cognitive processes as are used in other psychophysical and socioemotional judgments, and are well described by range frequency theory. This approach can further inform the existing body of research on context-dependent pain evaluation.

1. Introduction

Self-reported pain is understood to involve cognitive evaluation as well as neurological response [7,10,24,25,33–35], and can be conceptualised as involving 3 stages: (1) neurological detection of the stimulus, (2) cognitive evaluation of the stimulus, followed by production of a response (a subjective opinion of how painful the stimulus feels), and (3) encoding of that particular experience in memory. Whilst much research focuses on neurological response [5,23,24,26,47] and pain memory [2,3,8,16,30,37,41,45] including tests of peak-end theory [14,15,31,36,40,42], there is much less research on (and currently no quantitative model of) judgments made at the time pain occurs.

Some researchers assume that pain can be evaluated in isolation without reference to prior experience [2]; indeed, the assumption of context independence is implicit in the existence of pain rating scales [13,43,53], although use of these is now commonly believed to oversimplify the pain evaluation process [7,53]. Such an assumption would be consistent with an "absolute" account of pain judgment, according to which pain is predicted solely by the magnitude of the painful stimulus. Alternatively, as with other psychophysical judgments, real-time momentary pain judgments could be relative and depend on how a stimulus compares with other painful experiences. The basic understanding of self-reported pain depends on understanding how such relative judgments are made.

We hypothesize that ratings of current pain can be influenced by other recent pain. How might such context effects occur? According to adaptation-level theory [11,18,33–35], pain might be evaluated relative to a perceived mean stimulus in the recent context. Alternatively, people might use the same judgment processes as they have been shown to use for other psychophysical stimuli. Such judgments are typically well described by range frequency theory (RFT) [27,28]. A demonstration that RFT characterizes pain judgments could link pain research with the study of other psychophysical [27,29,32] and socioemotional judgments [6,20,22,38,48–52,54–57].

RFT states that judgment of a stimulus depends on a combination of its rank amongst other stimuli (the *rank principle*), and its position along the range of stimuli (the *range principle*). As applied to judgment of pain (a new domain for the application of RFT), the principles would operate as follows.

Under the rank principle, the higher a stimulus ranks amongst other stimuli, the more painful it seems:

$$F_i = (r_i - 1)/(N - 1)$$

where F_i is the judgment by rank of stimulus i, ranked at position r_i in a context of N stimuli.

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Under the range principle, the higher a stimulus lies along the range of stimuli, the more painful it seems:

$$R_i = (S_i - S_{min})/(S_{max} - S_{min})$$

where R_i is the judgment by range of stimulus i, of magnitude S_i, S_{min} is the lowest and S_{max} the highest stimulus in the context.

Overall judgment of a stimulus is expressed as:

$$J_i = wR_i + (1 - w)F_i$$

where w is a weighting parameter [55].

The studies reported below tested whether relative pain ratings are governed by the rank principle (Study 1) and the range principle (Study 2). Both studies tested RFT against the 2 rival accounts, absolute judgment and adaptation-level theory.

2. Methods – Study 1

Study 1 examined whether pain ratings were influenced by the ranked position of painful stimuli within different contexts. Using a methodology well established in research into rank-dependent judgment [6,20,55–57], we manipulated the rank position of painful stimuli while holding constant their distance from the mean, and from the highest and lowest stimulus in both contexts. We predicted that particular stimuli would be judged more painful in the context in which they ranked highest.

2.1. Participants

We recruited an opportunity sample of 51 participants (35 female) from the University of Manchester; 70.6% were first- and second-year undergraduates who received course credits for taking part, with the remainder consisting of postgraduate students and staff who took part voluntarily. All participants were blind to the objectives of the study and none were involved in pain research. Participants gave their informed written consent, and the study was approved by the University of Manchester School of Psychological Sciences Ethics Committee. Participants were aged between 18 and 49 years (82.4% under 25 years) and 21.56% were left-handed. The majority of participants described themselves as white (78.4%); the next most represented ethnicity was Pakistani (9.8%). Participants were tested individually with an experimenter present.

2.2. Design and procedure

All participants experienced 3 blocks each comprising 11 painful stimuli. Each stimulus was a pressure applied to the fingers by a pneumatic pain stimulator. We asked participants to judge the severity of pain from each stimulus at the point of experience, without explicit reference to previous responses. Participants' fingers were placed under the pain stimulator probe as described below, beginning with the ring finger of the left hand. In order to control for order effects, which might result in sensitization or habituation of receptors at the site of stimulation, participants changed finger for each stimulus, in the following sequence:

Left Ring; *Left Middle*; *Left Index*; *Right Index*; *Right Middle*; *Right Ring* ... repeating this sequence throughout the 3 blocks to avoid repetition of a particular stimulus on the same finger with repeated blocks.

Table 1
Pressure pain stimuli presented to unimodal and bimodal groups, Study 1.

