Duration Perception Versus Perception Duration: A Proposed Model for the Consciously Experienced Moment

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Abstract

Duration perception is not the same as perception duration. Time is an object of perception in its own right and is qualitatively different to exteroceptive or interoceptive perception of concrete objects or sensations originating within the self. In reviewing evidence for and against the experienced moment, White (2017) proposed a model of global integration of information dense envelopes of integration. This is a valuable addition to the literature because it supposes that, like Tononi's (2004) Integrated Information Theory, consciousness is an integral step above perception of objects or the self. Consciousness includes the perception of abstract contents such as time, space, and magnitude, as well as post-perceptual contents drawn from memory. The present review takes this logic a step further and sketches a potential neurobiological pathway through the salience, default mode, and central executive networks that culminates in a candidate model of how duration perception and consciousness arises. Global integration is viewed as a process of Bayesian Prediction Error Minimisation according to a model put forward by Hohwy, Paton and Palmer (2016) called 'distrusting the present'. The proposed model also expresses global integration as an intermediate stage between perception and memory that spans an approximate one second duration, an analogue of Wittmann's (2011) experienced moment.

Duration of Perception Versus Perception of Duration: In Defence of the Experienced Moment

Given that the object of perception is tangible and concrete, exteroceptive perception of objects and interoceptive perception of the self are relatively well-understood and conceptually distinct. Perception of abstract objects is, unfortunately, comparatively fraught and easily conflated with the other two. The perception of duration, although potentially indistinct from other abstractions of magnitude such as space and number (Bueti & Walsh, 2009), is one example of an abstract perceptual domain often confused with its inverse operation, i.e., the duration of perception(s). The two are markedly distinct and utilise different neural networks but are sometimes hard to differentiate theoretically and empirically. This paper is an attempt to clarify where and when references are made to the perception of duration versus the duration of perceptions, and in doing so aims to sketch a model of duration perception related to Bayesian Prediction Error Minimisation (PEM) and major brain networks associated with consciousness.

Of critical importance is the relationship between perception and conscious experience. While consciousness is difficult to define absolutely, a sufficient definition to distinguish it from perception is one provided by Chalmers (1996) which states that consciousness is the phenomenal experience which a hypothetical zombie, who acts like a conscious being in every other way, lacks internally or subjectively. More realistically, an analogous situation is one where sleepwalker can perceive and respond to their environment in sensible ways without being conscious. This distinction is critical if we are to understand the difference between duration perception and duration of perceptions. It also relates to Tonini, Boly, Massimini and Koch's (2016) axioms of conscious experience as unitary, specific and definite. Perception of objects is multimodal, not unitary, and so the temporal characteristics of those perceptions do not constitute conscious experience. A sleepwalker may be able to perceive sounds, visions, textures and balance but, by combining Chalmers' (1996) and Tononi et al.'s (2016) definitions, their perceptions do not become phenomenally unitary, specific and definite and so they remain unconscious. The present paper will argue that, while a sleepwalker's perceptions of concrete objects may be adequately timed, they may not perceive abstractions like time itself.

Tononi et al. (2016) also stipulated that the neural correlates of consciousness should be "consistent with estimates of the timescale of experience" (p. 453), but there is uncertainty as to what that timescale actually is. Tononi et al (2016) remained agnostic whereas Tononi (2004) originally allowed between a few tens of milliseconds up to a few seconds. White (2017) argued more recently against a duration called the *experienced moment* or *subjective present,* which Wittmann (2011), Pöppel (1989) and others define as an interval of around 2 – 3 s within which conscious phenomenal experience takes place. White (2017) concluded that the evidence from perception studies does not support the existence od an experienced moment defined by duration, proposing instead that *envelopes of integration* vary according to the sensory modality and the amount of information contained in a percept. The envelopes are therefore independent of duration and, accordingly, the 2 – 3 s experienced moment is not defined.

It is true that the White (2017) review shows that experiments investigating the duration of perception do not support an experienced moment. However, the review does not address the key distinction alluded to above. Instead, White (2017) casts doubt on whether duration perception "is even relevant to the issue of temporal integration in the construction of a 'subjective present'" (p. 738). This is a problem because White also asserts that there is a critical interval for duration perception between 1 – 1.5 s meaning that, if it were deemed relevant to temporal integration, then the experienced moment would be defined by a critical duration.

