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Review article

Systema Temporis: A time-based dimensional framework for consciousness and cognition

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A R T I C L E I N F O

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A B S T R A C T

This study uses a combined categorical-dimensional approach to depict a hierarchical framework for consciousness similar to, and contiguous with, factorial models of cognition (cf., intelligence). On the basis of the longstanding definition of time consciousness, the analysis employs a dimension of temporal extension, in the same manner that psychology has temporally organised memory (i.e., short-term, long-term, and long-lasting memories). By defining temporal extension in terms of the structure of time perception at short timescales (< 100 s), memory and time consciousness are proposed to fit along the same logarithmic dimension. This suggests that different forms of time consciousness (e.g., experience, wakefulness, and self-consciousness) are embedded within, or supported by, the ascending timescales of different modes of memory (i.e., short-term, long-term, etc.). A secondary dimension is also proposed to integrate higher-order forms of consciousness/emotion and memory/cognition. The resulting two-dimensional structure accords with existing theories of cognitive and emotional intelligence.

1. Introduction

Like cognition, consciousness has many aspects, functions, and forms. As a result, the most pressing problems in consciousness science – identifying neural correlates, discovering causal mechanisms, and establishing whether machines can become conscious – rely on clear and consistent definitions being applied throughout the literature. Historically, different *types* of consciousness have been proposed such as phenomenal consciousness (i.e., P-consciousness, the capacity to experience subjectively), access consciousness (i.e., A-consciousness, the capacity to report subjective experience), or self-consciousness (i.e., the capacity to reflect on subjective experience) (Block, 1995; Lenggenhager, Tadi, Metzinger, & Blanke, 2007). There are also different *contents* of consciousness (e.g., perception- and thought-like contents) and, as subsets of these content types, there are specific *qualia* such as feelings, mental states, imaginings, and other conscious perceptions (Balduzzi & Tononi, 2009; Edelman, 2003). All these and other forms or manifestations of consciousness abound in the literature and need to be appraised systematically within their own qualitative, taxonomic frameworks.

There is also debate about the existence or non-existence of graded *levels* of consciousness ranging from comatose-to-vegetative state, minimally conscious state, and on through various stages of sleep and wakefulness (Bayne, Hohwy, & Owen, 2016a, 2016b; Fazekas & Overgaard, 2016; Laureys, Owen, & Schiff, 2004). This debate appears to hinge on whether consciousness is a simplistic uni- or bi-dimensional construct, or a multifaceted, multidimensional construct. An example of a uni- or bi-dimensional theory is

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Integrated Information Theory (IIT) which proposes that the level or degree to which something is conscious depends upon the amount integrated information (cf. Φ or phi) contained within either a local state or the global state of the organism (Tononi, 2004, 2015; Tononi, Boly, Massimini, & Koch, 2016). Local perceptual contents with higher Φ are 'more conscious' than those with lower Φ, and global systems with higher global Φ are 'more conscious' than those with lower Φ.

However, and even though IIT refers to both global levels and local contents (Balduzzi & Tononi, 2009), it is unclear whether a one- or two-dimensional account of consciousness is sufficient. On the basis of a multidimensional framework of global states, which distinguishes between content-related and functional dimensions, Bayne et al. (2016a) questioned whether global states can indeed be ordered according to levels of Φ. Instead, Bayne and Hohwy (2016) argued that a multidimensional space is better described by categorical *modes* of consciousness which, in addition to more classical depictions (Laureys, 2005), includes atypical states such as stupor, epileptic seizure, dementia, and delirium.

In order to find a middle ground, perhaps a combined dimensional-categorical approach is required to describe both quantitative (i.e., dimensional) and qualitative (i.e., categorical) distinctions between aspects of consciousness. The many facets of cognition can be categorised according to the various functions of attention, memory, computation, problem-solving, and comprehension, but cognition as a whole can also be quantified in terms of the information processing required and the degree to which a person or system is deemed to be 'intelligent' (Carroll, 2003). The key to understanding both categorical and dimensional accounts simultaneously is to integrate the various functions within a systematic and hierarchical framework, something cognitive science has modeled, tested, and refined over many decades (Gardner, 1999; Horn & Cattell, 1966; Terman & Merrill, 1960; Wechsler, 2008). The current paper starts from the premise that consciousness science could perform the same conceptual integration and systematisation. In fact, in describing a hierarchical structure that overlaps with cognitive intelligence, this preliminary dimensional-categorical analysis proposes that consciousness and cognition are conceptually contiguous.

To be clear, the aim is not to simply categorise or taxonomise the plethora of conscious states, levels, contents, qualia, modes, and so on within each category. As above, each of these requires their own domain-specific taxonomy. Instead, the goal is to arrive at an integrated and systematic description of the many *categories* of consciousness within a *dimensional* framework. To this end, a quantitative aspect of consciousness is required that supplies a basic, unitary, and un-qualified (as in without other qualities of state, content, etc.) dimension.

According to Uher (2016, 2018), a transdisciplinary approach to taxonomic models of any psychical phenomena is constrained by three *meta*-theoretical and methodological factors: (1) non-spatiality or non-physicality (i.e., psychical phenomena have no spatial extension); (2) fundamental imperceptibility (i.e., psychical phenomena are not perceptible by others); and (3) variable temporal extension (i.e., psychical phenomena are observable over a range of durations, some long and some short). Temporal extension is therefore the only one of these three *meta*-theoretical factors able to serve as a metric for a dimensional account of a psychical phenomenon like consciousness (J. Uher, personal communication, March 6, 2019). Fortunately, time has long been a central theme of consciousness science and psychology (Andersen & Grush, 2009).