	Voltage into system	Pressure under probe (kg/cm^2)	Rank position within distribution	
			Unimodal	Bimodal
	0.45	1.53	1	1
	0.48	1.89		2
	0.52	2.25		3
	0.55	2.61		4
Target stimulus 1	0.59	2.97	2	5
	0.62	3.33	3	
	0.66	3.69	4	
	0.69	4.05	5	
Target stimulus 2	0.73	4.41	6	6
	0.76	4.77	7	
	0.79	5.12	8	
	0.83	5.48	9	
Target stimulus 3	0.86	5.84	10	7
	0.90	6.20		8
	0.93	6.56		9
	0.97	6.92		10
	1.00	7.28	11	11

2.2.1. Pain stimulation

We delivered pressure pain using a pneumatic pain stimulator system designed by Dancer Design (St. Helens, UK). The system included a pneumatic force controller, which uses compressed air to lower a 1-cm^2 circular rubber probe at variable force. The circular probe was lowered onto the finger at the junction with the fingernail bed, centrally placed to cover an equal area of nail and skin. Each stimulus was delivered by passing a specific voltage into the pain stimulator, which translates this into pressure at the probe in a range from 0.00 kg/cm^2 (generated from 0.00 v input) to 7.28 kg/cm^2 (generated from 1.00 v input). Specific voltages were generated by a bespoke computer program written in MATLAB 7.5.0 (MathWorks Inc, Sherborn, MA, USA) and passed into the pain stimulator via a LabJack U12 device (LabJack Corp., Lakewood, CO, USA). With a finger placed under the probe, each complete stimulus comprised a 3-second depression time, followed by maintenance of full pressure for a further 3 seconds, after which pressure was released immediately. An emergency pressure release switch was accessible at all times, and we made clear to participants that they could abort the process and withdraw their finger immediately should the pain become too uncomfortable.

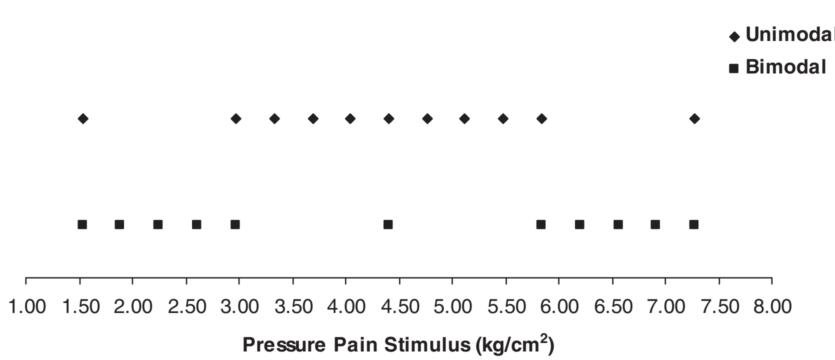

Fig. 1. Illustration of unimodal and bimodal distributions of stimuli, Study 1.

Table 2
Mean pain ratings for target stimuli by unimodal and bimodal groups, Study 1.

Stimulus	Pressure (kg/cm^2)	Group			
		Unimodal (n = 21)		Bimodal (n = 25)	
		M	SD	M	SD
Target stimulus 1	2.97	2.76	1.10	3.26	1.42
Target stimulus 2	4.41	5.83	1.68	5.94	1.89
Target stimulus 3	5.84	8.12	1.22	7.48	1.76

2.2.2. Self-report measure

The intensity of each pressure pain stimulus was rated on the 0–10 Numeric Pain Rating Scale [21], anchored by "No pain" (0), "Moderate pain" (5) and "Worst possible pain" (10). Participants made their response on a paper copy of the scale immediately after each stimulus, using only the whole integers on the scale.

We allocated odd-numbered participants to one group of 25 participants, and even-numbered participants to another group of 26 participants. All participants underwent 3 blocks, each of which consisted of 11 different pressure pain stimuli to the finger. The 11 stimuli were presented in random order, as generated by the MATLAB computer program. Participants were not aware of the division into 3 separate blocks, but were presented with 33 stimuli as a single sequence. The first block was not intended for analysis, being the context-establishing block. This was followed by experimental blocks 1 and 2 (each identical to the context-setting block, in the same random order), results of which were averaged for analysis.

The 2 groups received different series of 11 stimuli. One group (n = 25) received stimuli in a unimodal distribution and the other group (n = 26) received stimuli in a bimodal distribution. These distributions are illustrated in Fig. 1. Three target stimuli were common to both groups, but differed in rank position between the groups. The stimuli presented to each group are shown in Table 1. Both groups received stimuli ranging from 1.53 to 7.28 kg/cm^2, and the mean stimulus was the same for both groups (4.41 kg/cm^2). Means were based on the average pressure delivered to each group, which is appropriate as pain ratings from pressure stimuli have been shown to increase in a linear fashion as pressure increases [1]. To explicitly test the RFT rank principle against adaptation-level theory, the magnitude of each of the 3 target stimuli relative to the mean was kept constant between the 2 distributions.

If pain judgments were not dependent on context, but were based on the intensity of each stimulus alone, then the 3 target stimuli, being of equal pressure between the 2 groups, should elicit the same pain rating from both groups. If pain ratings were based on comparison with the mean, as adaptation-level theory might suggest, again, the target stimuli should each produce the same pain rating from both groups, as the magnitude of each target stimulus relative to the mean was the same for both groups. However, if pain judgments are dependent on rank within context, then the same stimulus should be judged more painful in the context in which it ranks higher, so target stimulus 1 (2.97 kg/cm^2) should be judged more painful by the bimodal group (where rank = 5) than by the unimodal group (where rank = 2). Target stimulus 2 (4.41 kg/cm^2), ranked in sixth place in both distributions, should be judged equally painful by both groups. Target stimulus 3 (5.84 kg/cm^2) should be judged more painful by the unimodal group (where rank = 10) than by the bimodal group (where rank = 7). Thus, a cross-over interaction was expected, whereby the unimodal group would report less pain from target stimulus 1, but more pain from target stimulus 3, with the cross-over occurring at target stimulus 2.