It is understandable how White (2017) came to this conclusion. In a later section, he acknowledged that the "review deliberately avoided the issue of consciousness" which otherwise could "make full sense of an envelope of integration or 'subjective present'" (p. 750). Without consciousness, a critical feature of the experienced moment is lacking and the distinction between the perception of duration versus duration of perceptions is obscured.

The real problem though is that the review does not in fact avoid the central issue of consciousness. It refers to critical aspects of Chalmers' (1996) and Tononi et al.'s (2016) definitions in reference to *global integration* of locally integrated products of modular perception. Global integration is Tononi et al.'s (2016) axiom of conscious integration by another name, especially since "windows of temporal integration are defined in terms of information density" (p. 735). Tononi (2004) proposed the Integrated Information Theory (IIT) of consciousness over a decade prior, and so the following comment by White (2017) is hard to interpret in any way other than as a reference to previous definitions of consciousness:

> Although, as in the case of speech perception, a good deal is known about local integration (where, for present purposes, the whole of speech processing is local in the sense of being distinct from, say, visual layout processing or the kinaesthetic body map), there has been little if any research on the integration of different local processing outputs into a globally integrated representation, the envelope of integration as a whole. (p. 750)

This is an interesting point. A "globally integrated representation" is strikingly similar to Tononi et al.'s (2016) axiom of integration: "In other words, the content of an experience (information) is integrated within a unitary consciousness" (p. 452). White (2017) even uses the term experience in precisely the same way:

> Thus, information currently being attended has the *subjective experience* of global coherence, and this property is assumed to hold for all other information about what is going on, but this is not so much the case for information that is not at the focus of attention. Nevertheless, it is this *experience* of global coherence that perhaps does more than any other single feature to give the envelope of integration its *subjective* character. (p. 750, italics added)

As for the extent to which Chalmers (1996) conflates experience and consciousness, in the index of his seminal book, *The Conscious Mind*, the entry under "Experience" merely says "*See* Consciousness" (p. 408). The same entry is also placed under "Subjective experience" (p. 413). Experience, subjective experience and consciousness are synonymous according to Chalmers (1996) and so, by postulating global integration of local information-dense envelopes, White (2017) is referring to none other than the integration of perceived objects into consciousness as per IIT. Normally, the precise distinction between the enduring perceptions (i.e., of a sleepwalker) and the subjective experience of someone who is fully conscious would not be an issue. However, White (2017) reviewed evidence for the the experienced moment which is conscious by definition (Wittmann, 2011) and so it is important to be precise. White (2017) attempted to isolate consciousness from the subjective present and experienced moment:

> Is the "subjective present" concerned with temporal units of consciousness, or temporal units of perception? The authors of the proposals referred to consciousness (see quotations above), but the products of many kinds of processes, both perceptual and post-perceptual, may form part of the contents of consciousness, so consciousness, whatever that may be, should not be taken as defining the "subjective present." (p. 737)

Later, when discussing global integration, White (2017) clarifies the term "post-perceptual" by stating that the subjective present "straddles the boundary (to the extent that there is one) between perception and memory, or between perceptual processing and post-perceptual cognitive processing" (p. 750). So, that only begs the question: If perceptions and memory are the temporally short and long contents of consciousness, and consciousness is synonymous with subjective experience (Chalmers, 1996), how could they be contained temporally by anything besides the experienced moment? Further to this, if Tononi et al. (2016) require that the spatio-temporal grain of consciousness be "consistent with estimates of the timescale of experience" (p. 453), then the experienced moment has to be consistent with *global* perception, not *local* perceptions across various modalities.