2. Time perception and time consciousness

Although not without its detractors (Blackmore, 2002), *stream of consciousness* is a term originally coined by James (1890) to describe the temporal flow of experience without regard to either its form or content. Conscious temporal flow was an early conceptualisation of consciousness based on the notion of a *specious present* coined by Clay (1882), popularised by James (1890), and elaborated by Husserl (1928) to a theory of inner *time consciousness* (Andersen & Grush, 2009). Time consciousness is the unfolding of subjective experience from one present moment to the next and so represents a basic, unitary, and un-qualified dimension that can be quantified in empirically supportable ways. The present paper will therefore use time as the quantifier for a systematic, dimensional framework of consciousness.

Time-based frameworks are not at all new to psychology. The transduction of physical stimuli to sensory impulses and then on into memory is conceptualised along a temporal dimension from sensory input to short-term memory (STM) or working memory (WM) over seconds to hours (cf., STM and WM are used interchangeably), long-term memory (LTM) over hours to months, and long-lasting memory (LLM) over months to a lifetime (McGaugh, 2000). Contemporary memory theory is based on many decades of research and represents a solid foundation for consensual scientific discussion about distinct memory processes, contents, modules, neural correlates, and a host of related phenomena. Consciousness research should strive for the same level of understanding and agreement, and a time-based approach is a logical starting point to establish a similarly systematic framework.

One form of time consciousness has a particularly distinct and well-researched timescale of operation. Although again not without its detractors (White, 2017), time perception research over the past several decades suggests that conscious experience takes place over a canonical duration of approximately 1–3 s (Montemayor & Wittmann, 2014; Pöppel, 1989, 1997, 2009; Wittmann, 2011). In isolation, though, one instance of time consciousness cannot define a comprehensive temporal dimension of consciousness because, to put it bluntly, consciousness lasts longer than a few seconds. Additional instances and conceptualisations are required to yield a broad timescale that represents, not only consciousness at one time, but consciousness over extended periods of time.

Fortunately, this fundamental duration of the specious present, sometimes called the *subjective present* (Pöppel, 1989, 1997) or *experienced moment* (Montemayor & Wittmann, 2014; Wittmann, 2011), is flanked by two other canonical durations (one longer and shorter) related to (non-conscious) sensation and memory processes. Rapid *functional moments* synchronise multimodal sensory data up to approximately 125–200 ms post-reception, whereas *mental presence* retains sensory data in WM over longer timescales up to approximately 30–100 s (Wackermann, 2007).

It is important at this stage to emphasise that the temporal structure of time consciousness is integrated *within* the temporal

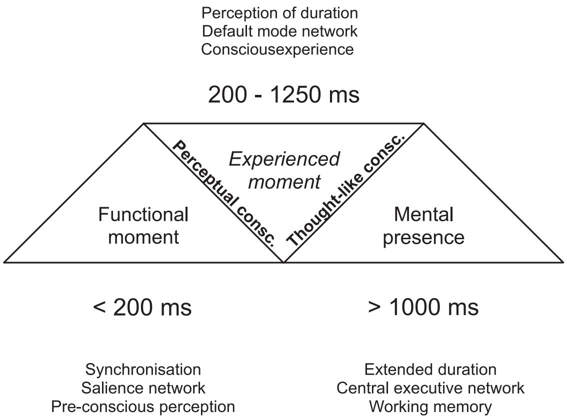

Fig. 1. A model proposed by Kent (2019) of the experienced moment as a top-down process spanning approximately 1000 ms and supported by bottom-up perceptual and working memory processes culminating in perceptual and thought-like consciousness.

structure of memory, not parallel or separate to it. It is not simply a matter of the relationship *between* consciousness and memory, or *between* memory and its conscious contents. It is a model of consciousness integrated *within* McGaugh (2000) temporal delineations of memory. Consciousness exists at the intersection of immediate multisensory impressions and STM/WM *because* it has an integral function stitching those contents together into a seamless, continuous stream (Dainton, 2002). Without this stitching, there could be no temporal order, no temporal extension, and no duration to our conscious experience (Montemayor & Wittmann, 2014). The integrated temporal structure of *both* consciousness and cognition (memory) presented simultaneously, as it were, is a critical feature of the framework because it conveys the notion that consciousness is a (strongly) emergent feature of underlying cognitive processes (Chalmers, 2006). According to this view of strong emergence, consciousness is entirely dependent upon cognition but also separable from it. The framework outlined below shows this graphically and conceptually in terms of an interleaving temporal structure of conscious and non-conscious mental processes.

As per Fig. 1, a model of time perception proposed by Kent (2019) contrasts time consciousness against pre-conscious sensorimotor and post-conscious WM processes according to timescale. The Kent (2019) model incorporates the activity of three major brain networks: (1) the salience network comprising key anterior insular and anterior cingulate cortical nodes related to arousal; (2) the default mode network comprising key cortical midline structures related to temporal awareness; and (3) the central executive with key dorsolateral prefrontal and posterior parietal cortices related to WM processes (Menon, 2011).

As above, rapid functional moments synchronise multimodal sensory data up to approximately 200 ms post-reception. The salience network is responsible for high-order integration of sensory information and either: (1) passes perceptual information directly into the default mode network for integration into conscious experience; or (2) bypasses consciousness and passes the information on to the central executive network for integration into WM (Goulden et al., 2014). The default mode network integrates both perceptual and thought-like consciousness within a typical timescale of around 1 s duration. WM operates over a duration of approximately 1–100 s; what Wittmann (2011) referred to as mental presence.

In order to create a temporal dimension underpinning these three stages of time perception, their typical range of activity can be cast into approximate timeframes: (1) functional moments span approximately three orders of magnitude between 10^{-3} and 10^{-1} s; (2) the experienced moment is situated at approximately 10^{0} s; and (3) mental presence spans approximately three orders of magnitude between 10^{0} and 10^{2} s. This establishes a simple logarithmic pattern whereby conscious experience, spanning a single order of magnitude, is underpinned by two memory processes that each span three orders of magnitude.