2.3. Results

Two participants chose to abort the test and withdrew. A further 3 cases were excluded due to restricted use of the scale; those participants did not report even moderate pain during the experimental blocks. Table 2 shows mean reported pain for the 3 target stimuli. The differences in pain intensity rating between the groups appeared as predicted. As Table 2 illustrates, target stimulus 1 appeared to be judged to be more painful by the bimodal group (where rank = 5) than by the unimodal group (where rank = 2). Target stimulus 2 (which occupied the same ranked position in each condition) appeared to be judged similarly by both groups (occupying the same rank in both), and target stimulus 3 appeared to be judged more painful by the unimodal group (where rank = 10) than by the bimodal group (where rank = 7). A 2 (between: group) × 3 (within: target stimulus) mixed-model analysis of variance (ANOVA) revealed a main effect of target stimulus; $F(2,88) = 257.02$, $P < 0.001$; confirming that higher pressure was judged more painful, and no main effect of group. As expected, there was a significant interaction effect of target stimulus × group; $F(2,88) = 3.69$, $P = 0.03$, which suggests that the rank position of a given stimulus amongst other painful stimuli influences judgment of how painful it appears. This interaction is shown in Fig. 2, which illustrates that the intersection occurs around target stimulus 2, the mean pressure applied, with rank = 6 for both groups. (To confirm that the responses from undergraduates did not differ substantially from those from postgraduates and staff in Study 1, we conducted a 2 [between: group] × 3 [within: target stimulus] mixed-model analysis of covariance [covariate: student/staff status]. After controlling for possible effects of student/staff status, the main effect of target stimulus remained; $F(2,86) = 37.61$, $P < 0.001$. The interaction effect of group × target stimulus was also retained; $F(2,86) = 3.47$, $P = 0.04$.)

As the target stimuli for Study 1 were of the same absolute magnitude, and were at the same distance from the mean (4.41 kg/cm^2)

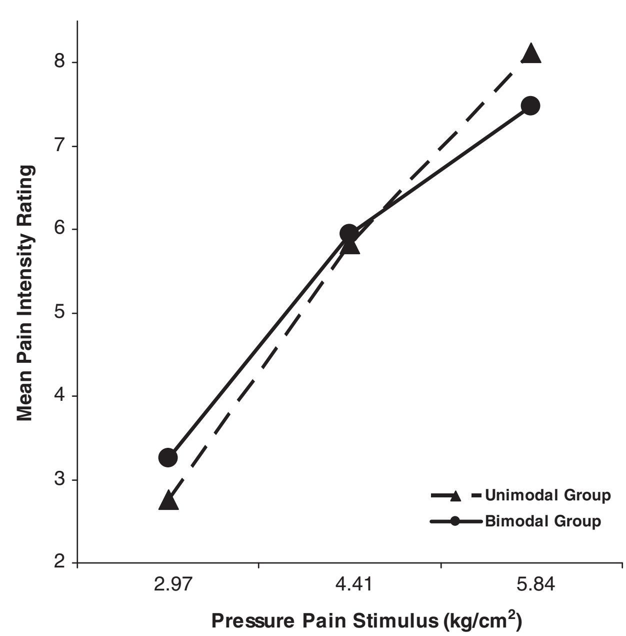

Fig. 2. Interaction between the unimodal and bimodal groups' pain intensity ratings of the 3 target stimuli, Study 1.

in both distributions, differences in evaluation of these stimuli between the 2 groups must be wholly attributable to rank effects, and not due to differences in absolute magnitude, nor to comparison with a central tendency, as would be suggested by adaptation-level theory. As noted in other literature on RFT [6,20,55–57], the true test of the theory is whether there is a significant and symmetrical interaction effect, indicating that the results are based on relative rank position of stimuli. Effect sizes, calculated from the differences between mean responses from the 2 groups to target stimulus 1 and target stimulus 3, were moderate (d = 0.40 and d = 0.43, respectively).

It is possible that the order of presentation might influence lower-level processes such as sensitization or habituation, which could contribute to the context effect. Following the logic of previous RFT work on sensory judgments of taste [32], it seems likely that such effects would manifest as an influence of a preceding stimulus on judgment of the following stimulus. We tested this by analyzing the effect of the preceding stimulus on the ratings of each of the 3 target stimuli, common to both groups. For each of the 3 target stimuli, we calculated whether the preceding stimulus had been higher or lower in each of the 2 experimental blocks, and conducted 6 2 (between: group) x 2 (between: high/low predecessor) 2-way independent ANOVAs. These revealed no significant main effect of high/low predecessor on the pain ratings given to any of the target stimuli with statistics ranging from $F(3,42) = .68$, $P = 0.41$ to $F(3,42) = 2.45$, $P = 0.13$. There was no significant interaction effect of group × high/low predecessor on any of these pain ratings, with statistics ranging from $F(3,42) = .02$, $P = 0.89$ to $F(3,42) = .68$, $P = 0.41$. (Amongst the results of tests of the effect of the preceding stimuli on the target stimuli in Study 1, one extremely nonsignificant interaction of group × high/low predecessor [$F(3,42) = 0.00$, $P = 1.00$] was disregarded, as only one participant in the unimodal group had received a higher predecessor to that stimulus). These results suggest that there was no systematic effect of the previous stimulus on judgment of the current stimulus, and therefore no evidence of sensitization or habituation, and that this is equally true of both distributions.