That begs a further question: What is global perception and how does it relate to experience/consciousness and time? There is a simple answer: global perception is analogous to duration perception. Time is not just a property of perceptions, it is an object of perception itself. The White (2017) review and others by the same author (White, 2018) acknowledge that temporal integration synchronises local perceptions by cancelling out latency effects. Synchrony is a temporal property of local perception but global deals with duration and change, not static synchronous moments. The main difference between synchrony and duration is that time is a property of *local* perceptions whereas *global* perception is a property of time. As proposed by Wittmann (2011):

> Whereas the duration of the *functional moment* is not perceived, an *experienced moment* relates to the experience of an extended now. According to this conception, the *experienced moment* has duration. (p. 4, italics in original)

The functional moment generates synchrony through temporal integration but the experienced moment generates duration through global integration of perception into a unitary conscious experience (Tononi et al., 2016). This is what is meant by the difference between the duration of perception(s) and the perception of duration. White (2017) also acknowledges that global integration "deals with the outputs of multiple processes operating on the suprasecond scale" (p. 750), but laments that "there has been little if any research on the integration of different local processing outputs into a globally integrated representation, the envelope of integration as a whole" (p. 750). However, according to the view that duration perception is analogous to global/conscious integration of local perceptions, the vast and varied time perception literature represents the precise type of research that White (2017) views as lacking. His assertion (p. 738) that time perception studies show a critical duration between 1 – 1.5 s proposes that there may yet be a critical window of experienced time within which conscious experience takes place, i.e., the experienced moment. But, as White (2017) rightly points out, it is not sufficient to merely state that time experience/perception and global perceptual integration are synonymous. Empirical evidence must be put forward. As such, the rest of the current paper will be devoted to substantiating the claim.

Consciousness and duration within the experienced moment

As stated above, there is a general confusion regarding the relationship between consciousness, experience and duration. The account offered below is not intended to explain the lack of support for a 2 – 3 s experienced moment in White's (2017) empirical analysis of perception studies, but rather to demonstrate how conscious experience of time differs from either perception of sensory inputs or working memory processes. It takes the position agreed upon by both White (2017) and Wittmann (2011) that the latter two are relatively distinct.

There is functional synchronisation of sensory input over approximately the first 125 ms within White's (2017) envelopes of integration and Wittmann's (2011) functional moments. The at longer time scales there is also mental presence, which is a corollary of working memory processes, operates over a wide range of perhaps 100 s. The only difference between the two conceptualisations is that White (2017) claims that there is probably no "sharp distinction between the envelope of happening and mental presence" (p. 749), whereas Wittmann (2011) places the experienced moment at an intermediate time scale of approximately 1 – 3 s. For current purposes it is sufficient to assume that the longest time scales of conscious experience are at the lower end of Wittmann's (2011) definition given that this overlaps with White's (2017) critical range of duration perception, i.e., 1 – 1.5 s. The lower-bound of duration perception is then also assumed to be the upper-bound of perceptual synchronisation as proposed by White (2017), i.e., 200 ms.

The window of the duration perception is therefore assumed to span approximately one second between 200 ms and 1.25 s. As White (2017) points out, consciousness contains both perceptual and post-perceptual (i.e., memory) contents and so it is also assumed that perceptual contents enter consciousness early on in process whereas memory contents are typically integrated more slowly. This agrees with current estimates of the time scale of peak neural activity for consciousness of visual perceptions between 200 – 250 ms (Koch, Massimini, Boly, & Tononi, 2016). The assumption is that memory contents become conscious via the same process of global integration but at the opposite end of the time scale around 1.25 s.

The next question is: What exactly is the process of global integration and how does it relate to duration perception? The short answer is that we do not yet know but one proposal to be explored is that global integration is synonymous with Hohwy, Paton and Palmer's (2016) Bayesian prediction error minimisation (PEM) paradigm called "distrusting the present". If, as Hohwy (2013) and others propose, the brain is fundamentally a hypothesis testing machine, then the aim is to keep errors of predictive inference to a minimum. When prediction is likely to be accurate, for example in familiar and moderately challenging contexts, inferences are made thick and fast and time flows freely. However, when prediction is likely to be inaccurate or error is more critical, such as during unpredictable emergency situations or overly predictable boring situations, predictions are made more sparingly and time slows down (dilates). It is the rate of updating from one predictive inference to the next that determines the rate of perceived duration. (Hohwy et al., 2016)

In terms of the one-second window of duration outlined above, a threatening emergency situation is assumed to make sensory-perceptual information more salient and so the window is accelerated towards the millisecond range. It has been known for decades that duration is commonly perceived to slow down or dilate in an emergency because arousal spikes with adrenaline and people report perceiving things in slow motion (Leonov & Lebedev, 1968). In an emergency, people notice nearly every detail of things happening around them and the effect of perceiving more change has been demonstrated experimentally to dilate duration (Herbst, Javadi, van der Meer, & Busch, 2013).

