



The neural basis of event-time introspection

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ABSTRACT

We explored the neural mechanisms allowing humans to report the subjective onset times of conscious events. Magnetoencephalographic recordings of neural oscillations were obtained while human subjects introspected the timing of sensory, intentional, and motor events during a forced choice task. Brain activity was reconstructed with high spatio-temporal resolution. Event-time introspection was associated with specific neural activity at the time of subjective event onset which was spatially distinct from activity induced by the event itself. Different brain regions were selectively recruited for introspection of different event types, e.g., the bilateral angular gyrus for introspection of intention. Our results suggest that event-time introspection engages specific neural networks to assess the contents of consciousness. Subjective event times should therefore be interpreted as the result of complex interactions between introspection and experience networks, rather than as direct reproduction of the individual's conscious state or as a mere post hoc interpretation.

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1. Introduction

In the seminal study of Libet, Gleason, Wright, and Pearl (1983), healthy human participants had to make introspective judgments about the onset times of their movement decisions while their brain activity was recorded with electroencephalography. The finding that a brain potential related to action preparation starts several hundred milliseconds before the participants introspectively decide to move has had major impact on discussions about the significance of consciousness and free will (Banks & Pockett, 2007; Haggard, 2008). Yet, even though the results were reproduced and extended by independent groups (Haggard & Eimer, 1999; Trevena & Miller, 2002), as well as with fMRI measurements (Soon, Brass, Heinze, & Haynes, 2008), and with single neuron recordings (Fried, Mukamel, & Kreiman, 2011), their implications remain a matter of debate, in particular because it is unknown how we introspect and whether introspective reports are accurate (Banks & Pockett, 2007; Danquah, Farrell, & O'Boyle, 2008; Klein, 2002). Participants in these studies were typically asked to watch a rapidly rotating clock hand, to memorize its position each time they "felt the urge to move", and to report it after the actual physical movement, and this has been commonly referred to as the *Libet-paradigm*. The Libet-paradigm presumably is associated with numerous concurring cognitive processes, including, among others, movement planning and execution (Ball et al., 1999; Deiber, Ibanez, Sadato, & Hallett, 1996; Deiber et al., 1991; Gerloff et al., 1998; Guggisberg, Dalal, Findlay, & Nagarajan, 2007; Thaler, Chen, Nixon, Stern, & Passingham, 1995), visual processing (Jastorff & Orban, 2009), working

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memory (Bledowski, Rahm, & Rowe, 2009; Muller & Knight, 2006; Smith & Jonides, 1998), assessment of time and simultaneity (Battelli, Pascual-Leone, & Cavanagh, 2007; Grondin, 2010), and introspection.

The term *introspection*¹ is generally defined as intermittent re-representation of the contents of consciousness and is separated from a non-introspective form of consciousness responsible for the primary processing of events (Marcel, 2003; Overgaard, Koivisto, Sorensen, Vangkilde, & Revonsuo, 2006; Overgaard & Sorensen, 2004; Schooler, 2002), also referred to as *primary consciousness* in this article. In the Libet-paradigm, consciously making a decision or a movement are examples of primary consciousness, whereas re-representing these decisions or movements are instances of introspection.²

In this paper, we focus on this specific cognitive process crucial in the Libet-paradigm, i.e., the introspection of the timing of conscious events such as movement intentions. We hypothesize that participants have to re-represent primarily conscious events in order to determine their onset time. We call this process *event-time introspection*. The process of event-time introspection will determine how we have conscious access to, and how we can report, subjective event times, and valuable insights can be gained by examining its neural mechanisms.

Several opposing theoretical models of introspection in general have been proposed, which might also apply to event-time introspection in particular. While we can by far not provide a complete overview, we will outline the main features of three influential groups of hypotheses which make experimentally testable predictions.

