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Measuring pain: An introspective look at introspection

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Abstract

The measurement of pain depends upon subjective reports, but we know very little about *how* research subjects or pain patients produce self-reported judgments. Representationalist assumptions dominate the field of pain research and lead to the critical conjecture that the person in pain examines the contents of consciousness before making a report about the sensory or affective magnitude of pain experience as well as about its nature. Most studies to date have investigated what Fechner termed "outer psychophysics": the relationship between characteristics of an external stimulus and the magnitude and nature of pain experience. In contrast, Fechner originally envisioned that "inner psychophysics" should investigate the relationship between physiological states and subjective experience. Despite the lack of established research tradition, inner psychophysics has a potential utility in elucidating underlying mechanisms for the production of phenomenal self-report. We illustrate this, using causal modeling analyses of the accuracy of self-reported pain ratings from our laboratory. We submit that the results are inconsistent with representationalist assumptions. Converging trends from several domains of consciousness studies seem to suggest that we need to abandon the unquestioned doctrine of representationalism and search for a more viable framework for understanding the generation of subjective self-report.

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1. Introduction

Introspective self-report is an essential tool for sciences of consciousness because it provides an important window onto that of which the person is aware. It is true that self-report is not the only window to the mind and that non-invasive functional brain imaging methods have greatly advanced recently, but we still have a long way to go before objective measurements of consciousness become reality. Even in the future, it is very likely that we will still have to depend upon self-report as an essential tool for investigating consciousness. Given the critical role that self-report plays in gathering what needs to be explained involving consciousness, one might assume that we must know a great deal about *how* self-report comes about. On the contrary, we actually know very little about how our brains produce self-report.

This paper addresses some critical issues on the nature of self-report in the domain of pain measurement. We first discuss the psychophysics of pain and representationalist assumptions implicit in the application of psychophysics to pain. In order to critically examine representationalist assumptions, we discuss the determinants of the accuracy of subjective pain reports, using findings from our causal modeling study. We demonstrate that the accuracy of pain report depends in part on physiological arousal (sympathetic nervous system activation) rather than purely on an internal representation of a noxious stimulus. We conclude by discussing converging trends from other domains of consciousness research and suggest future directions for research.

2. Pain measurement

Pain measurement is probably one of the most important areas for pain research and pain medicine (Chapman, 1989). Early pioneers of pain research who worked on pain measurement adapted psychophysics as a guiding framework for how to go about measuring pain. Psychophysics is the science of dealing with the correlation of the physical characteristics of a stimulus (e.g., intensity, frequency, etc.) with the subjective response to the stimulus. Fechner's original ambition was to develop what he called "inner psychophysics" (relating physiology with phenomenal report), but his vision of inner psychophysics never materialized because it was too much ahead of his time. Consequently, psychophysics as we know it today corresponds to what he called "outer psychophysics" (relating stimulus with phenomenal report). It is true that psychophysics advanced our knowledge about how different sensory modalities operate. In particular, psychophysical approaches to pain measurement have succeeded in generating a substantial body of studies relating physical characteristics of nociceptive stimulus and pain sensation. (See Price, 1999 for a comprehensive summary of this area.) However, complete specifications of the underlying mechanisms for the production of self-report still elude the psychophysicists. For present purposes, it is critical to spell out assumptions in the psychophysical approach to pain measurement. To do this, we need to discuss representationalism in general and proceed to reveal hidden assumptions deeply ingrained in the psychophysics of pain.

At a most general level, representationalism relates brain activity to phenomenal report in the following way. Its basic premise is that neural activity in the brain is a function of the features and causal impact of a noxious stimulus on the individual. Patterns of brain activity are internal representations of triggering events, either external or internal (somatic or visceral). In other words, the brain is reflecting the external or internal environment through such neural activity. This leads to the conjecture that pain report is a function of an internal representation to which the individual has introspective access. We use the word "conjecture" here because no studies to date have explicitly illuminated the nature of this representation and how a conscious individual comes to have access to this representation.

