

## Prediction of Perception

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### Abstract

**Background:** The intricate relationship between perception, sensory input, and internal expectations significantly shapes our understanding of the world. Perception emerges from the interplay of incoming sensory information and top-down predictions, with prior personal experiences playing a vital role in both interpreting and influencing our perception of our environment.

**Objective:** This literature review proposes new directions for future studies using the predictive processing model to study the collaboration of sensory information with cognitive predictions, taking into account the role of psychiatric conditions, trait absorption, and psychedelics in perceptual processing.

**Methodology:** We reviewed the current literature on perception, multisensory integration, and biorhythms to understand the factors influencing the effect of predictions on sensory processing. Additionally, we applied the predictive processing model to explain how perceptual priming's influence on emotional awareness and interoception results in paranormal experiences.

**Results:** This review indicates many different factors influence predictive processing, including interoception, psychiatric conditions, trait absorption, and psychedelics. Analysis of the relevant research suggests that the administration of psychedelics and levels of high trait absorption facilitate the emergence of new sensory integration pathways, cultivating the potential for novel or transcendent experiences.

**Conclusion:** This review reveals a variety of factors affecting perceptual processes. Based on the application of the predictive processing model, this review suggests that future studies on perception should focus on reducing the role of expectation in the perceptual processes by means of the administration of psychedelics or the selection of individuals with high levels of trait absorption. A greater understanding of the power of prediction on our perception has the potential to impact the way we experience pain, hunger, thirst, temperature, and even anxiety and depression. Such knowledge could open new doors for treatments or medical interventions.

**Keywords:** perception, sensation, interoception, exteroception, absorption, psychedelics.

## **Laying the Groundwork for Perception**

Perception is constructed at the shifting border between incoming sensory evidence from our environment and our internal conceptual predictions and expectations. Incoming sensory perception is filtered through a complex lens of existing expectations, beliefs, and emotions. Fundamentally, our prior experiences either lead, follow, or get out of the way during sensory integration and, in turn, amend our perception. Perception is, in essence, the meaning we make of the current environment. Perception may be the foundation of human wellbeing, from relationships and conflict resolution to chronic pain and trauma. Understanding the factors that significantly influence our perception has the potential to inform therapeutic strategies in the context of extraordinary experiences and the transformative effects of psychedelics on human well-being.

Isolated in the darkness and silence of the skull, the brain receives data about the external environment only via electrical signals carried by neurons. At each moment, electrical signals about our environment arise via our senses. If the individual's expectations about the shape of those signals are strong enough, perception curates the experience that those expectations predict by filling in the gaps in sensory information to match that prediction.

This means uncertainty is inherent to perception. Given this inherent uncertainty, principles of probability provide the most effective strategy for drawing useful inferences about perception. Specifically, the Bayesian brain theory serves as the foundation for the prevailing perspective on inferential processes within the brain (Hohwy, 2017). Bayesian brain theory holds that the nervous system encodes predictions about sensory information to reduce sensory uncertainty and promote efficient survival (Friston et al., 2016). Employing Bayesian brain theory, the predictive brain aims to enhance the accuracy of its predictions to minimize subsequent errors in prediction (Clark, 2013). The brain uses prior experiences of the body and the corresponding sensory inputs to generate predictions about what the body (interoceptive sensations) and the world (exteroceptive signals) will be like in the future, thereby minimizing prediction error signals (van Elk, 2016). The predictive processing framework helps explain how difference in the weighting of interoceptive and exteroceptive information may form the basis of philosophical or religious beliefs and experiences (van Elk, 2017).

