**INTERDISCIPLINARY PERSPECTIVES ON LOCATING
REPRESENTATIONS IN BRAIN**

Weighing in on decisions in the brain: neural representations of pre-awareness practical intention

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Abstract

Neuroscientists have located brain activity that prepares or encodes action plans before agents are aware of intending to act. On the basis of these findings and broader agency research, activity in these regions has been proposed as the neural realizers of practical intention. My aim in this paper is to evaluate the case for taking these neural states to be neural representations of intention. I draw on work in philosophy of action on the role and nature of practical intentions to construct a framework of the functional profile of intentions fit for empirical investigation. With this framework, I turn to the broader empirical neuroscience literature on agency to assess these proposed neural representations of intention. I argue that while these neural states in some respects satisfy the functions of intention in planning agency prospective of action, their fit with the role of intention in action execution is not well supported. I close by offering a sketch of which experimental task features could aid in the search for the neural realizer of intention in action.

If my old-fashioned datebook, covered in chaotic scribbles of events to attend and deadlines to not miss, is revealing of anything about me, it is that I have (foolishly, perhaps) planned to do many things in the future. I intend to attend that philosophy conference next week. I intend to go to the beach with the kids tomorrow. I intend to run today at 3 pm, and so on. I am planning to do these activities in the future. These plans are the result of practical decisions I've made—practical in the sense that they concern what to do as opposed to what is the case (e.g., I decide that it is sunny today). Further, when the time comes, when it is 3 pm today, I will—I hope—have

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an intention just then to go outside now and start my run. That intention to run just then will, if all goes well, motivate and drive me to physically move my body past the comfy couch and out into the summer heat, where I'll move about intentionally for a few miles. Despite the familiarity of all this, it is not transparent to me as the agent where or what my intention to run just then is neurally speaking. Now we are beyond personal-level states—in the realm of sensorimotor and executive functioning processes in the brain, subpersonal processes that govern those overt bodily movements like running and walking and grasping door handles. What would it take to infer that some aspect of this neural system is the neural representation of an intention to act?

Neuroscientists have located brain activity that prepares or encodes action plans before agents are aware of intending to act. On the basis of these findings and broader agency research, activity in these regions has been proposed as the neural realizers of practical intention. My aim in this article is to evaluate the case for taking these neural states to be neural representations of intention. In section one, I outline one such candidate neural realizer of intention, activity in the supplementary motor area (SMA) and pre-SMA. In sections two and three, I draw on work in philosophy of action on the role and nature of practical intentions to construct a framework of the functional profile of intentions fit for empirical investigation. Finally, with this framework, in section four, I turn to the broader empirical neuroscience literature on agency to assess these proposed neural representations of intention. I argue that while these neural states in some respects satisfy the functions of intention in planning agency prospective of action, their fit with the role of intention in action execution is not well supported. I close by offering a sketch of which experimental task features could aid in the search for the neural realizer of intention in action.

1 Candidate neural realizers of practical intention

One natural place to start when looking for practical intentions in the brain is the neural underpinnings of intentional action. Intentional actions are a kind of goal-directed activity over which the agent has some control—for example, my running, my typing this sentence, etc. An analysis of intentional action is beyond the scope of this article, but philosophers of agency characterize intentional actions as those actions that are appropriately connected to our beliefs, desires, reasons, and/or intentions.[1] In particular, as we've noted, from an agential perspective intentions—especially intentions I am aware of having—seem often to be a precursor to and a cause of my intentional movement. First I decide to take that first step of my run now, and then my body prepares to move *because* I intend to so move. Or so it seems.

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[1] Non-human animals engage in goal-directed behaviors in some sense, but here the focus is a subset of goal-directed behaviors, human intentional actions. For a good overview of the analysis of intentional action, see Mele (2009b).

