

Tagline: Neuroscience

Title: Biased perception and learning in pain

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Standfirst: It is a general principle that we learn from experience, building expectations about the future, which then affect perception. A new study focuses on how expectations influence learning about pain and shows that we prioritise information which confirms our prior expectations, leading to a self-perpetuating bias in judging the intensity of pain.

At times, perception can go beyond the ordinary: we see movement where there is none, we seem to hear sound although it is quiet, and we feel pain where there is nothing to cause it. Not always are such phenomena the result of a pathology that requires treatment. Modern psychology has revealed that they can be rooted in strong expectations, which can directly influence the perceptual process¹⁻³. A new study⁴ reported in this issue of *Nature Human Behaviour* shows that expectancy effects on pain are not exclusively based on such changes in perception but are also driven by biased learning.

It is widely agreed now that *any* perception is influenced by expectations, as formalised in the theoretical framework of 'perception as inference' or predictive coding^{5,6}. In this view, expectations guide perception by favouring expected over non-expected interpretations of sensory input. Even more puzzling than the biasing influence of expectations is how persistent we can be in upholding our expectations even if they have repeatedly proven false. Such persistence can be based in perception itself: expectations directly affect the processing of incoming information in sensory cortices⁷ but also in higher-level associative or evaluative brain regions⁸. As a consequence, any subsequent step including the generation of expectations for future experiences will be biased. But the persistence could also reflect that disconfirming evidence is not taken into account, indicating biased learning.

Combining computational modelling of trial-by-trial expectancy and pain intensity ratings with functional neuroimaging in healthy human participants, Jepma and colleagues explored the influence of both changes in perception and biased learning in two experiments in healthy volunteers. In the first phase of the experiments, participants learned to associate one visual cue with low heat and a second cue with high, painful, heat. In a subsequent test phase, both

cues (as well as a third new cue) were followed by the same number of actual low and high heat stimulations. Trial-by-trial ratings of pain expectancy and pain perception allowed Jepma and colleagues to track learning and changes in perception as a function of expectancy.

Like a number of previous studies⁹, Jepma and colleagues found that higher pain expectations predicted higher pain ratings and stronger responses in an established network of brain regions involved in pain processing, confirming a direct impact of expectations on the perception and neural processing of pain. However, participants also were highly selective in the way they treated evidence from the previous trial to predict the subsequent one: If the perceived pain intensity was higher than expected, participants were more likely to increase their expectation for the next trial if they had been cued towards high pain and were more likely to discount their experience if they had been cued towards low pain. A similar confirmation bias was found for the opposite experience: If stimuli were perceived as less painful than expected, expectations for the next trials were more likely to be (down-)corrected when participants had been presented with a low pain cue before. In both cases, participants learned more from information that was consistent with their beliefs and ignored evidence that challenged them. Through extensive additional analyses which included comparison of the predictions made by a classical reinforcement learning model and a Bayesian model, Jepma and colleagues elegantly demonstrate that their findings were best explained by a combination of altered perception and biased learning.

Expectations are thought to reflect our prior knowledge about an upcoming situation. But expectations can be wrong – for instance, because there was not enough information available to derive a more fitting expectation or if cue-outcome contingencies change, as they do in the study by Jepma and colleagues. Any discrepancy between expectation and the actual

experience should challenge us to rethink and correct our expectation if necessary. It is therefore the learning from errors that keeps us from adopting a delusional view and from cultivating convictions that have little to do with facts. The findings by Jepma and colleagues suggest that not all evidence is treated equal but that we actively (albeit not necessarily consciously) create a percept that is moulded to our expectations – much like in a self-fulfilling prophecy where a false interpretation of a situation triggers behaviour that makes the original false conception come true. Neuroimaging results of this study provide insights into the neural basis of this confirmation bias: brain regions implicated in anticipatory anxiety, threat and affective value seem to reflect its impact on subsequent perception as their engagement during stimulus anticipation scaled with the confirmation bias. However, further studies are needed to explore the disconnect between the detection of expectancy violation (as reflected in PE processing) and course correction (as evident from belief updating).

The authors discuss implications of their findings for patients with chronic pain but also other patient groups (e.g., those suffering from anxiety or depression) for which maladaptive perception and learning is a hallmark. However, their results showing that the confirmation bias can also favour the perception of *less* pain suggests that we might also be able to harness our eagerness to confirm our expectations for the better. An often-cited example for this aspect is placebo treatments where perception lives up to the (positive) expectation induced by the sugar pill¹⁰. Before we rush to brand the confirmation bias as entirely maladaptive, we therefore need to think again – as in the end, resilience and our ability to hold on to positive expectations may be cut from the same cloth.

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