3. Methods – Study 2

Study 2 again used an established methodology [38,55,57], this time to test the range principle, according to which a stimulus appears more painful the higher it lies within the range bounded by other stimuli. The range principle suggests that if someone's painful experiences were negatively skewed, with most pain tending toward the top of their range of experience, they would report more pain than someone whose painful experiences were positively skewed, with pain clustered toward the bottom of their range, even if both suffered equal physical trauma. We predicted that stimuli would appear on average to be more painful when experienced in the context where the stimuli were negatively skewed.

Table 3
Pressure pain stimuli presented to positive and negative skew groups, Study 2.

Voltage into system	Pressure under probe (kg/cm^2)	Position within range of distribution	
		Positive skew	Negative skew
0.45	1.53		1
0.55	2.58		2
0.60	3.10	1	
0.61	3.20	2	
0.62	3.31	3	
0.63	3.41	4	3
0.65	3.62	5	
0.68	3.94	6	
0.69	4.04		4
0.71	4.25	7	
0.74	4.56		5
0.76	4.77	8	
0.77	4.88		6
0.80	5.19		7
0.82	5.40	9	8
0.83	5.50		9
0.84	5.61		10
0.85	5.71		11
0.90	6.24	10	
1.00	7.28	11	

3.1. Participants

We recruited an opportunity sample of 40 participants (23 female) from the University of Manchester; 80% were third-year undergraduates, postgraduate students, and staff who took part voluntarily, with the remainder consisting of first- and second-year undergraduates who received course credits for taking part. All participants were blind to the objectives of the study and none were familiar with pain research. Participants gave their informed written consent, and the study was approved by the University of Manchester School of Psychological Sciences Ethics Committee. Participants were aged between 19 and 35 years (77.5% under 27 years) and 15% were left-handed. The majority of participants described themselves as white (90%); the next most represented ethnicity was Chinese (5%). Participants were tested individually with an experimenter present.

3.2. Design and procedure

We allocated odd-numbered participants to one group and even-numbered participants to another group, with 20 participants in each group. All participants underwent 3 blocks, each of

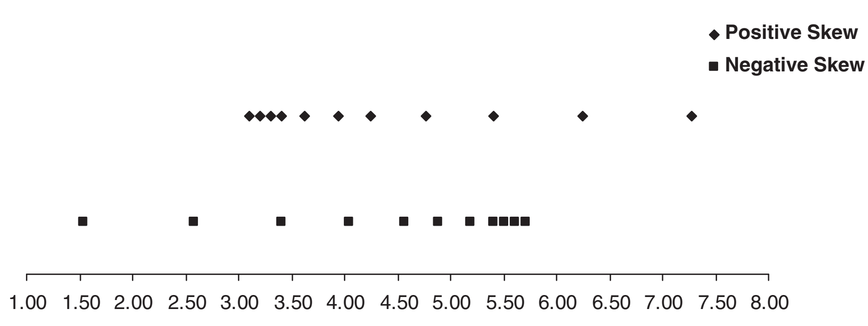

Fig. 3. Illustration of positively skewed and negatively skewed distributions of stimuli, respectively showing stimuli clustered toward the low and high end of the range, Study 2.

which consisted of 11 different pressure pain stimuli to the finger, as described in Study 1. The 11 stimuli were presented in random order, as generated by the MATLAB computer program. The first block was not intended for analysis, being the context-establishing block. It was made clear to participants that the first block would be a practice block, and that 2 further blocks would be presented containing the same number and range of stimuli, but not necessarily in the same order. The 11 stimuli were re-randomised before each of experimental blocks 1 and 2, results of which were averaged for analysis.

The 2 groups received different series of 11 stimuli. One group received a positively skewed distribution of stimuli (where most stimuli clustered toward the lower end of the range of stimuli) and the other a negatively skewed distribution (where most stimuli clustered toward the higher end of the range of stimuli). These distributions are illustrated in Fig. 3. Both distributions had a range of 4.18 kg/cm^2, both had aggregate pressure of 48.4 kg/cm^2, and the average pressure was 4.4 kg/cm^2 in both distributions. Construction of averages is appropriate as pain ratings from pressure stimuli have been shown to increase in a linear fashion as pressure increases [1]. The stimuli presented to each group are shown in Table 3.