Neuroscience of agency has made much progress in investigating the neural mechanisms underpinning intentional action, especially endogenously generated ones. Endogenously generated actions are action for which the cue for acting does not come from an external stimuli or from the experimenter but rather from within the participant, much like my taking that first step of the run. The bulk of this empirical work, however, has focused on simple overt movements. For example, the agent, the participant, pushes a button when or how they desire to do so. Given the presumed self-initiated nature of such actions, brain regions implicated in the production of endogenously generated actions in the lab have been prime candidates for the neural realizers of intention.

The roots of the contemporary neuroscience of endogenously generated actions go back to electroencephalogram (EEG) studies in the 1960's conducted by Kornhuber and Deecke (1965). They found that when participants make endogenously generated movements there is detectable bilateral, symmetric precentral and parietal cortical activity up to approximately, on average, 800 ms prior to movement.[2] Averaging over trials and multiple participants, this detectable early slow increasing negative brain activity over the SMA and pre-SMA pre-movement becomes a ramp-up pattern termed the bereitschaftspotential or readiness potential (RP). The RP was taken to be a proxy indicator of preparation to move (Deecke et al. 1976). Further, event-related potential (ERP) activity, such as the lateralized readiness potential (LRP), is evidenced to precede self-paced movement: When an agent makes a unilateral movement (e.g., left movement or right movement), the LRP represents the difference in electrical potential to the left and right of the vertex prior to that movement. LRPs are generated from the motor cortex (Eimer 1998; Miller and Hackley 1992).

But intentional actions are actions which seem to be driven by our intentions to act. So Libet and his fellow researchers asked when participants become aware of their intention to move[3] in relation to the onset of the RP. Their aim was to test that commonsense picture of agency. As Libet later puts the question: "When does the conscious wish or intention (to perform the act) appear?" (2011, p. 2). Libet reasoned that if intentions to move cause or initiate action preparation, then they ought to occur prior to or at the very beginning of preparation to move. Like earlier work on simple endogenously generated movement, participants in the Libet paradigm were asked to make a self-paced wrist or finger movement in each trial when they felt the urge or decided to do so. Participants watched a sped-up analog clock on a computer screen, one that made a revolution every 2.56 s, while both EEG and electromyography (EMG) measurements were recorded. The beginning of each trial was signaled by a beep. After each self-paced movement, recorded by EMG, participants indicated the position of the clock when they first became aware of their

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[2] Earlier studies show that frontal areas evidence positive activity during the timeframe prior to movement when negative potentials, and the readiness potential, is measurable in parietal and precentral areas (Deecke et al. 1976).

[3] Libet et al. (1983) understood this reported mental item more broadly to be the participants' urge, desire, or intention to move.

intention to move. This is called W-time. Libet and his colleagues replicated earlier findings that RP onset occurs prior to movement—about 550 ms prior—in trials in which the participant acts spontaneously, i.e., without pre-planning. Strikingly, the average W-time, reported time of first awareness of intention to move, occurs about 200 ms (206 ms) prior to movement. That is, the findings suggest that the reportable personal-level intention occurs *after* the brain starts to prepare to move.

Libet (Libet et al. 1983; Libet 1985) and others (e.g., Wegner 2002; Harris 2012; Gazzaniga 2011) infer from this result that our simple intentional actions are unconsciously initiated prior to our awareness that we intend to so act. Although Libet did not test the latency of the RP and W-time in the lab for complex actions, he took the RP to precede awareness of intention for all overt intentional movements. He argued that if a RP is detectable for all overt movements and W-time appears after the onset of the RP in his studies, then RPs occur prior to our awareness of our intentions and initiate action for all intentional actions, even complex ones (Libet 2005, p. 560).