Psychophysics makes it possible to correlate the features of stimuli with subjective phenomenal reports. Performance accuracy in self-report gauges this correlation. How do we get phenomenal reports out of the individual in question? Assuming that the experience of pain is accessible to introspection, one can examine one's own immediate memory traces of sensory register. Subjective report of pain is basically an accurate translation of what one finds in the sensory register, mixed with measurement error (i.e., noise) in the system.

What is the origin of the conjecture that there must be an internal (i.e., neural) representation that correlates with conscious perception of pain? In other words, why do we believe that tracking down the neural representations that correlate with conscious experience is necessary and sufficient for understanding the nature of pain in particular and of consciousness in general? Perhaps this conjecture stems from the assumption that the discovery of perfect correlation would allow us to believe that we had identified the neural activity sufficient to produce the experience (Chalmers, 1996). Furthermore, there has been a tendency to subscribe to what Pessoa, Thompson, and Noë (1998) have called analytic isomorphism. Analytic isomorphism states that for every experience, there will be a neural substrate whose activity is sufficient to produce that experience and that there will be an isomorphism between features of the experience and features of the neural substrate (i.e., neural representations). The presumed existence of such an isomorphism makes acceptable the claim that the discovery of such a neural substrate would explain the occurrence of conscious perception.

Is this logic conceptually sound? It may be that no neural state will be sufficient to produce visual or somatosensory experience. O'Regan and Noë (2001) provide a nice analogy: "Just as mechanical activity in the engine of a car is not sufficient to guarantee driving activity (suppose the car is in a swamp, or suspended by a magnet) so neural activity alone is not sufficient to produce vision." Both analytical isomorphism and representationalism have served mainstream neural and cognitive sciences during the 20th century. Do they still remain viable to guide 21st century sciences of pain and consciousness?

3. Evaluating representationalism

To examine implicit assumptions associated with representationalism and psychophysics, we focus on the question of what determines the accuracy of self-reported pain ratings. We addressed this question in our recent paper (Chapman et al., 2002). Note that our study addressed *the causal determinants of the accuracy of pain reports rather than the magnitude of pain reports*. Our study employed path analysis, a causal modeling statistical method that permits the examination of causal relationships among multivariate variables. More specifically, path analysis can examine the nature of mediated pathways in causal chains specified in a particular model.

This study involved 100 volunteer subjects (56 males, 44 females). The subjects experienced three levels of noxious finger-tip electrical stimulation. The subjects did not know that there were only three stimulus intensities, delivered in random order over 144 trials. On each trial, we recorded pupil dilation, skin conductance response, heart rate, and event-related late near field evoked potentials, and collected self-reported pain ratings from the subjects in response to noxious electrical stimulation. (For those readers interested in further procedural details, see Chapman et al., 2002.)

For the purpose of estimating the "accuracy" of pain report, we reasoned that stimulus intensity level could serve as a "gold standard" against which to judge the magnitude of the pain report. The magnitude of nociceptive signaling within the subject's nervous system should vary at least ordinally as a function of the magnitude of the electrical current delivered. Although we did not formally instruct subjects to distinguish stimulus levels in this study, their pain reports nonetheless constitute implicit numerical evaluations of the different intensities. High agreement between pain ratings and stimulus levels denotes high criterion validity, while poor agreement shows lack of criterion validity. Thus, we decided to use the term "accuracy" in a specialized sense to describe the extent of this agreement between pain rating and stimulus level (recognizing that in clinical and other settings there may be no comparable criterion against which to judge accuracy). We estimated accuracy by calculating for each subject the squared nonlinear correlation ratio (η^2), the proportion of variance in the pain report that the stimulus level can explain: $\eta^2 = 1.0 - (SS_{err}/SS_{tot})$. Cohen (1988) has provided guidelines for interpreting the sizes of squared correlation ratios. In the context of criterion validity, coefficients greater than .5 represent moderately high levels of agreement, while coefficients greater than .7 indicate excellent agreement.