- (i) According to one model first proposed by Brentano (1874), the introspective awareness, e.g., that I have now the urge to move, arises automatically as a “secondary object” from the primary consciousness of my intention without requiring additional cognition.
- (ii) In an alternative model, notably proposed by the phenomenologist tradition (Gallagher & Zahavi, 2010; Husserl, 1984) but also in newer work (Jack & Shallice, 2001; Marcel, 2003; Overgaard & Sorensen, 2004; Overgaard et al., 2006; Schooler, 2002), introspection involves a specific conscious act in addition to the conscious processing of the event itself, in that it additionally requires re-representing and attending to the contents of primary consciousness.
- (iii) A third model denies that humans have introspective access to their intentions and instead suggests that subjective reports result from an interpretation of perceptual recollections (Carruthers, 2010; Lyons, 1986).³

Results from previous studies provide some evidence for model (iii). The subjective time of intention reported by human subjects can be manipulated with a short focal TMS pulse that transiently disturbs neural processing, even if this pulse is applied up to 200 ms *after* execution of the corresponding movement (Lau, Rogers, & Passingham, 2007). Moreover, if a deceptive auditory signal is presented 5–60 ms *after* the action to signify the movement time later than it actually occurred, subjects also introspectively report the intention onset to occur later in time (Banks & Isham, 2009; Rigoni, Brass, & Sartori, 2010). The speed of the clock used in the Libet-paradigm also influences the reported event onset times (Danquah, Farrell, & O’Boyle, 2008). These findings show that introspective reports depend, at least in part, on post-action neural and perceptual processing. However, the question remains what happens at the moment of intention processing and of the subjective intention onset, i.e., whether humans have introspective access to their intentions.

The above three models of introspection make differing predictions with regards to the neural processes that underlie event-time introspection. Hence, we can empirically test each of them by measuring the neural activations induced by the Libet-paradigm with functional imaging. Under model (i), the neural activation induced by Libet-type introspection should be identical to the activation related to the primary conscious processing of intentions. Under model (ii), introspection of intention onset times should be associated with distinct measurable neural activity responsible for the introspective assessment, which should co-occur in addition to, but roughly at the same time as, the activity related to intention itself. Under model (iii), the subjective assessment of intention onset times should induce neural activity related to interpretation of perceptual data in addition to activity related to intention. This additional activity should peak at times when relevant perceptual information becomes available, e.g., at the time of or after the corresponding movement.⁴

The neural mechanisms observed during event-time introspection have profound consequences on interpretations of subjective event-time reports. Only in the absence of introspection-related activity, i.e., in model (i), can we consider introspective reports as the direct reproduction of conscious intention times. Alternatively, in model (ii), introspective reports would have to be interpreted as the result of complex interactions between intention and introspection processes, whereby the introspection process can additionally influence subjective event times (Marcel, 2003; Schooler, 2002). In case of model (iii), subjective event times would be essentially blind to the conscious processing of intention.

¹ Our usage of the term *introspection* is synonymous to *meta-consciousness* as defined by Schooler (2002).

² The term *introspection* is used in the context of the Libet-paradigm because of the reflexive character of the task which requires the re-representation of primarily conscious events. Note however, that that event-time introspection does not necessarily require an inward-direction of attention. For instance, when the participants judge the onset time of their perception of external events, they may direct their attention towards the external event rather than towards their internal experience of it. While there are important conceptual differences between inward and outward oriented attention (and probably differences in the corresponding neural processing, see Overgaard et al., 2006), they both require a re-representation of the primary conscious event. Hence, both world- and self-focused re-representation can be introspective in this sense (Marcel, 2003). Event-time introspection also does not involve a narrative description of more qualitative aspects of experience. It therefore differs from the forms of introspection used in the phenomenologist and meditation tradition, which are more clearly inward-directed towards qualitative aspects of experience.

³ Carruthers (2010) allows introspective access to perceptual events, but denies it for intention.

⁴ The possibility of activity related to inner speech will be considered in Section 4.

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