Others have replicated and extended Libet's result that brain activity linked with preparation to move precedes reported awareness of intention to move.[4] Moreover, the methodology and conclusions of this study and related ones are the subject of continued critical discussion among philosophers, psychologists, and neuroscientists alike.[5] One factor explaining the interest and significance of the study is that, at least at first glance, the results threaten our possession of free will. The thought is that if our intentional actions are caused and/or initiated by unconscious processes, here neural ones for which we lack immediate awareness, then we the agents aren't in control and so aren't free agents after all.[6]

These proposed threats to free will are not the focus of the present paper. Rather, the target of this paper is a claim about neural representation of intention sometimes made in the service of those who press the unconscious initiation worry, that *the early RP measures the neural realizer of an intention to act*. To unpack this, recall, first, that since the first studies of the RP, neuroscientists take it that the neural activity captured by the early RP is indicative of neural preparation for a committed particular movement (e.g., Deecke et al. 1976; Libet et al. 1983). That is, the RP is taken to capture the neural system's settled status on, say, flexing or pressing the button at time t or pressing the left button (versus the right button). To say that one is settled on a course of action A is to say that one is committed to A-ing, but not irrevocably. Philosophers talk of having an attitude of settledness towards a plan of action in this way in terms of having a practical intention (Mele 1992; 2009b). The

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[4] Extensions of the Libet findings include, for instance, an fMRI study (Soon et al. 2008) and a single-cell recording study (Fried et al. 2011).

[5] For a wide-ranging review of the neuroscience of free will, see Waller (2019) and Waller and Brager (forthcoming). For a book anthology of empirical and philosophical work on the Libet paradigm, see Sinnott-Armstrong and Nadel (2011). For a book length treatment of science and free will, see Mele (2009b).

[6] My use of the terms conscious and unconscious here and throughout should be taken thinly to mean intentions of which the agent is aware or unaware of, respectively. Conscious intentions are one species of personal-level mental states. Other proposed challenges to free will from neuroscience include the dualist threat and the epiphenomenal threat (e.g., Mele 2014; Nahmias 2010; Waller forthcoming).

RP is generated from bilateral activity in the SMA and pre-SMA (Fried et al. 1991; Libet 2011). So the assumption, explicit or implicit, is that the brain activity in the SMA and pre-SMA captured by the early RP represents a practical intention to act in thus-and-so way. The brain decides, or intends, to move in thus-and-so ways or at thus-and-so time before the agent is aware of having so decided.

But can EEG methodology adequately support the localization of neural representations? One merit to locating neural representations using EEG is that the EEG recording offers good temporal resolution. And, our decisions, the formation of intentions to act now, are events that happen quickly in the lab.[7] As Mele has noted, in reaction time studies, studies in which agents move when given a go signal, participants generate the appropriate movement roughly 230 ms after the trigger stimulus (Mele 2009b; Haggard and Magno 1999). If there are intentions operative in these paradigms, they are occurring within those 230 ms. ERPs can capture events at these short-duration time scales. One limitation, however, to locating neural representations using EEG is that the technology offers poor spatial resolution. The brain activity measured by each node of the electrode cap, for instance, encompasses the activity of a large population of neurons. If locating intentions is the goal, no fine-grained localization takes place with just EEG studies.

Beyond EEG, related neuroimaging measures and interventions, such as single-cell electrode recordings, brain stimulation techniques, and functional magnetic resonance imaging (fMRI), aid in spatial resolution and establishing claims of functional localization. Multiple lines of work support that neural activity reflected by the RP are accurately localized to the SMA: For instance, patients with unilateral lesions to the SMA show more positive—lower amplitude—readiness potentials compared to neurotypical controls (Deecke et al. 1987). Readiness potentials have been recorded from subdural electrodes located in the SMA in epilepsy patients during movement tasks (Yazawa et al. 2000).