The accuracy estimated by the procedures described above ranged from .07 to .91 with a median of .64. Using the criterion (.5) suggested by Cohen, we documented that the majority of the subjects demonstrated a pretty high level of accuracy. However, it is equally important to recognize that there are substantial individual differences in how accurately the subjects rated noxious stimuli in the study. Additionally, there was no difference in the overall accuracy per se between male and female subjects. Having observed that individual differences in the accuracy of pain report are considerable, we proceeded to investigate what determined the accuracy of pain report, using a causal modeling approach.

3.1. What are causal models?

Causal models specify systems of linear equations that adumbrate plausible population mechanisms for generating observed data. For testing a particular model, the analysis regresses a target variable on a set of other variables that, according to the model, are causes. The goal of causal modeling analysis is to identify the best fitting parsimonious model consistent with sound scientific understanding. In such models, causality involves a hypothesized sequence of determination between explanatory and dependent variables. Because the same data are always consistent with more than one model, absolute proof is never possible. Instead, the modeler pursues the more modest goal of showing that a scientifically plausible model is consistent with the data. In theoretically appropriate causal models, for example, the temporally earlier variables predict the later variables, and the reverse presumably cannot occur. (See Joreskog & Sorbom, 1982 for more complete descriptions of path analysis and causal modeling.) For the present analysis, predictors of accuracy included: (1) electrical current intensity, (2) event-related late near field evoked potential (N150), and (3) arousal (overall sympathetic nervous system arousal derived from the combination of: (a) skin conductance response, (b) pupil dilation, and (c) heart rate).

Causal modeling begins with a simple theory that translates the scientific predictions into causal paths (regressions) and variable intercepts. For our model-testing sequence, we placed this initial model within a general causal hierarchy that derived from psychophysiology and current understanding of nociceptive pathways. Nociceptive stimulation clearly activates brainstem areas that in turn activate limbic structures, and direct spinohypothalamic pathways suggest that nociceptive traffic may activate a generalized, hypothalamically mediated sympathetic nervous system arousal (Burstein, Cliffer, & Giesler, 1998; Burstein, Dado, Cliffer, & Giesler, 1991; Willis & Westlund, 1997). Given this body of scientific understanding, we formulated the following initial set of predictions implemented in Fig. 1: Stimulus level thus operated at the highest causal level, potentially determining all other responses. The N150amp could influence Arousal and Accuracy, but the converse could not occur. Arousal had a direct influence on Accuracy alone. Accuracy proved to be completely

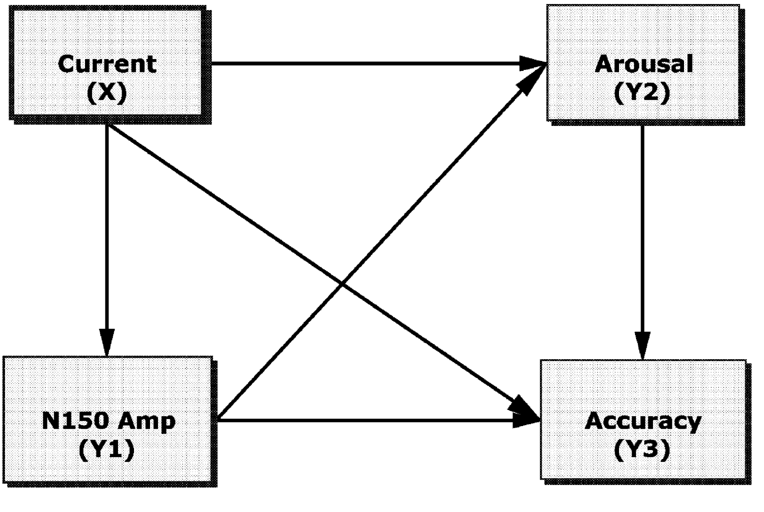

Fig. 1. Path diagram illustrating the initial model for causal analysis. Parameters of the model are not shown for simplicity.