We receive input via exteroceptive signals from vision and sound, proprioceptive signals from body movement, and interoceptive signals from the heart and other organs. Multisensory integration is how the brain combines the information from our different senses, like sight, touch, sound, smell, and balance, to create a clear understanding of our body and surroundings. (Blanke et al., 2014). However, biorhythms continually impact our multisensory integration. For example, saccadic suppression of vision during saccadic eye movements blocks incoming visual information every 250 ms. (Kunzendorf, 2019). This results in less visual input to our occipital lobe during saccadic eye movements. Meanwhile, the consistency of saccadic suppression itself varies with the heartbeat (Galvez-Pol et al., 2020; Ohl et al., 2016). Heart rate, in turn, vacillates in response to our breath rate, autonomic nervous system, and activity level. Thus, the quantity and quality of incoming sensory signals changes moment to moment depending on current physiological conditions and biorhythms.

Exteroceptive signals seem to undergo a process of hierarchical Bayesian inference, in which higher-order cortical regions guide lower-level cortical areas, thereby facilitating sensory processing (Friston, 2005; Lee and Mumford, 2003; Summerfield and Koechlin, 2008; Yuille and Kersten, 2006). Sensory processing is narrowed or honed by our intentions and cognitive

assessment of context. Using functional magnetic resonance imaging (fMRI) and multivariate pattern analysis (MVPA) techniques to measure the content of neural activity in the visual cortex of 22 human volunteers (Kok et al., 2012), the findings of the study revealed how contextual expectations smooth exteroceptive processing in boisterous and ambiguous settings by sharpening early sensory representations (Friston, 2005). This means that our brain fills in sensory gaps to match our cognitive assessment of the environment based on context.

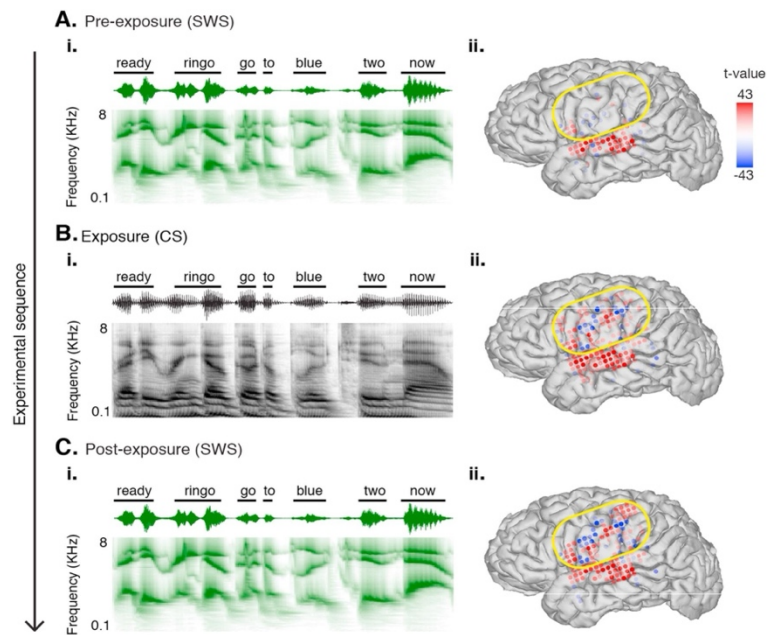
In this same vein, by repeated exposure to a stimulus, perceptual priming works as an unconscious form of perceptual memory, resulting in more accurate recognition of that stimulus (Moldakarimov, 2010). Even one exposure to a stimulus can sharpen perceptual processing. *An example of this is found in Sine Wave Speech (SWS), which sounds like strange beeps and whistles that match the bare frequency of words (Remez, Rubin, Pisoni, & Carrell, 1981). Upon initially hearing an audio clip of SWS, the sounds are indecipherable (CJD, n.d.). Although the auditory system receives input, the neural processes involved in comprehension are not activated, and phonological, lexical, or semantic information is not retrieved. However, once a person hears the words underlying the audio clip of SWS, their pre-central and inferior frontal cortex fills in the gaps to comprehend the words clearly the second time they listen to them. Notably, the auditory cortex representations do not change with the intelligibility of SWS (Fig. 1.) It is a clear example of predictive processing at work in deciphering language (Koshkhoo et al., 2018).*