3. Memory and extended time consciousness

Across different domains, consciousness is not always viewed as unitary construct with a single definition. Its parsimonious identification with phenomenal experience (i.e., phenomenal consciousness) is perhaps the dominant definition in consciousness science. However, even within this one field there are alternative definitions (e.g., access consciousness and self consciousness) and, in other fields of science, consciousness can refer more basically to whether an organism is awake or asleep, or whether individuals have a persistent and stable self-concept (e.g., disorders of consciousness) (Block, 1995, 2007; Kihlstrom, 2005).

This variety in definition can lead to confusion for what it means to be conscious. For example, an organism that termed ‘conscious’ when awake and ‘unconscious’ when asleep. But being awake does not mean they are having phenomenal experience – they could be sleepwalking or they could be a zombie (Chalmers, 1996). Similarly, being asleep does not mean they are not having phenomenal experience – they could be dreaming. While the ‘hard problem’ and phenomenal experience are undoubtedly central or even fundamental to any definition of consciousness, this double dissociation between wakefulness and phenomenal experience implies that there is room to further define aspects or types of consciousness as emergent from different forms of memory and cognition. Such distinctions may also facilitate extant debates regarding whether, or to what extent machines can be conscious (Carter et al., 2018). Perhaps machines can be conscious in that they are awake and alert (i.e., turned on as opposed to off) but, like a

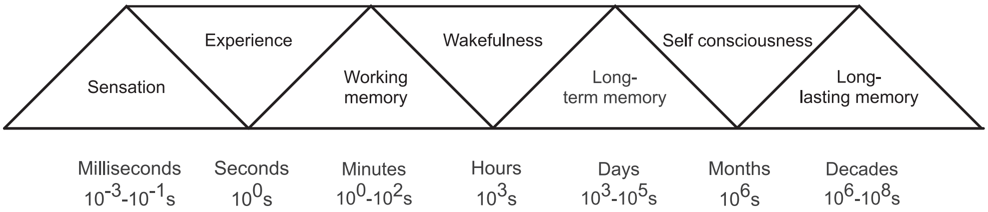

Fig. 2. Timescales of consciousness and memory on a logarithmic scale (s). Note: timescale labels are indicative only.

sleepwalker, this does not entail that they have a subjective phenomenal experience.

In terms of time consciousness, it is possible that these alternative forms of consciousness could be distinct on the basis of their temporal structure. This temporal structure may also simply extend the logarithmic pattern depicted in Fig. 1. To cast McGaugh (2000) memory modes into logarithmic timescales, as shown in Fig. 2, WM (10^0–10^2 s), LTM (10^3–10^5 s), and LLM (10^6–10^8 s) also span approximately three orders of magnitude each. According to the pattern established above, this implies two further types of consciousness in addition to conscious experience (10^0 s) situated at approximately 10^3 s (i.e., hours) and 10^6 s (i.e., months).

Circadian *wakefulness* is a definition of consciousness that typically unfolds over the course of hours from a state of unconscious sleep, through diurnal (or nocturnal) conscious activity, and back again to sleep (Chalmers, 1996). As a higher-order form of time consciousness in Fig. 2, WM is the 'fast' memory process supporting wakefulness and LTM is the 'slow' memory process. This means there are no perception-like contents associated with this form of consciousness, only thought-like and recollected content drawn from memory stores. There is empirical evidence to support this concept of consciousness being situated at the intersection of STM/WM and LTM. It has been shown that sleep is critical to the consolidation of STM into LTM (Stickgold, 2005). As such, and although categorically distinct from conscious experience at the timescale of seconds, wakefulness can be defined as a concept of time consciousness of longer duration than experience according to the repeating logarithmic pattern established in Fig. 1.

Self-consciousness is also defined by this pattern as a concept of time consciousness supported by LTM and LLM over the typical range of months. Just as wakefulness is an enduring experience over the hours of the daily circadian cycle, self-consciousness is proposed as the prolonged experience/representation of self that endures over successive days, weeks, and months (i.e., one month equals approximately 2.6×10^6 s). Self-consciousness is a longstanding concept in consciousness science distinct from other forms of P-consciousness and A-consciousness (Block, 1995). In the classification of mental disorders, clinical theorists such as Kihlstrom (2005) also view the dissociative disorders, such as Dissociative Identity Disorder (DID) characterised by two or more personality states (American Psychiatric Association, 2013), as disorders of consciousness:

> The basis for this proposal is that the dissociative disorders are fundamentally disorders of consciousness, not of memory or identity. Patients with dissociative disorder are not consciously aware of personal experiences and other aspects of self-knowledge that nonetheless remain available in memory, and implicitly influence their ongoing experience, thought, and action…"dissociative" [is] a purely descriptive label referring to the divisions in consciousness, and dissociations between explicit and implicit memory and perception, that are at the heart of both the dissociative and conversion disorders. (p. 242)

Although a controversial and rare disorder (Elzinga, van Dyck, & Spinhoven, 1998; Gillig, 2009), 'divisions in consciousness' in DID is here interpreted to mean divisions in self-consciousness. Similarly, amnesia can be defined as disordered self-related time consciousness. In detailing the case of an amnesic patient (N.N.), Tulving (1985) observed that:

> N.N. clearly is conscious and he clearly has a good deal of preserved memory capability. At the same time, his consciousness and memory are severely impaired…[H]e seems to have no capability of experiencing subjective time…His case tells us that amnesia can be characterised as a derangement of consciousness and not just a derangement of memory for past events. (pp. 4–5)

This was not viewed as an isolated case but rather a tendency of prospectively amnesic patients (i.e., prospective implies temporal flow from present-to-future) to live in a permanent present that lacks both a past and a future. Whereas healthy people are capable of a type of mental time travel, N.N. and those with similar amnesic disorders completely lack *autonoetic consciousness* based on episodic memory (Tulving, 1985). Long-term time consciousness is therefore something that has more than conceptual implications. There are practical, clinical ramifications of disordered self-consciousness that profoundly affect people's lives as severely as if they were phenomenally blind (i.e., lacking conscious visual perceptual experience) or in a coma (i.e., lacking conscious wakefulness).

