Empirical Methods For Measuring Consciousness And Its Relationship With Attention

The relationship between attention and consciousness is a topic of significance and perpetual debate. Specifically, the study of consciousness has been associated with a recent focus on the problem of measurement. Many argue that a metric for consciousness is vital for experimental design and for mapping experimental results to current theories. “Because we feel that we understand both [attention and consciousness] intimately through our own experiences of them, it has often been supposed that we should be able to discover the relationship between them simply by introspection” (Kentridge, 2011, as cited in Mole, Smithies & Wu, 2011).

However, as Tallon-Baudry notes, But in order to measure something in the first place, the concept in question typically needs a definitive definition. With an established definition, the problem of measurement turns from a philosophical one into a technical one. The problem with a concept like consciousness is that any definition claiming to be categorical runs the risk of overlooking the subtler representations of consciousness. We can measure things like time, volume, and mass because these concepts have universal definitions with meanings that can be understood by most relatively intelligent individuals. However, this is not the case for consciousness. Skeptics argue that reliable methods are nonexistent as there is no consensus on how to adequately operationalize it. When determining whether something was consciously perceived by someone, they are usually simply asked to report whether or not they perceived it. The problem with this is that if they report they weren’t aware of it, we do not know whether this was due to a lack of attention or if they were genuinely not conscious of the presented stimuli. It seems that some way to measure consciousness aside from traditional, subjective self-reporting is needed. Whether any of the current research has an answer to this problem is something worth exploring.

This paper attempts to review and explain current methods for measuring consciousness – both behavioural measures and measures based on neurophysiological data. Current research that has used these methods are summarized, showing how they are being used to probe the relationship between attention and consciousness. All of the studies mentioned that explore this relationship use self-reporting in conjunction with empirical measures; using neural correlates of consciousness and neurophysiological measures; showing that associative measurements not derived from a fundamental understanding of consciousness can nevertheless further our scientific understanding of it and potentially lead to a more definitive definition.

Operationalizing Consciousness

Given that the concept of consciousness is perhaps one of the most subjective, finding the correct metric to measure such a thing has proven to be incredibly difficult, if not impossible. Consciousness is unique in that we all intuitively know what it is based on our personal experience of it, but trying to describe what it is that allows us to understand ourselves and our surroundings is not easy. So then, how are we supposed to measure consciousness or whether and to what degree a stimulus is consciously experienced? These measurements provide data that is vital to a better understanding of consciousness as a phenomenon, yet there is little

consensus on how this metric should be established.

Mitra (2014) states that creating a metric for consciousness is difficult both practically and conceptually:

It is important to note that the problem of measuring consciousness isn't equivalent to the problem of identifying unconscious processing though. Seth et al. states:

This makes the conceptual problem of consciousness more complicated. Consciousness is essentially characterized by its subjective nature. So by its very nature it seems to oppose any objective measurements by outside observers who cannot access the conscious experience except through the indirect, subjective report of the individual.

But although consciousness is a notoriously ill-defined concept, some operational definitions do seem to be consistent and commonly accepted in the literature now. Most often, researchers attempting to measure consciousness are referring to top-down consciousness, also known as endogenous, executive, selective, sensory, active, goal-driven, or phenomenal consciousness. As Lau and Rosenthal state, (2011, p. 365). The term consciousness is also sometimes used in the literature as a reference to thoughts and volitional states of which we are subjectively aware, but this is not the type of consciousness that researchers typically attempt to measure in their studies (Lau & Rosenthal, 2011). As such, all of the papers either mentioned or summarized below consider top-down consciousness only. They rely on an operational definition exactly like, or very similar to, the one above to either examine how consciousness can be measured, or how neurophysiological data can help to discern the relationship between attention and consciousness.

Measuring Consciousness

Behavioural Measures

The fact that there is no concrete and universal definition of consciousness is reflected in the measurements currently being used in studies of consciousness. Currently, the most used index of consciousness are subjective measures; measures that require subjects to report their experiences often during, or immediately after performing a perceptual task under experimental conditions designed to maximize accuracy. These ratings, typically communicated either verbally or via "commentary keys" are supposed to indicate whether a stimulus has been consciously perceived as opposed to merely "guessed". Turatto, Sandrini, and Miniussi (204) mention that despite the frequency of high subjective ratings often being correlated with task performance, they are distinct and are dissociable.

Like any index, these subjective reports have benefits and detriments. Of course, there are a number of obvious issues with them, in this case the most prominent of those being that these ratings are subject to dishonesty causing noise in the data despite subjects not typically being dishonest purposefully. So measuring consciousness continues to be a demanding task. It might be possible to attain useful correlative measurements of these subjective reports, but whether these measurements provide insight into the nature of consciousness needs to be explored further. In more recent studies, measures based on neurophysiological data have been used in conjunction with subjective ratings in an attempt to obtain a better understanding.