However, dilation of duration also occurs at the opposite extreme when people are bored and events in the world really are occurring slowly (Zakay, 2014). In an analogous way, people who are depressed also tend to experience duration dilation regardless of the situation (Thönes & Oberfeld, 2015). With respect to the one second duration window above, these situations are assumed to bias mental activity towards memory processes in the seconds range, and depression has been shown to cause deficits in both autobiographical (Brewin, Reynolds, & Tata, 1999; Dalgleish et al., 2007; Gibbs & Rude, 2004; Söderlund et al., 2014; J. Williams & Scott, 1988; J. Williams, Teasdale, Segal, & Soulsby, 2000; J. M. G. Williams et al., 2007) and working memory (Christopher & MacDonald, 2005; Joormann & Gotlib, 2008; Rose & Ebmeier, 2006).

So there are two routes to duration dilation with seemingly opposite valence of arousal but the same level of attention to duration. In high arousal emergency conditions, duration of perceptions is salient because there is time pressure but in low arousal boring conditions, duration of time is salient because there is no time pressure. Attentional effects on time perception are well-understood (Zakay & Block, 1996) and have been shown to affect time perception in depression (Sévigny, Everett, & Grondin, 2003). More attention paid to task makes duration accelerate but more attention to time makes duration dilate (Zakay & Block, 1995). Arousal and attention therefore have independent or semi-independent influences on duration perception (Gable & Poole, 2012; Gil & Droit-Volet, 2012; Mella, Conty, & Pouthas, 2011; Yarrow, Haggard, & Rothwell, 2004).

This reinforces the notion that duration is an object of perception and not just a property of object perception. Attention to duration when bored or depressed is, according to Hohwy (2012), an attempt to make predictions about time from prior experience. Prior experience is embodied in the predictive coding of autobiographical memory and so the rate of perceived duration in the Bayesian PEM model called ‘distrusting the present’ is driven by processes that combine features of attention, prediction, autobiographical memory, and duration (Hohwy et al., 2016).

Fortunately, a region of the brain called the default mode network (DMN) has been shown to underpin all of these functions: 1) DMN connectivity predicts sustained attention abilities (Bonnelle et al., 2011); 2) the DMN integrates past experiences in order to plan for the future (Buckner, Andrews-Hanna, & Schacter, 2008); 3) DMN activity supports autobiographical memory and prospection (i.e., expectations for the future); and 4) DMN variability has been shown to lead to temporal awareness (Lloyd, 2012). Two specific brain regions are of interest: 1) the inferior parietal lobule is one of the main nodes of the DMN (Buckner et al., 2008); 2) the adjacent superior parietal lobule is responsible for representing abstract magnitudes of time, space and number (Bueti & Walsh, 2009); and 3) both are part of the posterior cortical “hot zone” currently identified as one of the most likely neural correlates of highly perceptual conscious experiences (Koch et al., 2016). This area contrasts with medial frontal cortex, also part of the DMN, which is thought to be responsible for highly thought-like conscious experiences (Siclari, LaRocque, Bernardi, Postle, & Tononi, 2014). It has also been shown that DMN connectivity reflects the level of consciousness of non-communicative brain-damaged patients (Vanhaudenhuyse et al., 2009) and so there is suggestive evidence that duration and consciousness both revolve around DMN activity.

It is therefore highly likely that all three are interconnected and distinct from the two other major brain networks, the salience and central executive networks, that have been separately linked explicitly to perception and working memory, respectively. The salience and central executive networks complement the default network both in terms of function and their time scale of operation under Wittmann’s (2011) tripartite model (Bressler & Menon, 2010; Cao et al., 2016; Sridharan, Levitin, & Menon, 2008). Key nodes of salience network have been hypothesised to generate rapid ‘emotional moments’ of approximately 125 ms that align with Wittmann’s (2011) functional moments (Craig, 2009a, 2009b). For longer time scales, the central executive network is a higher-order function of working memory (Baddeley, 2012) which, unlike the DMN, is active when processing task-related information. Central executive working memory processes are thus assumed to relate to Wittmann’s (2011) mental presence over extended time scales up to perhaps 100 s.