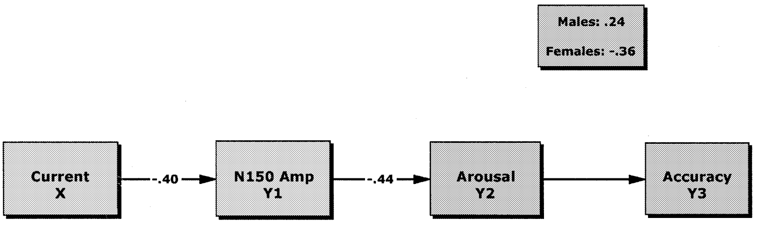

Fig. 2. Path diagram displaying the final model. The numbers on the arrows indicate regression coefficients characterizing linear linkages, and there was no difference between male and female subjects. However, there was a significant difference across the two groups in the last linkage between Arousal and Accuracy. Regression coefficient for the male group was .25, while that for the female group was −.36.

dependent, and did not affect any other variables. This general hierarchy led to the initial model appearing in Fig. 1.

To further refine this broadly defined initial model, we followed a backwards elimination strategy by successively eliminating statistically insignificant features of the initial model, until a final model remained that contained only statistically significant parameters. At the last model-testing step, no insignificant parameters remained and we accepted that model as the final characterization of the determinants of accuracy. Fig. 2 presents the final model.

The final model revealed a direct causal chain that links stimulus Current and Accuracy. First, stimulus Current determined the amplitude of N150, where N150 may possibly an indicator of attention. Second, N150 amplitude in turn determined the magnitude of Arousal. Third, Arousal turned out to be the unique determinant of the Accuracy of the pain report.

At each step of model testing, we sought to determine if a causal link in question differed across the male vs. female subjects in the study. There was a significant difference by sex on the magnitude of causal linkage between Arousal and Accuracy. Men who experienced higher levels of arousal produced more accurate pain reports than those who had lower levels of arousal. In contrast, women who had higher levels of arousal produced less accurate pain reports than those who had lower levels of arousal.

It may seem tempting to regard our causal model as one that truly explains the generation of pain reports, but this would mischaracterize the endeavor. The causal model provides a modest explanation for the accuracy of pain report scalings. The causal model addresses the question, "What makes a pain report accurate?" rather than "What makes a pain report?" The underlying mechanisms supporting the generation of self-reported pain ratings themselves remain undefined and require further scientific investigations.

4. Making sense and casting doubt on the status of representation

How can we make sense of these findings from our study? First, what does the evidence that Arousal determined Accuracy imply? Taken at a face value, it does not seem to support the conjecture that the accuracy of subjective pain report should depend on an internal representation of a noxious stimulus. Of course, this interpretation critically relies on what we mean by an internal representation of a noxious stimulus. If an internal representation of a noxious stimulus is what the brain accurately "registers" in response to noxious stimulation, whatever this representation might be, then it does not seem to determine the accuracy of self-report. This is the sense in which most pain researchers refer to a representation as the representation of tissue injury or trauma. Given this definition, the nature and magnitude of this representation should determine the accuracy of subjective self-report of pain. Data from causal modeling analyses do not fit this assumption.

Would it be possible to modify what we mean by an internal representation of a noxious stimulus and to make the data consistent with the representationalist assumption? If an internal representation of noxious stimulus includes sympathetic nervous system activation (arousal) as its essential feature, then one can argue that this modified internal representation seems to determine the accuracy of self-report, and consequently one can still hold onto the dominant representationalist Zeitgeist. However, making this move effectively violates what representationalist assumptions implicitly or explicitly entail, namely, the characteristics of a noxious stimulus are the properties of the noxious stimulus, independent of the person feeling pain. Engel (1999) reviewed the field of visual neuroscience and reached a similar conclusion characterizing representational accounts of visual perception. First, vision consists of recovering a pre-given world and constructing an internal image of the world. Second, relevant structures of external world are observer-independent and defined irrespectively of any cognitive activity of an agent. Taken together, if these characterizations of representationalism are more or less justifiable, we contend that the doctrine of representationalism as traditionally conceptualized will not survive any longer.