As Dieguez and Lopez point out, *“the body is the source of its own perception, a subject and an object at the same time”* (Dieguez & Lopez, 2017). Within the brain, the anterior insular cortex (AIC) is involved in visceral interoception and emotional awareness (Seth, 2013). Sympathetic and parasympathetic nervous system signals connect in the AIC and anterior cingulate cortex (ACC). Individual differences in interoceptive sensitivity, as measured by heartbeat detection, are predicted by the AIC and coupled with emotions (Gray, 2007). Emotions involve behavioral, experiential, and visceral changes. As Schachter and Singer famously demonstrated, emotions are modulated by arousal level. They used adrenaline injections to proximally cause physiological arousal, which would give rise to either anger or elation, depending on the context (Schachter & Singer, 1962).

Sensory precision and interoception disruption are significant in psychiatric presentations such as depression, anxiety, eating disorders, and substance use disorders (Khalsa et al., 2018;

**Figure 1**

*Electrodes Activated during Exposure to SWS and Clear Speech.*



Note: (i) Acoustic waveform and auditory spectrogram (ii) Electrodes responsive to SWS and clear speech (CS).

Smith, 2020). For instance, individuals with depression exhibit lower accuracy when counting their heartbeats (Dunn et al., 2010). The diminished interoception may contribute to visceral dysregulation when interoceptive disturbances occur, such as highly arousing negative emotional states. Studies of panic disorder find amplified interoceptive sensations in high-arousal states (Khalsa et al., 2016). One study used behavior during a heartbeat perception task to estimate differences in prior beliefs and sensory precision related to cardiac signals in both healthy individuals and those with depression, anxiety, substance use, or eating disorder symptoms (Smith et al., 2020). Interoceptive processing was stunted in the psychiatric population during altered physiological states, particularly during heightened arousal states (Smith et al., 2020). Although it is unclear whether the reduced interoceptive accuracy perpetuates an individual's symptoms or is a mere by product, this correlation warrants further investigation.

### **Absorption and Openness**

Tellegen and Atkinson's (1974) concept of absorption is associated with an experiential mindset, where absorption means a deep involvement with the object of experience. Low absorption aligns with a reality-oriented, rational mindset. Absorption predicts the frequency and intensity of extraordinary experiences people report (Hood, Morris, & Watson, 1993). Absorption overlaps with the concept of openness. McCrae and Costa (1997) define openness to experience as the permeability of consciousness. This means that individuals with closed minds exhibit a greater distinction between their conscious and unconscious thought processes. Therefore, enhanced access to primary process cognition can be advantageous because conventional conceptualizations are suspended, allowing the mind to embrace greater novelty. Similarly, Hartmann's (1991) notion of boundaries correlates with the permeability of consciousness. Thin boundaries indicate more permeability and high openness (McCrae & Costa, 1997), emphasizing more primary process cognition in awareness. By contrast, thick boundaries are less permeable and are effectively closed off from new subjective interpretations of incoming sensations. In this way, traits of openness and absorption facilitate a perceptual inclination toward novel perception with less weight on Bayesian predictive priors.

The Tellegen absorption scale has emerged as the dominant tool for conceptualizing and measuring the trait of absorption (Tellegen & Atkinson, 1974). Many items on the Tellegen absorption scale emphasize the inner landscape of fantasy and mental imagery, symbolic of lively imagination. An absorbed person is drawn to experience effortlessly, without effort or goal-seeking (Lifshitz, 2019). Absorption has also been associated with feelings of self-transcendence (Cardeña & Terhune, 2014), dissociation, and hallucinations (Perona-Garcelán et al., 2013; Perona-Garcelán et al., 2016). Tellegen and Atkinson (1974) considered absorption a fundamental trait that underlies aesthetic, peak, and mystical experiences. This conclusion has been supported by van Elk et al. (2016) findings that people with high trait absorption felt more awe than those with low trait absorption.