The model proposed here to account for duration perception therefore contrasts: 1) the first timescale up to 200 ms of the salience network that synchronises perceptual data into functional moments (Craig, 2009a): 2) the second timescale between 200 – 1250 ms of the

DMN that leads to the global perception and conscious experience of duration; and 3) the third timescale up to 100 s of the central executive network's working memory processing of mental presence (Wittmann, 2011). The various components of each stage are illustrated in Figure 1.

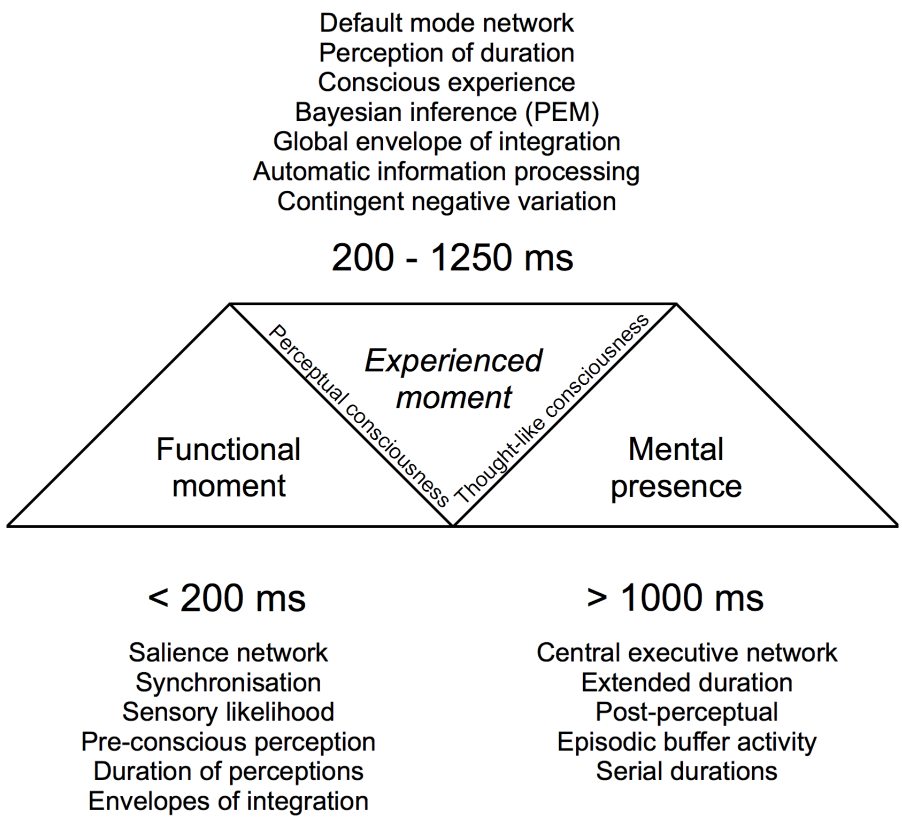

Figure 1. Schematic of three time scales of perception (functional moments), consciousness and duration perception (the experienced moment), and working memory (mental presence), their major brain networks and other corollaries.