There is also reason to believe that the timeframe of weeks or months is important for the classification of other psychopathological conditions. Many, if not most, psychiatric diagnoses are based on symptoms that endure over timeframes that range between one week (e.g., mania), two weeks (e.g., depression), one month (e.g., schizophrenia active symptoms), and six months (e.g., generalised anxiety and schizophrenia) (American Psychiatric Association, 2013; WHO, 1992). In terms of altered states of consciousness, an episode of dissociative fugue rarely lasts for longer than a few weeks or months (American Psychiatric Association, 2013; WHO, 1992), Also, a diagnosis of extremely severe Post Traumatic Amnesia (PTA), the highest classification as measured by the Westmead PTA Scale, is warranted by LTM disruption for more than four weeks (Carroll, Cassidy, Holm, Kraus, & Coronado, 2004; Marshman, Jakabek, Hennessy, Quirk, & Guazzo, 2013).

Regarding treatment, and although their clinical effectiveness has been questioned (Kirsch et al., 2008), it has been noted that Selective Serotonin Reuptake Inhibitor (SSRI) antidepressant medication has an immediate positive effect on attention, appraisal, and memory, but that it takes several weeks "for this positive bias in implicit emotional processing to become apparent at a subjective, conscious level" (Harmer & Cowen, 2013, p. 1). One month is also sufficient to establish a time-series analysis on mood in bipolar disorder in order to judge treatment effectiveness (Holmes et al., 2016). One month may therefore be a critical timescale for determining a stable and functioning self-consciousness or, in the case of many psychiatric disorders, a disturbance in the most extended flow of individual time consciousness.

4. Phenomenal, access, and self-consciousness

The preceding analysis suggests that, along with the three recognised forms of memory consolidation after sensory input, there may be three major forms of time consciousness – experience (i.e., stream of consciousness), wakefulness (i.e., an enduring stream of consciousness), and self-consciousness. It is possible that these are analogous to previously proposed forms of consciousness. Phenomenal experience is a parallel of Block (1995) phenomenal consciousness (P-consciousness) that includes perception-like (cf., "…experiential properties of sensations, feelings, and perceptions", p.230) and thought-like contents (cf., "…but I would also include thoughts, desires, and emotions", p.230). Block (1995) also identified access consciousness (A-consciousness) with contents that have been processed by WM functions of the executive network:

> A perceptual state is access-conscious, roughly speaking, if its content - what is represented by the perceptual state - is processed via that information processing function, that is, if its content gets to the Executive System, whereby it can be used to control reasoning and behaviour. (p. 229)

This suggests that wakefulness on the timescale of hours may be an analogue of A-consciousness on the basis that, according to Kent (2019) model, multisensory salience network activity is fed into WM via the executive network. Block (1995) distinguishes P-consciousness of both phenomenal (perception-like) *and* representational (thought-like) content from A-consciousness of *only* representational content. A-consciousness is, therefore, not directly perceived. Instead, it reflects states of *consciousness of* representational constructs, much as Wittmann (2011) mental presence "encloses a sequence of such moments for the representation of a unified experience of presence" (p. 5). Representational thought-like contents therefore appear in both P-consciousness and A-consciousness, suggesting that a further LTM-based content of consciousness complements WM-based thoughts or representations in A-consciousness. These LTM-based contents would also be shared with the next and longer form of time consciousness.

Block (1995) argued that self-consciousness is a distinct form of consciousness in addition to A-consciousness and P-consciousness. Self-conscious contents would, by extension of the Kent (2019) model above and as illustrated in Fig. 3, be drawn from Autobiographical LTM (ALTM) given that this is the repository of representational knowledge regarding personally experienced past events (Williams et al., 2007). If LTM serves as the fast memory process for self-consciousness in the range of months, then ALTM events will feature heavily in the representational content. A-consciousness will also feature ALTM contents given that the episodic buffer of WM draws on episodic LTM (Baddeley, 2000). P-consciousness is therefore a composite of perception- and thought-like contents, A-consciousness is a composite of WM thought-like and ALTM contents, and self-consciousness is a composite of ALTM content and, presumably, other sources of representational knowledge that were not necessarily personally experienced.

Identity, self-esteem, and self-categorisation are concepts related to self-consciousness that depend on external social and cultural factors that arise and extend beyond an individual's autobiographical experiences (Tajfel & Turner, 1979). Perhaps, given its dimensional and abstract nature, time consciousness will permit definitions of collective consciousness that extend beyond the decades of an individual lifetime to consider shared beliefs, attitudes and experiences that comprise a society over time (Durkheim, 1926, 2014), perhaps via interpersonal processes like transactive memory (Wegner, 1987). This is a separate discussion to the current aim of categorising or 'dimensionalising' aspects of time consciousness as they relate to memories that are inherently intra-individual, not inter-individual.

The next step is to use this taxonomic dimension as a means of reintegrating the phenomena depicted in Fig. 3 according to a systematic hierarchy. In psychometrics, a common way of conceptualising hierarchy is through statistical models such as factor analysis and structural equation modelling, especially in personality and intelligence research (Carroll, 2003; Digman, 1990, 1997; McCrae, 1987; Terman & Merrill, 1960; Wechsler, 2008). Beginning with cognitive intelligence, the factorial structure of intelligence as it relates to memory will be used to reintegrate various concepts of higher-order cognition.