Levels of absorption and openness also correlate with an individual's propensity to perceive paranormal events. Michael Persinger developed the renowned "god helmet" that induced a weak magnetic field in the temporal lobes (Cook and Persinger, 1997; Hill and Per, Singer, 2003). However, when the helmet was not turned on, participants still reported spiritual experiences. Their suggestibility predicted the strength of these experiences. (Granqvist et al., 2005, Granqvist and Larsson, 2006). Other studies using placebo god-helmet manipulations have shown that pre-existing spiritual beliefs enhance spiritual experiences (Andersen et al., 2014; Granqvist and Larsson, 2006). French et al. (2009) also demonstrated this placebo effect in

an infrasound and electromagnetic haunted room experiment. According to French, the frequencies were less likely to cause ghost sightings than merely telling someone they might see a ghost (French et al., 2009).

Based on these studies, it is clear that individual levels of absorption and openness influence human perception. The exact mechanism may be related to the role of serotonin. Absorption has been linked to serotonin 2A receptor association with greater signaling (Ott et al., 2005). Inherently, the trait of novelty seeking, which is associated with dopaminergic activity, is less pronounced for those who experience placebo-evoked somatic sensations (Beissner et al., 2015) but absorption was not measured in that study. Bessner, 2015, nonetheless supports the proposition: “expectation and prior knowledge, profoundly shape the way that sensory input is processed.”

### **The Inherent Uncertainty in Perceiving**

Our perception is limited by what our senses are capable of detecting. Moreover, a large discrepancy between incoming sensations and our prior experiences and beliefs produces greater perceptual uncertainty. Similarly, if new sensory information is given too much or too little weight compared to our predictions, perception of reality may become distorted (Howes et al., 2020; Kube et al., 2020; Smith et al., 2020).

For example, by synchronously stroking an artificial rubber hand with a participant’s real hand while directing the participant’s visual attention towards the artificial hand, the participant perceives the artificial hand as part of their own body (Botvinick, 2004). Comparable effects have been observed in face perception (Bufalari et al., 2019) and whole-body ownership (Ehrsson, 2007). Induction of the rubber hand illusion results in a lower temperature (Mosley et al., 2008) and higher histamine reactivity of the actual hand (Barnesly et al., 2011). Additionally, threats to the rubber hand during the perceptual illusion trigger enhanced skin conductance responses (Armel & Ramachandran, 2003).

The Temporo-Parietal Junction (TPJ) merges somatosensory, auditory, and visual input and resolves intersensory conflict. (Papeo et al., 2010). Specifically, TPJ activity is common in out-of-body experiences (OBEs) (Blanke et al., 2004, 2005). Focal electrical stimulation of the TPJ has resulted in the induction of an illusory shadow person, who was perceived to loom slightly behind the participant’s body (Arzy et al., 2006). Similar observations were made in a group of patients characterized by damage to the left TPJ, who frequently reported the feeling of a presence in daily life (Blanke et al., 2003; Blanke et al., 2014).

Electrical stimulation of the hippocampus and the amygdala has been shown to result in déjà-vu experiences, visual hallucinations of well-known scenes, and feelings of “strangeness” (Vignal et al., 2007). Moreover, stimulation of the parahippocampal area has been shown to result in the perception of familiar places (Megevand et al., 2014). Stimulation of more lateral parts of the temporal lobe, such as the fusiform face area, resulted in the perception of illusory faces (i.e., pareidolia) and strong distortions in face perception and recognition (Parvizi et al., 2012). Similarly, a study using transcranial magnetic stimulation (TMS) found that inhibition of the left lateral temporal area reduced the tendency to perceive meaningful information through visual noise (Bell et al., 2007). In one study, Mengotti et al. (2017) applied online TMS over the right TPJ during a special cueing task. The disruption in the TPJ neural activity interfered with participants’ ability to contextually update their prior beliefs based on novel incoming information, suggesting the right TPJ plays a crucial role in reconciling predictions with incoming stimuli.

Electrical stimulation is not the only avenue to identify brain regions involved in mystical perception. Spontaneous discharges in temporal areas and the limbic system in patients with temporal lobe epilepsy can lead to profound religious experiences (Joseph, 2001). Moreover, symptoms associated explicitly with temporal lobe discharges include hyper-religiosity, visual hallucinations of animate objects, and multi-modal sensory experiences (Chan et al., 2009).