Representationalism and its conceptual foundation, analytic isomorphism, have been the main engines that have driven psychophysical approaches to pain measurement. Can we go beyond the metaphysical dogma of analytic isomorphism? To address this question further, we need to go beyond pain research and identify common threads that cut across several different domains of inquiry.

5. Converging trends from consciousness studies

The notion of representation is central to our understanding of how the mind/brain works in both cognitive science and cognitive neuroscience (Clark, 1997; DeCharms & Zador, 2000). Among scientists working in these disciplines, the consensus exists that both brains and computer models are presumably housing "internal representations." What is a function of these internal representations? As Miller and Freyd (1993) succinctly stated, "the strengths of representationalism have always been the basic normative conception of how internal representations should accurately register important external states and processes" (p. 13). This characterization is consistent with the representationalist assumptions we reviewed above.

Reviewing the concept of representation in both neurophysiology and neuroscience, DeCharms and Zador (2000) similarly affirmed the central importance of representation in these fields. According to them, representation is defined by two principal and overlapping characteristics, namely, content and function. Content is the information that a representation carries. In fact, DeCharms and Zador argue that content is a principle hallmark of neuronal representations. Within philosophy and psychology, this property of having content corresponds to intentionality, which some people think of as the principle hallmark of all subjective mental processes (see Dennett, 1987). In contrast, function is the effect the representation can have on cognitive process and resultant behavior. The function of neural representation is to provide a highly correlated and information-rich mirror of the environment and to support adaptive behavior (Churchland, Ramachandran, & Sejnowski, 1994). It is interesting to note that this notion of internal representation really fits the metaphor of "mind as mirror": the mind/brain accurately reflects frequently occurring regularities of the external environment.

What seems uniform across these two views (one from cognitive science and the other from neuroscience) is the strong dependence upon internal representation as a vehicle for representing the content of consciousness. The thesis of internal representations runs deep in contemporary sciences of the mind/brain. In our views, psychophysics is another discipline that explicitly or implicitly endorses the same thesis. Working from perspectives of inner psychophysics, we demonstrated that representationalism reflected in psychophysics seemed to fail to account for causal modeling data from our multivariate psychophysiological study of noxious stimuli. Are we alone in questioning the status of internal representation?

Investigators working in several different areas associated with consciousness have begun to question the notion of internal representation strictly couched in the representationalist framework. We discuss two examples to illustrate the converging trends that may help us transcend a narrowly defined representationalist framework.

O'Regan and Noë (2001) recently came to question the working assumption in vision research that when we see, the brain produces an internal representation of the world. In other words, the activation of this internal representation gives rise to the experience of seeing. O'Regan and Noë argue that this approach basically leaves unexplained how the existence of such a detailed internal representation might produce visual consciousness. They reject the assumption that vision consists in the creation of an internal representation of the outside world whose activation somehow generates visual experience. Instead, they propose to treat vision as an exploratory activity. The central idea of their approach is that vision is a mode of exploration of the world, which is mediated by knowledge of what they call sensorimotor contingencies. The experience of seeing occurs when the organism masters so-called governing laws of sensorimotor contingency. In support of their proposal, they assembled several lines of empirical evidence including evidence from experiments in sensorimotor adaptation, visual "filling in," visual stability despite eye movements, change blindness, sensory substitution, and color perception.

Freeman (1995, 2000) has been consistently critical of the notion of internal representation on the basis of his work on EEG correlates of olfactory perception in animals. First, a sensation from an odorant does not create a pattern in the brain (an internal representation) that is fixed and stored away in a memory bank. Freeman argues instead that brain activity patterns are constantly dissolving, reforming, and changing in relation to one another. When an animal learns to respond to a different odor, this will lead to a shift in all other patterns (that are not directly involved in the current learning). Freeman argues that there are no fixed representations in the brain; there are only meanings constructed by and within the brain. His view resonates with the pragmatist philosophy of Thomas Aquinas. At a more general level, Freeman characterizes perception as an active process that originates in the limbic system. Perception emerges through goal directed action onto the world, followed by alternation of the self through learning in accordance with the consequences of the intentional action. For Freeman, the process by animals and humans engage the world is intentionality. The biology of intentionality manifests itself in nonlinear chaotic dynamics of the forebrain. What is relevant to the present discussion is the primacy of meaning rather than that of internal representations in Freeman's story of chaotic dynamics that characterizes an enactive, embodied perception.