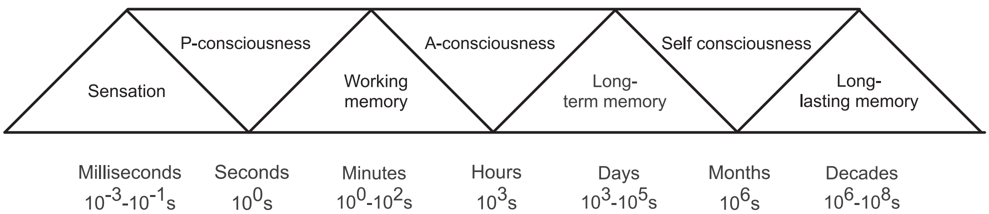

Fig. 3. Ascending log timescales of Block (1995) P-consciousness, A-consciousness, and self-consciousness and their respective memory components (above the line). *Note:* timescale labels are indicative only.

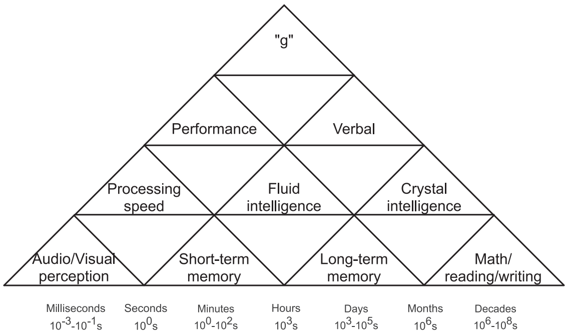

Fig. 4. Composite model of the Cattell-Horn-Carroll and the WAIS performance and verbal IQ measures within the hierarchical framework of time consciousness (cognitive constructs only, conscious constructs excluded).

5. Cognitive intelligence

Intelligence can be viewed as either a singular or factorial trait (Carroll, 2003). Early hierarchical theories of cognitive intelligence placed the singular *g*-factor of intelligence above subordinate factors such as fluid and crystal intelligence (Cattell, 1963). Although not assessed here in terms of timescale, alternative factorial models propose different configurations such as eight separate types of intelligence (Gardner, 1999) or three types of giftedness (Sternberg, 1985). However, the single *g*-factor model of cognitive intelligence, known as the Cattell-Horn-Carroll theory, has arguably the most longstanding and robust factor-analytical evidence supporting it (Carroll, 2003; Cattell, 1963; Horn & Cattell, 1966). It is also the basis for most prominent intelligence tests: the Wechsler Adult Intelligence Scale (WAIS) (Wechsler, 2008), and the Stanford-Binet Intelligence Scales (Fifth Edition, SB5, 2003) (Terman & Merrill, 1960).

The Cattell-Horn-Carroll theory posits three hierarchical levels (i.e., narrow, broad, and general abilities), a single intelligence factor (i.e., *g*), and eight broad abilities (acquired knowledge, fluid reasoning, quantitative knowledge, reading/writing ability, STM, LTM, audio/visual processing, and general processing speed). As shown in Fig. 4, it is proposed that four of the broad factors of the Cattell-Horn-Carroll model equate to the first four categories of perception and memory in Fig. 2: (1) sensation equates to *audio/visual processing*; (2) STM and WM are equivalent; (3) LTM is directly matched; and (4) LLM is a composite of *reading*, *writing* and quantitative (*arithmetical*) knowledge.

Within these groupings there is, again, an inherent timescale. Auditory and visual perception take place over the shortest timescales of milliseconds, whereas the learning and recall of reading, writing, and arithmetical abilities requires access to information stored in LLM that has been acquired over years and decades (McGaugh, 2000). Although automatic and seemingly instantaneous, declarative and non-declarative LTM are both critical to performance of complicated cognitive tasks such as reading, writing, and arithmetic (Squire, 2004).

Processing speed, *fluid reasoning*, and *acquired knowledge* are also arranged according to their temporality (i.e., processing speed at shortest timescales and acquired knowledge at longest timescales), but are depicted as higher-order factors than the previous four. This reflects both early trends in intelligence research giving initial priority to fluid and crystal intelligences, here termed fluid reasoning and acquired knowledge, as higher-order factors of intelligence (Cattell, 1963; Horn & Cattell, 1966). More recent findings also highlight the key dependency of fluid intelligence on processing speed, a relationship mediated by WM (Fry & Hale, 1996). Therefore, in terms of the time-based framework: (a) processing speed integrates sensory and WM abilities in seconds; (b) fluid reasoning integrates WM and LTM abilities over hours; and (c) acquired knowledge integrates LTM and LLM over months. All these abilities are interdependent but separable in terms of the timescale to which they typically apply.

Measures of *performance* IQ and *verbal* IQ from the WAIS (Wechsler, 2008) are then shown a further step up the framework hierarchy as composites of the taxa below. Performance IQ integrates perceptual organisation (i.e., audio-visual perception) and processing speed, whereas verbal IQ integrates WM (or STM) and comprehension abilities (i.e., from acquired knowledge) (Wechsler, 2008). Again, the key difference is temporal. Performance IQ represents relatively fast processing and perceptual abilities, whereas verbal IQ represents relatively slow memory processing from longer-term stores in the form of language comprehension.

The *g*-factor then sits another step up the hierarchy as a combination of performance IQ and verbal IQ. General IQ integrates timescales ranging from millisecond sensations up to LLM over the decades-long human lifetime. Individual cognition is therefore viewed to comprise four overlapping timescales of sensation/memory that are integrated over four hierarchical levels into a singular *g*-factor.