The trajectory of informational flow within Figure 1 is then illustrated in Figure 2 and elaborated as follows: 1) multimodal exteroceptive sensory data is received from asynchronous sources; 2) the internal interoceptive, autonomic, and cardiovascular rhythms of the anterior insular (Craig, 2009a, 2009b) and cortico-striatal-thalamic oscillators (Allman & Meck, 2012) of the salience network then synchronise incoming multimodal sensory information within the first 125 – 200 ms; 3) the homeostatic and motivational salience of the incoming perceptual data for the “sentient self” is then determined by the anterior insular cortex in the form of a “global emotional moment”, here interpreted as global perceptual integration (p. 1934) (Craig, 2009a); 4) the anterior insular cortex then directs salient global perceptual information to either the DMN or central executive network depending on whether or not the information is required to perform a cognitive task (Goulden et al., 2014); 5) global perceptual information sent to the DMN undergoes automated processing of “rapidly selecting appropriate responses under predictable circumstances” (p. 12821)(Vatansever, Menon, & Stamatakis, 2017); 6) this automatic processing of learned patterns is a process of Bayesian inference that seeks to resolve incoming sensory-perceptual information (i.e., sensory likelihood distribution) with prior information (i.e., prior distribution) in order to make accurate predictions about the future with minimal error (Hohwy, 2013); 7) the process and rate of resolving sensory-perceptual information with prior experience leads to the experience of temporal flow via a Bayesian inferential mechanism called ‘distrusting the present’ (Hohwy et al., 2016); 8) the upshot of DMN Bayesian PEM is conscious perception (Hohwy, 2012); 9) on this account, consciousness is comprised of a relatively fast perceptual process (i.e., sensory likelihood) and a relatively slow thought-like process (i.e., prior distribution)(Koch et al., 2016); 9) salient information sent to the central executive network is attended to via working memory processes (i.e., episodic buffer) over intervals up to approximately 100 s (Goulden et al., 2014; Wittmann, 2011); 10) episodic memory contents are then integrated into declarative autobiographical memory and fed back into the DMN to regulate Bayesian PEM in the form of hierarchical prior distribution(s) and thought-like consciousness (Chen et al., 2013; Hohwy et al., 2016; Koch et al., 2016; Siclari et al., 2014).

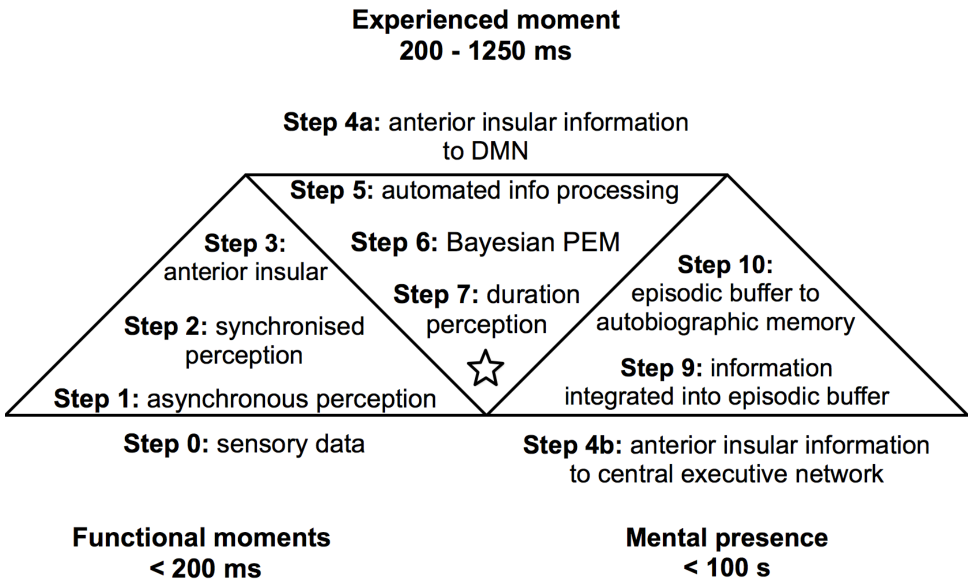

Figure 2. Informational flow through functional moments, the experienced moment and mental presence, culminating in consciousness in the experienced moment as an analogue or corollary of duration perception.

To be at all credible, the intermediate DMN conscious process must have some features that lend it to taking place within the 200 – 1250 ms range. He and Raichle (2009) proposed a link between slow cortical potentials (< 4 Hz but generally > 1 Hz) and volitional or agentic aspects of consciousness (i.e., thought-like consciousness). Northoff (2016) has more recently proposed a link between these slow cortical potentials and “inner time consciousness” and the “width of the present (p. 174). A recent study of DMN contributions to automatic information processing involved an automated card-sorting task with response latencies of approximately 1200 ms (Vatansever et al., 2017) and the contribution of DMN activity to temporal awareness was assessed using inter-stimulus intervals of 1000 ms (i.e., DMN activity is associated with off-task inter-stimulus intervals)(Grady, Springer, Hongwanishkul, McIntosh, & Winocur, 2006; Lloyd, 2012). Contingent negative variation (CNV), an electroencephalographic signal of predictive expectancy, also peaks with delay intervals of around 1 s (Loveless & Sanford, 1975). As with duration perception (Block & Zakay, 1997; Gil & Droit-Volet, 2012; Mella et al., 2011; Zakay & Block, 1995; Zakay & Block, 1996), CNV is also related to both arousal and attention processes and a critical interval window around 1 s (Tecce, 1972).