Measures Based on Neurophysiological Data

Contrast response functions. Contrast response functions (CRFs) describe how a neuron's firing rate depends on the intensity (contrast) of a visual stimulus – for very low contrasts they don't fire at all, but at a middle range of contrast they rapidly increase their rate of firing. Gain functions, which are deviations from the standard CRF, describe the strength of signal enhancement. According to van Boxtel (2017), mapping CRFs has provided insights into the mechanisms underlying conscious (visual) processing.

Neural amplification. Many researchers suggest that neural amplification plays a vital role in whether or not information reaches consciousness. Also referred to as sensory amplification, neural amplification states that for a stimulus to be registered consciously, a certain amount of sensory activation must occur. The idea is that different inputs compete, and the "loudest" (most amplified) input is the one that reaches consciousness, characterizing a neural correlate of consciousness in terms of "competing cellular assemblies" (Crick and Koch, 2003). Neural amplification is a major contributor to most of the results in experiments on consciousness: activity evoked in sensory areas of the brain consistently appears to be larger in response to consciously seen stimuli compared to unseen stimuli (Sergent, Baillet & Dehaene, 2005).

Neural synchrony. Also referred to as oscillatory synchrony, neural synchrony is considered to be a mechanism capable of coordinating neural activity between and across cortical regions. Many researchers have reported that consciousness arises from transient neuronal synchrony (Seth et al., 2008) in the gamma (30–70 Hz) and beta (15 Hz) ranges. Seth et al. (2008) report that research has revealed a connection characterized by gamma range activity and steady-state visual-evoked potentials between synchrony and consciousness. However, studies interfering with gamma band synchrony have not yet shown that this disruption results in a disruption of consciousness (Seth et al., 2008), possibly indicating "… that neuronal synchrony might at best be necessary but that is not sufficient for consciousness" (Seth et al., 2008).

Neural complexity. Recent studies have demonstrated that, "… conscious scenes are distinguished by being simultaneously integrated (each conscious scene is experienced 'all of a piece') and differentiated (each conscious scene is composed of many distinguishable components and is therefore different from every other conscious scene)" (Seth et al. 2008). Tononi and Edelman (1998) propose that neural activity in the thalamocortical system with these features gives rise to consciousness, as measured by a metric called "neural complexity" (CN). Event-related potentials. Event-related potentials (ERPs) measure brain responses that directly result from specific sensory, cognitive, or motor events (Luck, 2014). ERPs have been used to determine whether a presented stimulus is perceived or not. Fu et al. (2013) investigated whether people can learn without conscious knowledge, specifically how implicit and explicit knowledge is reflected in ERPs in sequence learning. They recorded ERPs while subjects performed a serial reaction time task. Their results revealed that implicit knowledge is expressed in relatively early components (N2) and that this is distinct from explicit knowledge which emerges in later (P3) components (Fu et al., 2013). Their findings suggest that we are capable of learning without consciously knowing and that there could be different neural mechanisms underlying the acquisition of implicit and explicit knowledge (Fu et al., 2013).

Widespread activation. Evidence indicates that compared to inputs that do not reach consciousness, inputs that are consciously perceived evoke widespread activation in the brain

(Baars, 2002). By talking to patients during an fMRI scan, this method allowed Monti, Coleman, and Owen (2009) to distinguish between vegetative or minimally conscious state patients. Observing the brain activity produced, they found that four patients presumed to be vegetative were actually not, and were able to conjure up mental imagery and even answer yes-no questions signalled via recognized motor output. However, Monti, Coleman, and Owen (2009) admit that their technique is not a direct measure of consciousness, as it is possible that some patients may retain some level of consciousness but lack the ability to produce motor output. Hayward (2014) states that using this measure under some circumstances

Casali et al. (2013) presented an objective measure of consciousness that claimed to have the capability of differentiating between vegetative and minimally conscious patients. Similar to other studies of consciousness, their metric utilized electroencephalography (EEG) to measure activity evoked directly in the brain using a transient magnetic field (i.e. transcranial magnetic stimulation). The spatial and temporal patterns generated in the brain by the electric currents were then derived from the EEG measurements and quantified to create the metric. The method they used to quantify the spatial and temporal distribution of electric currents is particularly interesting. The idea is that unconscious activity is characterized by localized or distributed and uniform activity (such as during slow wave sleep or epileptic seizures), and conscious activity is characterized by a distributed but non-uniform spatiotemporal pattern. Casali et al. (2013) applied the Lempel-Ziv algorithm (the same compression algorithm used to encode GIF image files) to a binary matrix to evaluate the information content provided by the TMS and distinguish between. The degree of compressibility of the spatiotemporal pattern taken from the EEG is the consciousness metric – what they call “the perturbational complexity index” (PCI). This data-driven metric has been shown to effectively discriminate between varying degrees of consciousness in individuals (such as during wakefulness, sleep, and anesthesia, as well as vegetative and minimally conscious patients previously in a coma) (Casali et al., 2013).

