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

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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.

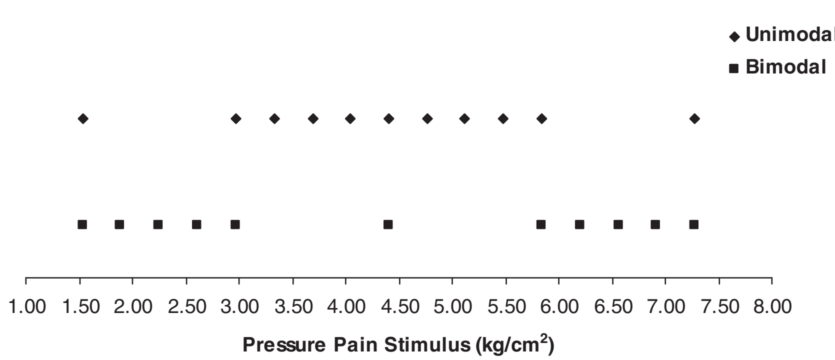

Fig. 1. Illustration of unimodal and bimodal distributions of stimuli, Study 1.