Because both groups received the same average pressure, absolute judgment of each stimulus in isolation, using only the magnitude of each stimulus for evaluation, would result in both groups reporting the same average severity of pain. Such a result would also be consistent with adaptation-level theory. The 2 distributions consisted of stimuli with the same mean and aggregate magnitude, which were symmetrical around that common mean. Comparison with the mean, as might be suggested by adaptation-level theory, should result in a net zero difference in judgment between the 2 groups. However, according to the range principle, people in the negative skew group should judge the experience more painful because most of the painful stimuli clustered toward the higher end of the range of pain they experienced. In this case, "relatively-more-painful" stimuli would occur more frequently, and each of these should be judged more painful than if they were at the lower end of the range. We therefore tested the range principle against both adaptation-level theory and the absolute judgment account, and predicted that the negative skew group would report a higher average intensity of pain.

3.3. Results

The usual method of analysis of RFT range effects is to compare the average response from the 2 groups of stimuli [38,55,57]. As expected, the mean pain intensity reported on the 0 through 10 scale by the negative skew group ($M = 5.60$, $SD = 0.93$) appeared to be higher than that reported by the positive skew group ($M = 4.54$, $SD = 1.51$).

We analyzed all responses (after averaging across experimental blocks 1 and 2) from the 2 groups with a 2 (between: group) $\times$ 11 (within: stimulus) mixed-model ANOVA, which revealed a main effect of stimulus; $F(5,190) = 155.46$, $P < 0.001$ (Greenhouse-Geisser), confirming that higher pressure was indeed judged to be more painful, and also a main effect of the group; $F(1,38) = 7.14$, $P = 0.01$, indicating that the negatively skewed group generally reported more pain than the positively skewed group. The results of the ANOVA suggest that people found the stimuli in the negative skew distribution (where most stimuli were at the higher end of the range) more painful, despite the mean and aggregate pressure being the same for both groups. Although the individual judgment of each stimulus would be influenced by both range and rank principles, the average relative rank of the stimuli was exactly the same in both distributions, eliminating rank effects from the result. Because we administered the same aggregate and mean magnitude of stimuli to both groups, neither absolute judgment nor adaptation-level comparisons can explain the results, which we can therefore attribute to the range effect. The effect size, calculated from the difference between overall means of the responses from the 2 groups, was large, $d = 0.96$. (To confirm that the responses from undergraduates did not differ substantially from those from postgraduates and staff in Study 2, we conducted a 2 [between: group] $\times$ 11 [within: stimulus] mixed-model analysis of covariance [covariate: student/staff status]. After controlling for possible effects of student/staff status, the main effect of stimulus remained; $F(5,185) = 10.38$, $P < 0.001$ [Greenhouse-Geisser]. The main effect of group was also retained; $F(1,37) = 6.36$, $P = 0.02$.)

As described in Study 1, we tested whether low-level processes such as sensitization or habituation could have contributed to the context effect. We analyzed the effect of the preceding stimulus on the ratings of each of the 2 stimuli common to both groups. We conducted 4 2 (between: group) x 2 (between: high/low predecessor) 2-way independent ANOVAs. These revealed no significant main effect of high/low predecessor on the pain ratings given to either of the 2 stimuli common to both groups, with statistics ranging from $F(3,36) = .02$, $P = 0.89$ to $F(3,36) = 2.87$, $P = 0.10$. There was no significant interaction effect of group $\times$ high/low predecessor on any of these pain ratings, with statistics ranging from $F(3,36) = .07$, $P = 0.80$ to $F(3,36) = 3.22$, $P = 0.08$. Again, the results suggest that there was no systematic effect of the previous stimulus on judgment of the current stimulus, and therefore no evidence of sensitization or habituation, and that this is equally true of both distributions.

4. Discussion

The combined results of the studies show that evaluation of pain is a cognitive judgment process that takes into account the rank position of a painful stimulus and its proximity to the high or low extreme of the range of stimuli. Prior research has suggested that pain ratings are influenced by the context of other pain [5,17,18,33–35,46], and clinicians are aware of psychological factors in pain evaluation. Our results add to this literature by providing a quantitative model of how these context effects occur. They also complement prior work that has suggested that people impose their own context on their use of scales, comparing present pain with their "usual" or "worst" pain [53]. Furthermore, clinicians' judgments that do not match patients' own pain evaluation [7,19,44] might suggest that the clinician and patient make assessments relative to different contexts. Previously it was unclear which of the 3 potential models (absolute judgment, adaptation-level theory, or RFT) might best describe these processes. Our research can assist in the interpretation of this existing literature by proposing RFT, and not adaptation-level theory, as the model for the cognitive processes underlying relative pain judgments.

We can be sure that RFT is the explanation for our results as we explicitly tested RFT against both adaptation-level theory and absolute judgment. We achieved moderate effect sizes for Study 1, likely to be due to the size of the manipulation, there being a difference of only 3 positions in the rank of target stimuli 1 and 3 between the 2 distributions. The indication that the rank manipulation was responsible for the results is the resulting symmetrical interaction (illustrated in Fig. 2), this being the well-established method of testing rank effects in RFT research [6,20,55–57]. If judgments had been based on the absolute magnitude of stimuli, one would expect similar responses to target stimuli 1 and 3, as was the case for target stimulus 2, which ranked at the same position in both distributions. A similar result might be expected if judgments had been made relative to the adaptation level, as the distances from the mean of target stimuli 1 and 3 were kept constant in the 2 distributions.