Measuring the Relationship Between Attention and Consciousness

Below are papers using self-report measures in conjunction with the brain-based measures outlined in the previous section. The research results suggest that attention and consciousness have different neurobiological mechanisms. However, it is important to note that showing that the mechanisms underlying attention and consciousness are distinct is not denying that they interact, but their separable neurobiological mechanisms supports the view that attention and consciousness are autonomous processes and that they can be fully dissociated (i.e. there can be forms of attention without consciousness and vice versa).

Attention without consciousness. Wyart, Dehaene, and Tallon-Baudry (2012) demonstrated that we can attend to objects before becoming conscious of them. To determine whether spatial attention would enable weak stimuli to be consciously perceived by increasing their contrast during early visual processing, they evaluated the early attentional amplification of visual responses (~100 ms following stimulus onset) to see whether there was an an apparent effect on conscious detection.

MEG signals were recorded while subjects were cued by a predictive arrow to attend either to their right or left lower visual field. After 600 ms, a target grating at detection threshold was briefly presented for 17 ms either at the cued or uncued location (or occasionally was not presented at all), and was followed after 50 ms by a mask surrounding the target location. After

target onset (400 ms), subjects completed a discrimination task which required them to first select and subsequently perceive the orientation of the target grating among two choices, and then report whether they had detected the presence of a target before the mask.

What they found was that spatial attention increased early occipital responses around 100 ms equally for both detected and undetected stimuli. So spatial attention neither controlled conscious access nor did it increase the amount of detected stimuli.

In another study, Tallon-Baudry (2012) demonstrated that oscillatory neural synchrony plays a role in both attention and consciousness. EEG studies have shown cases of attention being elicited by cues that do not reach consciousness. Attention and consciousness examined at the neural level indicate a dissociation between them. In one experiment, analysis of EEG data revealed that seen and unseen attentional cues are initially processed along the dorsal stream in the same way. It was also found that attention can modulate the neural processing of stimuli that don't reach consciousness, and whether a stimulus is seen or unseen can be independent of whether or not the stimulus is attended to. In another experiment, neural responses were compared to stimuli that were identical but that could be consciously perceived or not, and attended to or not (on a trial-by-trial basis). Subjects directed their attention towards faint gratings at a threshold for awareness. Analysis of MEG data revealed that larger, high-frequency gamma-band oscillations occurred for attended stimuli, either see or unseen, and larger, low-frequency gamma-band oscillations occurred for seen stimuli, either attended or unattended.

This review shows that the neural mechanisms of attention and consciousness are separate but can interact. Consciousness without attention. Meijs, Slagter, de Lange, and van Gaal (2018) explored the dynamic interaction between top–down expectations and conscious awareness by conducting three different experiments. The first experiment addressed how expectations affect the likelihood of conscious stimulus perception. For this they used an attentional blink (AB) paradigm. The first target predicted which of the second targets would be most likely to appear (on 20% of trials a random distractor letter was presented instead). At the end of each trial, subjects were asked to report whether they had seen any of the two T2 targets (seen / unseen response), the identity of T2, and the identity of T1. What they found was that expectations modulated T2-detection rate; detection of T2 was significantly better when T1 validly (as opposed to invalidly) predicted T2.

The second experiment tested if expectation violations could be elicited by unconsciously processed unpredicted stimuli. Subjects' brain activity was measured with EEG while they performed a task similar to that of experiment 1. They found that validly predicted T2s were detected better than invalidly predicted T2s. They investigated potential differences in the neural processing of predicted and unpredicted stimuli (as a function of stimulus awareness) and found a significant difference over frontocentral electrode channels: greater T2-elicited negativity for invalidly predicted compared to validly predicted trials reflected a type of mismatch response. This was further analyzed to see whether the difference was attributed to conscious perception of T2 and it was found that the size of the mismatch was independent of T2 awareness, signifying that both seen and unseen T2s generated this mismatch response.

In their last experiment, they addressed the question of whether expectations themselves can form without awareness and influence conscious access. To do this, they changed the color of T1 from green to white and staircased T1 duration so that T1 was accurately identified 75% of

the time. A significant AB for missed T1s was detected, indicating an unconsciously triggered AB (reflecting the time taken to allocate selective attention). Mejis and colleagues argue that, “this cannot be explained by an overall T2-detection performance benefit for targets presented later in the trial because the AB was larger for trials on which T1 was presented but missed compared with trials on which no T1 was presented in the trial” (2018).