Augmented divergence between new sensations and past contextual experience increases perceptual uncertainty. Whether through electrical stimulation, altered neural function, or strategic optical and tactile illusions, a large discrepancy between sensory signals and contextual memory fosters unique and paranormal perception. Now, let us consider how psychedelics similarly enhance perceptive uncertainty and fertilize synaptic potentials for sensory integration.

### **Psychedelics and Perception**

Psychedelics have the potential to inform therapeutic strategies, especially in the context of extraordinary experiences. Deviations in the dynamic interactions between sensation, expectation, and inference explain how psychedelics alter perception. Serotonergic psychedelics diminish the impact of preconceived expectations and their inferences, allowing sensory data to navigate new neural pathways. Psychedelics involve alterations in multisensory integration, where information from various sensory modalities becomes excessively interlinked.

The use of psilocybin has been associated with the experience of “ego-dissolution,” where people experience a loss of time and space (Griffiths et al., 2006). Like with the god helmet, psilocybin studies have found that absorption was the second most important predictor (besides dosage) of mystical-type experiences (Studerus et al., 2012). What serotonergic psychedelics appear to do is relax the influence of top-down beliefs so that sensory information can find new channels. For example, the psychedelic experience of synesthesia involves the perception of stimuli via a discordant sensory modality (Carhart-Harris et al., 2014). Absorption has also been linked to the intensity and frequency of synesthesia induced by ayahuasca (Bresnick & Levin, 2006), LSD (Terhune et al., 2016), and near death experiences on the potent serotonergic psychedelic DMT (Timmermann et al., 2018). Based on these studies, abnormal serotonergic functioning, as in the trait of absorption, may contribute to both psychedelic synesthesia and NDEs.

Another psychoactive substance, ketamine, an NMDA (N-methyl-D-aspartate) glutamate receptor antagonist, is not generally known to produce hallucinations. However, ketamine has induced auditory hallucinations when the participants were placed inside an fMRI scanner (Powers, 2015). This curious finding begins to make sense taking into consideration how ketamine intensifies sensory experiences. With ketamine, both auditory and visual perception acuity is amplified, and background stimuli become more prominent (Krystal et al. 1994; Oye et al. 1992; Vollenweider et al. 1997a, b). The odd visual and auditory input of the MRI, merged with magnified interoception induced by ketamine, created hallucinations comparable to psilocybin’s (Corlett, 2009). Thus, it is more than mere serotonin signaling that allows for the astonishing and fantastic perception experienced after ingesting psychedelics.

### **Discussion**

The factors discussed in this article were chosen for their significant impact on perception and their potential to inform therapeutic strategies, especially in the context of extraordinary experiences and the transformative effects of psychedelics on human well-being. Future research should investigate the unique sensory processing mechanisms associated with psychedelically

induced altered states and individuals with high trait absorption levels. Additionally, future studies should specifically measure trait absorption levels in the context of somatic placebo-induced sensations.

### **Conclusion**

This review seeks to synthesize the current research surrounding the intricate relationship between sensory input, cognitive predictions, and interoception, emphasizing the importance of these factors in shaping perception. By applying Bayesian brain theory to the roles of multisensory integration, biorhythms, absorption, and psychedelics, existing research on sensory processing and prediction errors provides valuable insights into how we might curate novel therapeutic and extraordinary experiences.

There has long been a gap between our subjective and objective reality, which has slowly shrunk over time. We are now to the point where this gap occurs in milliseconds within our brains and bodies. Fluctuations in the precision of our sampling of sensory evidence lead to more or less emphasis on prior knowledge and experience, leading to revised predictions about objective reality. Appreciating the interconnectedness of these subjects contributes to a holistic understanding of human cognition and sensory capabilities while getting us closer to answering the question we ask ourselves every day—what is real in this moment?

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