The effect size from Study 2 was large, which can only be attributed to the range manipulation, as the average relative rank of stimuli was the same for both groups, eliminating rank effects from the results. We can be sure that absolute judgments were not made, as this should have resulted in similar responses from both groups, as the aggregate and average pressure was the same for both. The same result would be expected if judgments had been made relative to the adaptation level, as the symmetrical distributions around equal means should have resulted in a net difference of zero between the 2 groups.

It is important that the correct model for judgment is understood. Although it is most important to manage and minimise pain, it is also a warning mechanism to register illness or injury [24], described as "the fifth vital sign" [44]. Imagine a person whose pain is measured regularly to track progress of a medical condition. An absolute account of judgment would suggest that increased or decreased pain ratings would, respectively, correspond to worsening or improvement of their condition. An account based on adaptation-level theory would suggest that their adaptation level would shift to reflect the new mean, and pain ratings would remain fixed, despite changes in the underlying cause. According to an RFT account, under the rank principle, pain ratings would similarly remain fixed, as the relative rank positions of painful episodes would remain the same even if the overall range of pain became more or less severe, thus potentially masking any deterioration or improvement in their condition.

However, the RFT range principle could create something of a paradox. If an individual's experienced range of painful events becomes more positively skewed, with occasionally more extreme pain extending the overall range, pain ratings could be generally lower, as most painful episodes cluster toward the lower end of the range of experience. This might at first appear beneficial; pain is generally felt to be intrinsically a bad thing that should be avoided or reduced [4]. Yet, under-reporting of pain could mask any worsening of the underlying cause, and obscure that "vital sign."

Conversely, if an individual's pain becomes more negatively skewed, with fewer episodes of low-intensity pain, most painful episodes would cluster toward the top end of their range of experience. Ratings could be generally higher even if their worst pain remains the same, as the more painful episodes would be relatively more frequent. This introduces implications that could inform future research into pain reduction. If analgesia is successful for low levels of pain but not for more severe episodes, the context might become negatively skewed, and these unimproved episodes could appear more painful. Reported pain could potentially increase rather than decrease.

Our study focused on testing the processes underlying momentary pain judgments, although we believe our results also complement peak-end theory [14,15,31,36,40,42] and other work on memory for pain [2,3,8,16,30,37,41,45]. A recent extension to RFT, Decision by Sampling [39], has suggested that when making judgments from memory, people construct a mental sample populated from selected memories as well as the immediate context. Evaluation of a particular stimulus is derived from its rank position within this constructed sample. It is possible that particularly salient stimuli from memory would be more likely to contribute to this sample, for example, the peak and end of an experience [14,15,31,36,40,42]. If the stimuli sampled from memory are representative of momentary painful experiences on a daily basis, we would expect a high correlation between the daily judgments and retrospective evaluation. However, should the sampled stimuli not be entirely representative of the experiences on a daily basis, possibly due to displacement by other more salient stimuli, we would expect less correlation. This might go some way toward explaining the debate about the accuracy or otherwise of memory for pain [2,8,16,30,45].

4.1. Potential limitations

All results were based on self-report. However, self-report was our required outcome in order to understand how individuals evaluate their current pain in real time, during the second stage of self-reporting, using a pain rating scale of the kind used in clinical assessment.

We used evoked pressure pain in the laboratory. One concern with such research is that participants can anticipate increasing pressure and simply produce successive higher pain ratings accordingly. Participants have been shown to respond with such an ascending pattern of ratings even when anaesthetised [9]. Our presentation of stimuli in double-blind random order removed the potential for such stimulus-independent bias.

Our results were achieved using only acute pain, and with the participants' knowledge that they could terminate the source of pain instantly. This context is very different to that of clinical, and especially chronic, pain and it may not be possible to generalise these results to that context. A background context of chronic pain was not examined during these initial studies, but could be considered for future studies into RFT effects of pain evaluation.

A particular concern regarding the RFT paradigm is that participants might simply rate the size of the stimuli presented in each context, rather than properly judge how painful each stimulus is at that moment [55,57]. If participants were simply labelling each stimulus according to the scale presented, one might expect them to use the full range of the scale, including the lowest and highest points. However, of 86 final participants in total, across all 4 conditions in 2 studies, only 3 participants averaged "0" as their lowest response and "10" as their highest, therefore participants clearly did not simply rate the stimuli from "0" through "10" without engaging with the task.

It is possible that order effects might have led to increased or decreased ratings over the course of the experiment, due to low-level processes such as sensitization or habituation. We took precautions to control for order effects by changing and resting fingers between stimuli, and randomising stimuli to avoid repeated pressure of similar magnitude at the same site. Habituation to pain is rarely reported, and seems to be associated with repeated stimuli to the same site [12]. Sensitization appears not to occur with interstimulus intervals of more than 3 seconds [12], and our participants took longer than this to write their responses and change fingers. The additional analyses of the effect of preceding stimuli found no evidence that the context effects might have occurred because of such low-level sensory processes.

4.2. Conclusion

This research is the first to quantitatively model the mechanism by which current pain is evaluated in real time with reference to other painful experiences, as described by RFT. It is the first to apply RFT effects to judgments of physiological (as opposed to hedonic [28]) pain, and supports both rank and range principles as the cognitive processes that underpin such judgments. These results contribute to existing literature on context-dependent pain evaluation, and forge a link between pain research and other psychophysical and socioemotional judgments.

Conflict of interest statement

All authors declare that there was no conflict of interest.