6. Emotional intelligence and the empathy quotient

In addition to these factors of cognitive intelligence, Fig. 4 also appears able to accommodate complementary constructs relating to emotional intelligence (EI) as measured by an empathy quotient (EQ). Emotion and consciousness are closely related concepts, with feelings akin to the conscious experience of emotional states such as perceptual cues (i.e., bodily responses) or thought-like stimuli (i.e., memories) (Tsuchiya & Adolphs, 2007). EI is therefore more closely aligned to self-referential, "hot" information

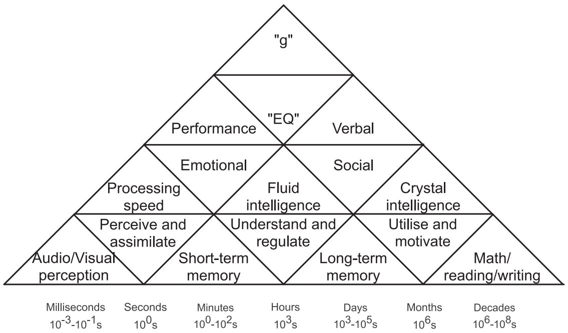

Fig. 5. Theoretical constructs of emotional (EQ) and general intelligence (*g*) embedded within the hierarchical model of time consciousness.

processing of conscious states as opposed to underlying, "cold" information processing of cognitive states (Mayer, Caruso, & Salovey, 1999).

As depicted in the base level in Fig. 5, four 'branches' of EI proposed by Mayer et al. (1999) fit within the first two consciousness constructs (i.e., experience and wakefulness) and smaller timescales, because the authors characterised the lower-order branches (i.e., *expressing and assimilating*) as more "molecular" and the higher-order branches (i.e., *understanding and regulating*) as more "molar". This characterisation implies that the latter is an aggregation of the former, interpreted here as an aggregation over time.

Salovey and Mayer (1990) also proposed a third type of emotional intelligence, namely *utilising and motivating*, which individuals use to plan and motivate behaviour in the longer-term. These three facets of EI (i.e., expressing and assimilating, understanding and regulating, and utilising and motivating) therefore demonstrate an underlying timescale: (a) expression and assimilation as immediate forms of EI associated with the seconds range of direct P-conscious experience(; b) understanding and regulation of emotion and mood in the hours range of daily A-conscious wakefulness; and (c) utilisation and motivation of emotion to reflect upon and plan behaviour that is consistent with an individual's self-consciousness over the coming or preceding weeks and months (Mayer et al., 1999; Salovey & Mayer, 1990). Content analysis of academic and non-academics use of the terms 'emotion' and 'mood' demonstrates a general consensus that emotions are short-term experiences whereas moods are longer-term, adding credence to a temporal ordering of EI constructs (Beedie, Terry, & Lane, 2005)

These conceptualisations are supported by direct experimental data. Firstly, factor analyses conducted by Schutte et al. (1998) concluded in favour of these three facets of EI – expression, regulation, and utilisation. Secondly, the factorial structure of empathy or EQ is similar to that of EI. Exploratory and confirmatory principal components analyses of EQ measures found three underlying factors – emotional reactivity, (cognitive) empathy, and social skills (Allison, Baron-Cohen, Wheelwright, Stone, & Muncer, 2011; Lawrence, Shaw, Baker, Baron-Cohen, & David, 2004). Fig. 5 aligns emotional reactivity with P-conscious experience as both include perception-like content in the form of feeling-states associated with the salience network (Craig, 2009a, 2009b). Empathy is the ability of an individual to understand that others have thoughts just as "I do" (i.e., theory of mind), and so this blend of thought-like and autobiographical content is aligned with A-conscious wakefulness (Baron-Cohen & Wheelwright, 2004; Baron-Cohen, Leslie, & Frith, 1985). Social skills are aligned with self-consciousness due to the common theme of self- (i.e., ALTM) and presumably other-derived knowledge content, as above. Although not depicted in Fig. 5, these factors are also broadly consistent with theoretical EI constructs of assimilation (i.e., reactivity), understanding (i.e., empathy), and utilisation (i.e., social skill), respectively (Mayer et al., 1999; Salovey & Mayer, 1990). Thirdly, and although limited evidence was available until more recently (Andrew, Cooke, & Muncer, 2008; Petrides & Furnham, 2000), factor analyses have since shown that EQ can be conceptualised unidimensionally (Allison et al., 2011). Overall, these data show that the time-based dimensional account of EI and EQ are supported by a factorial model that culminates in a singular factor similar to *g* for cognitive IQ.

The second, intermediate level of EI distinguishes between shorter and longer forms of EI that are either immediately felt or more considered over time. EQ theoretically comprises two components that fit these descriptions: 1) reactive, affective or *emotional* EQ related to the ability to perceive and regulate emotional responses expressed by others and one's self; and 2) reflective, cognitive or *social* EQ related to mindreading, theory of mind, and the ability to imagine or understand the thoughts and feelings of others (Baron-Cohen & Wheelwright, 2004; Carver, Johnson, & Joormann, 2009; Gyurak, Gross, & Etkin, 2011). These are similar constructs to the combined model of *emotional* and *social* intelligence conceptualised as distinct from cognitive intelligence (Bar-On, 2006). Viewed as an integral part of subjective wellbeing (Bar-On, 2010), emotional and social intelligence relate to neural systems implicated in consciousness: (1) global emotional processing within the salience network (i.e., amygdala and insular cortices) and self-referential evaluation of directly-accessed, spontaneously-recalled ALTM within the default mode network (i.e., medial prefrontal cortex) (Addis, Knapp, Roberts, & Schacter, 2012; Akirav & Maroun, 2006; Bar-On, Tranel, Denburg, & Bechara, 2003); and (2) the generative, effortful retrieval of generic ALTM (i.e., lateral prefrontal and temporal cortices) (Addis et al., 2012).