Incidentally, those criticisms directed at the notion of internal representation may also equally apply to inner psychophysics, in so far as the main emphasis remains to identify isomorphic correlates of conscious perception in question. In fact, the very idea of inner psychophysics is quite analogous to another very popular idea in consciousness studies: neural correlates of consciousness (NCC). Is NCC still couched in terms of representationalism we discussed in this paper? We simply raise this question here to encourage further inquiries into the conceptual foundations of NCC enterprise.

6. How should we conceptualize self-report?

How should we conceptualize the production of self-report? It seems that the field of pain research has depended upon a simple model/theory in which self-report is viewed as an accurate readout of sensory and affective registers. Is there any viable framework for making sense of the generation of self-report response?

We have been advocating a constructivist approach to understanding pain perception (Chapman & Nakamura, 1999; Nakamura & Chapman, 2002). Our approach suggests one possible way to think about the generation of self-report. Under this framework, we can think of the generation of self-report as constructive processes by which the brain assembles and intermingles information from multiple sources (from sensory inputs, memory schemata, goals and plans) to create a coherent interpretation (i.e., meaning) out of multiple activated mental and neural structures. Viewed this way, self-report is not a simple readout of an internal stimulus representation that is isomorphic to an external proximal noxious stimulus. As Freeman suggested in his work, the key to understanding brain function is the meaning constructed by the brains, not internal representations presumed to be housed in the brains. The time may be ripe to question the doctrine of representationalism that dominated prevailing psychophysical approaches to pain measurement.

Pain is a complex subjective experience. Especially in clinical settings, the only viable approach to pain measurement is self-report based on introspection. Unfortunately, the pain report itself is rarely the simple window on private experience that clinicians and researchers wish it to be. Examining various types of pain ratings in a clinical setting, Williams, Davies, and Chadury (2000) found poor concordance in pain report between patients and weak pain reporting consistency within patients. They suggested that "the action of arriving at a (pain) rating is better conceptualised as an attempt to construct meaning, influenced by and with reference to a range of internal and external factors and private meanings, rather than as a task of matching a distance or a number to a discrete internal stimulus." This characterization of self-reported pain ratings is highly compatible with a constructivist framework briefly described above.

Nonetheless, some investigators may disagree with the conclusion of Williams et al. study on several methodological grounds. For instance, instructions for pain report and anchoring labels used in pain scale are critical to ensure the validity and reliability of self-reported pain rating data. The instructions used in Williams et al. study might have been ambiguous because they asked patients to rate pain in terms of how bad their pain was. It is conceivable that having patients rate the pain in terms of "badness" could have led them to use the scale as an evaluative scale, not a scale of the intensity of the painful sensation or of the degree of immediate unpleasantness. The use of "maximum pain" as an anchor used at the right end of the pain scale might have produced some ambiguities in responding to the scale used in William et al. study. Clearly, the context-dependent nature of pain report should warrant further investigations.

Representationalist assumptions have dominated the field of pain research and have led to the critical conjecture that the person in pain examines the contents of consciousness before making a report about the sensory or affective magnitude of pain experience as well as about its nature. We submit that the data presented here are inconsistent with the representationalist assumptions. Converging trends from several domains of consciousness studies seem to suggest that we need to abandon the unquestioned doctrine of representationalism and search for a more viable framework for understanding the generation of subjective self-report. It remains to be seen in the next several decades whether the 21st century sciences of pain will illuminate how the human brain generates subjective self-report of pain.

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