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References

[1] Bendtsen L, Norregaard J, Jensen R, Olesen J. Evidence of qualitatively altered nociception in patients with fibromyalgia. Arthritis Rheum 1997;40:98–102.
[2] Broderick JE, Schwartz JE, Vikingstad G, Pribbernow M, Grossman S, Stone AA. The accuracy of pain and fatigue items across different reporting periods. PAIN® 2008;139:146–57.
[3] Broderick JE, Stone AA, Calvanese P, Schwartz JE, Turk DC. Recalled pain ratings: a complex and poorly defined task. J Pain 2006;7:142–9.
[4] Broome J. More pain or less? Analysis 1996;56:116–8.
[5] Brown CA, Seymour B, Boyle Y, El-Deredy W, Jones AKP. Modulation of pain ratings by expectation and uncertainty: behavioural characteristics and anticipatory neural correlates. PAIN® 2008;135:240–9.
[6] Brown GDA, Gardner J, Oswald AJ, Qian J. Does wage rank affect employees' well-being? Ind Relations (Berkeley) 2008;47:355–89.
[7] Craig KD. The social communication model of pain. Can Psychol 2009;50:22–32.
[8] Erskine A, Morley S, Pearce S. Memory for pain: a review. PAIN® 1990;41:255–65.
[9] Gracely RH, Grant MAB, Giesecke T. Evoked pain measures in fibromyalgia. Best Pract Res Clin Rheumatol 2003;17:593–609.
[10] Hadjistavropoulos T, Hunter P, Dever Fitzgerald T. Pain assessment and management in older adults: conceptual issues and clinical changes. Can Psychol 2008;50:241–54.
[11] Helson H. Adaptation-level as frame of reference for prediction of psychophysical data. Am J Psychol 1947;60:1–29.
[12] Hollins M, Harper D, Maixner W. Changes in pain from a repetitive thermal stimulus: the roles of adaptation and sensitization. PAIN® 2011;152:1583–90.
[13] Jensen MP, Karoly P, Braver S. The measurement of clinical pain intensity: a comparison of six methods. PAIN® 1986;27:117–26.
[14] Jensen MP, Markedian JM, Lakshminarayanan M, Boye ME. Validity of 24-h recall ratings of pain severity: biasing effects of "peak" and "end" pain. PAIN® 2008;137:422–7.
[15] Kahneman D, Fredrickson BL, Schreiber CA, Redelmeier DA. When more pain is preferred to less: adding a better end. Psychol Sci 1993;4:401–5.
[16] Kikuchi H, Yoshiuchi K, Ohashi K, Kumano H, Yakamoto H, Kuboki T, Akabayashi A. Reliability of recalled self-report on headache intensity: investigation using ecological momentary assessment technique. Cephalalgia 2006;26:1335–43.
[17] Kurniwan IT, Seymour BA, Vlaev I, Trommershäuser J, Dolan RJ, Chater N. Pain relativity in motor control. Psychol Sci 2010;2:840–7.
[18] Kyle BN, McNeill DW, Weinstein BJ, Mark JD. Interaction of intensity and order regarding painful events. J Behav Med 2009;32:360–70.
[19] Lander J. Clinical judgments in pain management. PAIN® 1990;42:15–22.
[20] Maltby J, Wood AM, Vlaev I, Taylor MJ, Brown GDA. Contextual effects on the perceived health benefits of exercise: the exercise rank hypothesis. J Sport Exerc Psychol 2012;34:828–41.
[21] McCaffery M, Pasero C. Pain: clinical manual. St. Louis, MO: Mosby; 1999.
[22] Melrose KL, Brown GDA. Wood, AM. Am I abnormal? Relative rank and social norm effects in judgments of anxiety and depression symptom severity. J Behav Decis Mak (2012), http://dx.doi.org/10.1002/bdm.1754.
[23] Melzack R. Pain: past, present and future. Can J Exp Psychol 1993;47:615–29.
[24] Melzack R. Pain and the neuromatrix in the brain. J Dent Educ 2001;65:1378–82.
[25] Melzack R, Taenzer P, Feldman P, Kinch RA. Labour is still painful after prepared childbirth training. CMAJ 1981;125:357–63.
[26] Melzack R, Wall PD. Pain mechanisms: a new theory. Science 1964;150:971–9.
[27] Parducci A. Category judgment: a range–frequency model. Psychol Rev 1965;72:407–18.
[28] Parducci A. Happiness, pleasure, and judgment: the contextual theory and its applications. Hillsdale, NJ: Lawrence Erlbaum Associates; 1995.
[29] Parducci A, Wedell DH. The category effect with rating-scales: number of categories, number of stimuli, and method of presentation. J Exp Psychol Hum Percept Perform 1986;12:496–516.
[30] Read D, Lowenstein G. Enduring pain for money: decisions based on the perception and memory of pain. J Behav Decis Mak 1999;12:1–17.
[31] Redelmeier DA, Kahneman D. Patients' memories of painful medical treatments: real-time and retrospective evaluations of two minimally invasive procedures. PAIN® 1996;66:3–8.
[32] Riskey DR, Parducci A, Beauchamp GK. Effects of context in judgments of sweetness and pleasantness. Percept Psychophys 1979;26:171–6.
[33] Rollman GB. Signal detection theory pain measures: empirical validation studies and adaptation-level effects. PAIN® 1979;6:9–21.