These intermediate forms of EI/EQ are reflected in the dual-track model of emotion regulation that contrasts: (1) implicit or automatic emotion regulation centred on activity in the anterior cingulate cortex and medial prefrontal cortex; and (2) explicit or effortful emotion regulation centred on activity in the ventrolateral and dorsolateral prefrontal cortex (Gyurak et al., 2011). A related dual-process model of the serotonergic system has been framed in explicitly temporal terms: A lower-order system that responds quickly (i.e., in an emotionally responsive manner) versus a higher-order system that responds more reflectively and planfully (i.e., in a socially responsible manner) (Carver et al., 2009). Given that SSRIs are an effective treatment for depressive mood disorders, and mood regulation is proposed to take place at an intermediate timescale of hours, the placement of emotional (i.e., automatic, reactive) and social (i.e., effortful, reflective) EI/EQ is generally supported by these dual-track and dual-process theories of emotion regulation. Both are key parts of EI in that an individual needs to be able to express their feelings in the moment, while also being able to think about the consequences of those feelings over time.

Fig. 5 shows that, as with cognitive intelligence (*g*), a singular EI/EQ construct sits atop a multi-level hierarchy of emotional and social intelligences which are also horizontally spread across a related multi-level dimension of time consciousness. Cognitive and emotional intelligence both scale up from small-scale audio-visual sensation and emotional experience to the largest scales applicable to individual human cognition and consciousness (i.e., self-consciousness and LLM). Successively higher-order facets and factors span four tiers of the hierarchy from base-level memory and experience, through intermediate forms, and culminate in singular concepts – EQ and *g*. If this combined hierarchical-dimensional account of time consciousness is plausible, the consequences for previous perspectives on the dimensionality or categorical nature of consciousness must be addressed.

7. Discussion

Dimensionality is a longstanding issue in consciousness science and philosophy. In arguing against Block (1995) categories of P-consciousness and A-consciousness, Dennett (1995) proposed that Block was simply reiterating "*quantitative* headings *richness of content* and *degree of influence*", respectively (p. 252, italics in original). It could be argued that the same, or at least similar, quantitative dimensions are presented in Fig. 5 above. Richness of content could apply to the degree to which perceptual experiences are P-conscious experiences as a result of information processing, cf. IIT Φ (Tononi, 2015). This is contrasted with the degree to which A-conscious contents influence more effortful cognitive tasks during wakefulness, cf. a Global Neuronal Workspace (Dehaene & Naccache, 2001; Dehaene, Kerszberg, & Changeux, 1998). A minimal interpretation of the preceding analysis suggests that the incorporation of time consciousness adds little, if anything, new to the dimensional approach.

However, the addition of self-consciousness along a dimension of time-consciousness in Fig. 3, above, does provide scope to extend more conventional and simplistic distinctions between perception- and thought-like contents and dimensions. The fact that the framework is hierarchical also introduces three higher-order forms of consciousness that may help to explain the complexity associated with disorders of consciousness. In reference to IIT's (Oizumi, Albantakis, & Tononi, 2014) attempt to address the "classic distinction between *level* and *content* of consciousness" (p. 14, italics in original), philosophers also debate whether local and global states of consciousness are adequately described by just two traditional dimensions or a more flexible multidimensional approach is required (Bayne et al., 2016a, 2016b; Fazekas & Overgaard, 2016). In addition to a single dimension related to the gating of conscious contents, Bayne et al. (2016a) proposed that mutliplte functional dimensions are required to describe how these contents are made available for cognitive and behavioural control:

> The lesson to be drawn from the foregoing is that although the notion of a conscious level serves a useful heuristic function insofar as it draws attention to certain relations between global conscious states, it should not be treated as a legitimate theoretical construct in the science of consciousness. Attempts to model global states of consciousness in one-dimensional terms are no more plausible than attempts to model (say) intelligence in one-dimensional terms.

They argued that, instead of placing global states along a single continuum, multiple dissociable dysfunctions are evident during disordered global states of consciousness such as coma, minimally conscious state, vegetative state, deep sleep, and REM sleep. Subsequent research has shown that their approach to distinguishing between high- and low-level effects was effective for categorising patients with different disorders of consciousness (Sergent et al., 2017). Fig. 5, above, suggests that a "family" of high- and low-level functional dimensions used to describe these disorders may be inherent within a hierarchical framework of time consciousness that includes forms such as self-consciousness, the processing of lower-order emotional and higher-order social information, and a general measure of EQ. Each of these categories of time consciousness can be measured as a dimension in their own right and so, while there is an overarching temporal dimension *between* categories, there are also subordinate dimensions *within* each category. As per Section 1, a hierarchical framework allows for a simultaneous categorical-dimensional approach comprising lower-order facets and higher-order factors.

As well as being able to characterise disorders of consciousness, the time-based framework can also explain modes or global states of consciousness, such as dreaming (i.e., conscious experience without wakefulness). As above, sleep is associated with the consolidation of STM into LTM (Stickgold, 2005). Dreams may assist this process given that as much as half of experimentally recorded dream contents reference waking events of the previous day (Botman & Crovitz, 1990). Dreams typically contain distinct audio-visual perceptual contents and coherent episodic features (WM) that create some loose form of narrative, but the autobiographical origins (i.e., autobiographical LTM) of these contents are typically distorted (Nielsen & Stenstrom, 2005). Vivid dream events are retained in LTM in the same way as waking events (Botman & Crovitz, 1990) but, given that rates of dream recall vary widely, the consolidation process must be somewhat attenuated (Schredl, 2007). These findings suggest that dreaming experiences receive 'upstream' information from the salience network to create multisensory perceptions in the milliseconds range, and 'downstream' information from the central executive to create episodic WM narrative in the multiple seconds range. However, this information is not readily or steadily passed further 'upstream' for consolidation into LTM and so wakeful consciousness is not possible.