Their results indicate that valid expectations increase the likelihood stimuli being consciously accessed, their findings also suggest there is a dissociation between expectations and consciousness: top-down expectations for perceptual decisions seems to require conscious awareness, but prediction errors can be triggered outside of conscious awareness.

Attention and consciousness are distinct functions and can even have opposing effects. Like consciousness, attention has also been shown to alter the contrast response curve. To determine whether the similar or different neural mechanisms subserve consciousness and attention, Carrasco (2011) measured the duration of afterimages over a range of contrasts to determine behavioral CRFs and investigate how attention and consciousness alter the contrast response curve. Their results revealed that attention is capable of shifting the curve to the left, which facilitated detection by enhancing perceived stimulus contrast. This response modulation shows the largest effects at high contrasts and is referred to as a contrast gain function (van Boxtel, 2017).

Similarly, van Boxtel also used a method that controlled both attention and consciousness modulations to assess their separate effects on contrast response functions. Gain functions were calculated for attention and consciousness to determine whether they work through the same or distinct signal enhancement mechanisms (2017, p. 5913). Previous research investigating the effects of attention and consciousness on afterimage durations have showed that attention decreased afterimage durations while consciousness increased durations (van Boxtel, Tsuchiya & Koch, 2010), but didn’t provide insight as to how this dissociation comes about. To explore this, van Boxtel (2017) obtained contrast response functions from subjects by measuring afterimage durations to determine the visual mechanisms behind attention and consciousness. He calculated the gain functions for both attention and consciousness individually to determine whether they operate through the same or distinct signal enhancement mechanisms.

Each trial had three phases: phase 1 was the adaptation phase during which the afterimage inducer was shown in one eye for four seconds. To create conditions in which a low amount of attention was paid to the inducer, subjects were told to count the number of X’s that appeared in a stream of nontarget letters. In the high attention condition, the stream of letters were displayed but subjects were not instructed to perform any task. Instead, subjects were told to track the inducer by pressing and releasing a button. In phase 2, subjects were instructed to press a button as soon as they perceived an afterimage and release it when the afterimage disappeared (subjects were told to press the spacebar if no afterimage was perceived). In phase 3, subjects had to indicate the number of X’s they counted (in the high-attention condition, this question was skipped by pressing the spacebar).

His results revealed that attention lowered CRFs, whereas consciousness raised them. Furthermore, consciousness manifests itself as a contrast-gain function and attention manifests itself as a response-gain function. Contrast-gain functions predict an increase in sensitivity (characterized by a threshold shift in the contrast response function), while response-gain

functions predict an increase in firing rate. His findings show a strong dissociation between both the computational mechanisms behind attention and consciousness and their perceptual consequences.

Conclusion

This paper has attempted to explain and examine the problem of measuring consciousness. Six neurophysiological mechanisms that have been associated with consciousness were explained (neural synchrony, contrast-response functions, neural amplification, event-related potentials, widespread activation, neural complexity) and how they are being used in conjunction with self-report measures to discern the relationship between attention and consciousness. It seems that because the fundamental nature of consciousness is itself subjective, by its very nature it opposes objective measurements by outside observers – observers who cannot access the conscious experience except through the indirect, subjective report of the individual. However, as shown in more recent research, useful correlative measurements exist to supplement these subjective reports.

Why is it important to determine the relationship between attention and consciousness? It has yet to be determined whether consciousness has a function on its own or whether it confers a definite evolutionary advantage (Chalmers, 1995 as cited in Tallon-Baudry, 2012). Panpsychists aside, it is generally agreed upon that consciousness is categorically connected to the nervous system of animals. So instead of searching for a mathematical formula that can measure consciousness, examining the structure of neurological mechanisms involved in attention, intelligence, arousal, etc. may prove to be more useful. Consciousness has likely evolved from less complex life forms as a product of evolution by natural selection because it confers some utility. Discovering that the structure of neurological mechanisms and the kind of attention they control shows a natural progression between invertebrates and vertebrates could provide a general framework for understanding consciousness.

It is an attractive idea to think that a study claiming to possess a definitive definition and utilizing an empirical metric advances our scientific understanding of consciousness. However, this is not necessarily true. First of all, any research claiming that their definition or metric was acquired from a conceptual understanding of consciousness should be reviewed with caution. Furthermore, associative measurements not derived from a fundamental understanding of consciousness can nevertheless further our understanding of it. For example, physicians in the middle ages could diagnose the type of fever a patient had by observing their pulse – carefully noting the rate, power, and tempo of the pulsing artery – without any particular knowledge of the fundamental pathology.

Although we are still lacking a universal definition and measure of consciousness, researchers have still yielded many interesting results and useful insights into the nature of consciousness. Continuing down this path could eventually lead to a clearer definition and more concrete idea of what consciousness and its relationship to attention is. Determining the exact relationship between attention and consciousness may also in turn provide a path towards achieving a more refined definition of consciousness.