Further, versions of the Libet task paired with single-cell electrode recording (Fried et al. 2011) support the SMA and pre-SMA as a site of neural preparation to move pre-awareness. For example, using single cell recordings, Fried et al. (2011) replicated the general result that brain activity specifically in the SMA and pre-SMA precedes time of reported awareness of intention. Epilepsy patients, with electrodes implanted based on clinical need, performed a version of the Libet task. The W time across trials, like in Libet et al. (1983), was approximately 200 ms (mean of 193 ms; SD of 261 ms) prior to movement. Importantly, Fried and collaborators found via an analysis of individual trial data that neurons in the SMA, pre-SMA, and anterior cingulate—most significantly in the SMA and pre-SMA—exhibit gradual changes in firing rates (compared to baseline firing) as early as 1.5 s prior to W time. The data also support a correlation between relevant neural activity pre-awareness and

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[7] Here a practical decision should not be confused with practical deliberation. One can be uncertain about what to do and so deliberate—consider options—for hours or days. This deliberation is sometimes termed 'deciding what to do.' Here I take an act of deciding, a decision, to be the terminal event of resolving uncertainty about what to do. In this way, I follow the terminology and account of decisions in Mele (1992, 2009b). See Furstenberg (2014) for an explicit endorsement of EEG as a method for locating intentions in the brain.

W: In individual trials the activity of an assembly of 256 SMA neurons was predictive of W with 80% accuracy (700 ms) before participants were aware of their intention to press the button. Moveover, earlier work by Fried et al. (1991) demonstrates that localized stimulation of the SMA with transcranial magnetic stimulation (TMS) elicits a reportable urge to move in participants.

But do neuroscientists actually claim that the localized activity in the SMA and pre-SMA *represents intention to act*? Libet himself endorses in places stronger or weaker representational explanations for the significance of SMA and pre-SMA activity before endogenously generated movement. For example, in Libet et al. (1983), Libet and his co-authors seem to endorse that such neural activity constitutes an intention to act, stating that "…the brain evidently 'decides' to initiate, or at the least, prepare[s] to initiate the act at a time before there is any reportable subjective awareness that such a decision has taken place" (p. 740). Elsewhere it has been reported that Libet never termed the neural activity generating the early RP as an 'intention' to act.[8] However, even if that is the case, if, in line with his claims, that neural activity is proposed as encoding a settledness toward an action plan and as an initiator of action preparation, functionally that activity is playing a role of intention.

Others explicitly talk of the neural activity of the SMA and pre-SMA as (at least partially) representative of intention to move.[9] For instance, Beck and Eccles (1992) link personal-level 'mental' intentions to cellular-level events in SMA neurons. In one influential study, Lau et al. (2004) "conclude that activity in the pre-SMA reflects the *representation of intention*" (p. 1208; my emphasis). They support this claim with functional magnetic resonance imagining (fMRI) data that show that when participants in a Libet-like paradigm focus their attention on their intention and not on their movement, there is a significant increase from baseline in activation in the pre-SMA.

Desmurget and Sirigu (2009) identify a parietal-premotor network, inclusive of the SMA, that produces *intention to move* and awareness of movement. Schröder et al. (2014) offer a neurocomputational model of intention, detailing the interactions

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[8] Pacherie and Haggard (2011) note this in their discussion of Libet (p. 71).

[9] Perhaps the most explicit discussion of locating the representation of intention in the brain comes from the work of John-Dylan Haynes and colleagues, with striking titles such as "Reading Hidden Intentions in the Brain" (Haynes et al. 2007) and "The Neural Code for Intentions in the Human Brain" (Haynes 2014a, b). The neuroscientists mentioned previously investigate and discuss the neural realizers of intentions to act *prior to agent's awareness of intending* to act for endogenously generated movement. And, like those researchers, Haynes investigates endogenously generated activity. However, in contrast, Haynes is concerned specifically with the neural correlates of *conscious intentions*, or intentions that the agent is aware of having. In other words, Haynes is looking for the neural realizer of our personal-level intentions. In this sense, he is engaged in an agency-specific version of the search for the neural correlates of consciousness (Haynes 2014a). The neural correlates of consciousness refers to mapping a set of neurons' activity to the having of a conscious mental state of some stripe (e.g., sensory states). Haynes is explicitly committed to the use of neurotechnology, in particular multivariate pattern analysis of fMRI signals, as a means to infer the encoding or representation of individual mental states (Haynes et al. 2007; see especially Haynes 2014a, p. 157; Haynes 2014b, p. 173). For reasons of scope and space, unfortunately, I will not be addressing this proposal for the neural representation of intention in this present paper. Instead I focus on the candidate neural realizers of intention pre-awareness. Later in this article I return to his proposal of the prefrontal cortex (PFC) as the site of prospective conscious intentions.