In addition to characterising global states, and with the addition of self-consciousness and other high-order forms of time consciousness, it may also be possible to properly characterise dissociative, amnesic and other psychological disorders by the functional impairment of consciousness and/or cognition associated with each condition. Dissociative identity disorder (DID), derealisation/

depersonalisation, and dissociative amnesia are all related to traumatic experiences, typically in childhood (i.e., LLM), but all three have differential effects on self-consciousness, memory, and perceptual experience (American Psychiatric Association, 2019). Concerning Tulving (1985) reported amnesic case N.N., described above, the framework depicted in Fig. 5 suggests there may be as many as six hierarchically-organised forms of time consciousness, all of which are presumed to have some functional impact. Tulving (1985) observed that various injuries and impairments lead to complicated presentations such as that evidenced by N.N. (e.g., "his consciousness and memory are severely impaired, and impaired highly selectively", p.4), and that he seemed to be "living in a "permanent present" (p. 5).

Psychiatric disorders may also be classified according to the differential effects of time consciousness. For example, psychosis necessarily distorts immediate perception-like (i.e., hallucinations) or thought-like (i.e., delusions) contents of conscious experience, but effects on mood (i.e., emotion regulation) can be either present or absent (cf., schizoaffective disorder versus schizophrenia) (American Psychiatric Association, 2013). In contrast, mood disorders like depression necessarily entail dysregulated emotion, but effects on perception (e.g., psychotic versus major depression), wakefulness (i.e., symptomatic insomnia or hypersomnia), or self-conceptualisation (e.g., symptomatic feelings of worthlessness or excessive guilt) can be either present or absent (American Psychiatric Association, 2013). For each condition it may be possible to profile these differential effects and, if the results are sufficiently explanatory, a systematic time-based framework for the classification of mental disorders could be established as an alternative to the more *ad hoc* symptom-based approach currently used.

A central limitation of the current approach to time consciousness concerns the fundamental definition of time as indistinct from space, both in physical (Einstein, 1920; Misner, Thorne, & Wheeler, 1973) and psychological (Buzsáki & Tingley, 2018; Müsseler, 1999; Saj, Fuhrman, Vuilleumier, & Boroditsky, 2014; Vicario et al., 2008) domains. While these theories and studies leave little doubt that spatiotemporal variables are inextricably linked both physically and perceptually, the issue of spacetime unity has been suppressed for the sake of clarity.

A critical conceptual issue pertains to whether the framework incorporates the temporal structure of consciousness or just the cognitive bases of selective attention. Attention is generally conceived as either endogenous (i.e., driven by to-down cognitive processes) and exogneous (i.e., driven by bottom-up perceptual processes) (Koch & Tsuchiya, 2007). These processes are approximated by bottom-up multisensory activity of the salience network and the top-down attentional control of the central executive network (Baddeley, 2012; Craig, 2009b). As hypothesised above, cognition associated with the salience and central executive networks is distinct from default mode activity responsible for the conscious experience of time (Kent, 2019; Lloyd, 2012). Importantly, this distinction also applies to temporal structure given the dissociation between functional moments of the salience network, mental presence of the central executive network, and experienced moment associated with the default mode network (Kent, 2019; Montemayor & Wittmann, 2014; Wittmann, 2011). They are also dissociated in Bayesian terms related to the sensory likelihood (salience), prior (central executive), and posterior (default mode) distributions and their relation to time perception, attention, and consciousness (Hohwy, 2012; Kent, Van Doorn, & Klein, 2019; Kent, Van Doorn, Hohwy, & Klein, 2019).

In terms of future research in this area, an overall methodology to test the time-based system could come from Bayesian approaches to time consciousness such as Hohwy, Paton, and Palmer's (2016) 'distrusting the present'. Hierarchical Bayesian perceptual inference requires the weighting and integration of sensory (i.e., likelihood distribution) and memory (i.e., prior distribution) information to decide upon the most likely perceptual observation (i.e., posterior distribution). While experimental modelling shows promise in terms of emotion regulation in depression (Kent, Van Doorn, Hohwy, et al., 2019), the 'distrusting the present' framework has only been tested in reference to temporal flow within the brief timescales of conscious experience (i.e., 1 s). However, the Bayesian approach could be generalised to contrast the relative weighting and integration of LTM and LLM, for example, to test the temporal flow of self-consciousness over much longer timeframes (i.e., days, weeks, and months).

As much as Figs. 3, 4, and 5 are designed to serve as conceptual illustrations of hierarchical time consciousness, the quantitative relationships between the resulting variables of cognition and consciousness are also intended to be innately testable through rigorous experimentation. The temporal associations between factors of cognitive and emotional intelligence could be investigated, along with the relationship between differential effects of intelligence on time perception, temporal flow, and Bayesian perceptual inference. The preceding analysis is a sketch of the framework as best understood in light of current, incidental empirical evidence. No doubt that sketch would become much clearer in the light of data specifically targeting the logic and structure of hierarchical time consciousness.

One final matter is the temporal extent of framework and whether there is scope to further incorporate other constructs in psychology related to individual difference, personality, cognitive development, social psychology, and so on. At present, Fig. 5 only covers timescales applicable to individual lifetimes and, as such, cognitive and emotional intelligence that are also only applicable to the individual. In order to consider wider factors from social, cultural, and evolutionary perspectives, it is first necessary to extend the temporal dimension up through further sections of the logarithmic scale. This task is beyond the scope of the current paper but will be addressed in a forthcoming paper by present authors (Kent, Van Doorn, & Klein, in preparation).

8. Conclusions

Categorising forms of cognition and consciousness according to time offers a way to visualise: (1) the consolidation and cognitive manipulation of immediate multisensory input up through progressively, temporally-extended modes of memory; and (2) forms of time consciousness ranging through immediate phenomenal experience, extended wakefulness, and self-consciousness. As established by Kent (2019) and modeled on Wittmann (2011) hierarchical modes of time perception (i.e., functional, experienced, and mental time), a logarithmic pattern evident at the lowest scales of immediate time perception is extended up to the scales of decades-long

LLM. The re-integration of this temporal dimension creates a hierarchical framework of cognition and consciousness modeled on the factor structures attributed to cognitive and emotional intelligence.

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Appendix A. Supplementary material

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