[34] Rollman GB. Measurement of pain in fibromyalgia in the clinic and laboratory. J Rheumatol 1989;16:113–9.
[35] Rollman GB. Cognitive effects in pain and pain judgments. In: Algom D, editor. Psychophysical approaches to cognition. Amsterdam: Elsevier; 1992. p. 515–74. Available from: <http://psychology.uwo.ca/faculty/rollmanpdfs/35_1992% 20Rollman%20Cognitive%20effects%20in%20pain%20and%20Pain%20Algom%20book.pdf [accessed 23.04.12].
[36] Schneider A, Stone AA, Schwartz JE, Broderick JE. Peak and end effects in patients' daily recall of pain and fatigue: a within-subjects analysis. J Pain 2011;12:228–35.
[37] Schwartz N. Retrospective and concurrent self-reports: the rationale for real-time data capture. In: Stone AA, Shiffman SS, Atienza A, Nebeling L, editors. The science of real-time data capture: self-reports in health research. New York: Oxford University Press; 2007. p. 11–26. Available from: <http://sitemaker.umich.edu/norbert.schwarz/files/schwarz_retrospective_self-reports_ mdc_2007.pdf> [accessed 23.04.12].
[38] Smith RH, Diener E, Wedell DH. Intrapersonal and social-comparison determinants of happiness: a range–frequency analysis. J Pers Soc Psychol 1989;56:317–25.
[39] Stewart N, Chater N, Brown GDA. Decision by sampling. Cogn Psychol 2006;53:1–26.
[40] Stone AA, Broderick JE, Kaell AT, DelesPaul PA, Porter LE. Does the peak-end observed in laboratory pain studies apply to real-world pain in rheumatoid arthritis? J Pain 2000;1:212–7.
[41] Stone AA, Broderick JE, Schwartz JE, Schwartz N. Context effects in survey ratings of health, symptoms, and satisfaction. Med Care 2008;46:662–7.
[42] Stone AA, Schwartz JE, Broderick JE, Shiffman SS. Variability of momentary pain predicts recall of weekly pain: a consequence of the peak (or salience) heuristic. Pers Soc Psychol Bull 2005;31:1340–6.
[43] Strong J, Sturgess J, Unruh AM, Vicenzo B. Pain assessment and management. In: Strong J, Unruh AM, Wrigh A, Baxter GS, editors. Pain: a textbook for therapists. Edinburgh: Churchill Livingstone; 2002. p. 123–48.
[44] Tait RC, Chibnall JT, Kalauokalani D. Provider judgments of patients in pain: seeking symptom certainty. Pain Med 2009;10:11–34.
[45] Terry R, Niven CA, Brodie E. How well do patients recall past experience of pain? Nurs Times 2007;103:34–5. Available from: <http://www.nursingtimes.net/nursing-practice-clinical-research/how-well-do-patients-recall-past-experience-of-pain/266638.article> [accessed 02.05.12].
[46] Vlaev I, Seymour B, Dolan RJ, Chater N. The price of pain and the value of suffering. Psychol Sci 2009;20:309–17.
[47] Vossen HGM, van Breukelen GJP, van Os J, Hermens HJ, Lousberg R. Association between event-related potentials and pain ratings not as straightforward as often thought. J Psychophysiol 2011;25:18–25.
[48] Wedell DH. Contextual contrast in evaluative judgments – a test of preintegration versus postintegration models of contrast. J Pers Soc Psychol 1994;66:1007–19.
[49] Wedell DH, Parducci A. The category effect in social judgment – experimental ratings of happiness. J Pers Soc Psychol 1988;55:341–56.
[50] Wedell DH, Parducci A, Geiselman RE. A formal analysis of ratings of physical attractiveness: successive contrast and simultaneous assimilation. J Exp Soc Psychol 1987;23:230–49.
[51] Wedell DH, Parducci A, Lane M. Reducing the dependence of clinical judgment on the immediate context: effects of number of categories and type of anchors. J Pers Soc Psychol 1990;58:319–29.
[52] Wedell DH, Santoyo EM, Pettibone JC. The thick and the thin of it: contextual effects in body perception. Basic Appl Soc Psychol 2005;27:213–28.
[53] de C Williams AC, Davies HTO, Chadury Y. Simple pain rating scales hide complex idiosyncratic meanings. PAIN® 2000;85:457–63.
[54] Wood AM, Boyce CJ, Moore SC, Brown GDA. An evolutionary based social rank explanation of why low income predicts mental distress: a 17 year cohort study of 30,000 people. J Affect Disord 2012;136:882–8.
[55] Wood AM, Brown GDA, Maltby J. Thanks but I'm used to better: a relative rank model of gratitude. Emotion 2011;11:175–80.
[56] Wood AM, Brown GDA, Maltby J. Social norm influences on evaluations of the risks associated with alcohol consumption: applying the rank based Decision by Sampling model to health judgments. Alcohol Alcohol 2012;47:57–62.
[57] Wood AM, Brown GDA, Maltby J, Watkinson P. How are personality judgments made? A cognitive model of reference group effects, personality scale responses, and behavioral reactions. J Pers 2012;80:1275–311.