This association between expectancy, consciousness and duration is preliminary and speculative but, as Koch et al. (2016) concluded in their review of progress towards identifying the neural correlates of consciousness, “progress in this field will require, in addition to empirical work, testable theories that address in a principled manner what consciousness is and what is required of its physical substrate” (p. 317).

Duration perception research confers unique opportunities to theories of consciousness to test other aspects of experience besides the timing of object awareness. The rate of temporal flow is subjectively reportable and consistencies are found in optimal and suboptimal conditions such as: 1) high flow states during peak experiences (Nakamura & Csikszentmihalyi, 2002, 2014) or mania (Bschor et al., 2004; Mezey & Knight, 1965; Moskalewicz & Schwartz, 2018); and 2) low flow states when bored (Zakay, 2014) or depressed (Thönes & Oberfeld, 2015). Further to this, given that Bayesian PEM is a quantitative and empirically verifiable theory, there is also opportunity to test for differences in Bayesian inference as a corollary of duration perception and conscious experience. Integrated together in a single theoretical framework, Hohwy et al.’s (2016) ‘distrusting the present’ and Tononi et al.’s (2015) IIT could provide a more holistic account of thought-like and perceptual conscious experiences, respectively, that currently evade summary explanation (Siclari et al., 2014). White’s (2018) recent review of whether consciousness unfolds as a series of discrete frames is also a decisive step towards understanding both the nature of consciousness and duration perception. If discrete frames remain unsupported, as

White (2018) suspects, then duration will by definition have become a key feature of consciousness as Bergson (1913) proposed over a century ago.

One fruitful avenue of research could be duration perception associated with depression. A meta-analysis by Thönes & Oberfeld (2015) confirmed that depression tends to slow duration perception, a phenomenon called depressive time dilation. Depression has also been linked to increased task-negative activity in the anterior insular over intervals longer than the experienced moment (Wiebking et al., 2010), suggesting that boredom-like dilation of thought-like consciousness correlates with suppressed DMN activity (Chen et al., 2013; Koch et al., 2016; Siclari et al., 2014; Zakay, 2014). Contrary to this, subjective dilation of perceptual consciousness correlates with increased DMN activity (van Wassenhove, Wittmann, Craig, & Paulus, 2011) and so depression offers a way to isolate one of the two potential neurobiological mechanisms controlling the rate of duration perception. Both processes are, however, explicable under the framework of Bayesian PEM as dynamic effects of sensory likelihood and prior distributions on predictive inference and temporal flow (Hohwy et al., 2016). As Northoff (2018) recently proposed, an opportunity exists to develop a 'spatiotemporal psychopathology' and to discover the neural predispositions for time consciousness (Northoff, 2016) which, once elaborated, could draw firmer conclusions than possible in this introductory review regarding the relationship between duration perception, conscious experience, psychopathology, and the neurobiological drivers of all three.

In conclusion, it is vitally important to distinguish between duration perception and perception duration. White's (2017) review did a great service to time perception research by clearly showing that perception duration research is insufficient to explain duration perception because, as White (2017) rightly points out, consciousness contains both perceptual and post-perceptual contents. In order to understand duration perception, thought-like consciousness must be integrated into any theoretical account (Koch et al., 2016; Siclari et al., 2014). Recent advances in cognitive philosophy, such as Hohwy et al's (2016) 'distrusting the present' paradigm, offer empirical avenues to explore duration perception via testable theories of Bayesian PEM. The model proposed in the current paper is intended as a theoretical sketch of the types of steps, time scales, mechanisms and brain networks required to generate duration perception in the conscious mind. While not intended as a full fledged theoretical proposal, it is hoped that the reasoning above suffices to distinguish a clear difference between what it means to generate a perception in time as opposed to a perception of time.

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