and activity over a network of brain regions, including the sensory areas, PFC, basal ganglia, amygdala, anterior cingulate cortex, and SMA—as a distributed, multimodal representation of intention. On this model, the SMA is the "output structure" in which "different patterns of neural firing represent the different actions the model can take" (p. 859). I return to the distributed nature of this model of intention in discussion in section four.

More pointedly, Frith and Haggard (2018) in a review of the Libet paradigm and related agency studies suggest that

> The different components of agency—the intention and its outcome—can be linked with specific brain regions. The pre-supplementary motor area (pre-SMA) is concerned with the *representation of the intention to make a specific movement*, while inferior parietal cortex is concerned with a predictive internal model of the upcoming movement. (pp. 405–406; my emphasis)[10]

Most explicitly of all, Furstenberg (2014) takes a positive view of the neural activity measured by the RP and LRP as indicative of the neural representation of subpersonal intentions to act now. Furstenberg argues that EEG studies give us good evidence for the neural representation of intention, arguing

> a fundamental way to identify non-executed and non-conscious proximal intentions is through brain activity (for instance, electrical activity recorded with EEG)…a specific EEG signal is shown to be a neural correlate of a non-executed, non-conscious proximal intention (p. 13).

Furstenberg draws on studies in which participants are asked to rapidly push either a left or right button. In some of the trials, the participants can freely choose which to push but, critically, in other trials the participant is subliminally exposed to a left or right prime. In incongruent trials, trials in which the participant's button press, say left, is in conflict with the primed direction, say right, the LRP profile initially reflects preliminary activity associated with a right button press, albeit in the absence of a right button press. Furstenberg argues that "this LRP signal *represents a proximal intention to move in the direction indicated* by the prime" (2014, p. 16; my emphasis).

Activity in the SMA and pre-SMA thus has been implicated, and explicitly proposed, in function to serve as the neural realizer of practical intention pre-awareness. In the next section I say more about what it would mean to take seriously that the activity in these brain regions—or in any brain regions—could serve as neural representations of intention.[11]

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[10] In opposition, Desmurget and Sirigu (2012) support that the intention to move, or 'want' as they term it, is generated by activity in the inferior parietal cortex, whereas the SMA provides the 'urge' to move, which appears to be more indicative of timing of the movement.

[11] For an empirically-based argument that intentions cannot be localized in the brain, see Schurger and Uithol (2015). Schurger and Uithol (2015) argue that given the neural and indeed broader physiological distribution of interdependent action-related states, "the origins of actions cannot be confined unambiguously in space and time" (p. 764). I will not take up a detailed response to that argument here, but note that the SMA and pre-SMA are among the sites that make up this distributed action-related activity.

2 Neural representation and its commitments

Talk of neural representation is bound up with one's ontological and epistemic commitments: What is the status of intentional states? Do or can our best neuroscientific practices 'get at' the underlying reality of the states and mechanisms operative in our exercise of cognitive competencies?

I will assume that there exist some physical vehicles that, approximately speaking, play the functional role of the intentional mental state intention in planning and action production.[12] Here we can make a distinction between pinpointing the locus of practical intention to this physical structure, say brain region, versus the more arduous task of identifying the neural signature, in terms of patterns of activation, however localized, that represents the agent's having a practical intention to act. Here I acknowledge that any given brain region or sets of regions can be implicated in a variety of neural processes via distinct neural networks in which that region participates. Below I say more about how despite epistemic content indeterminism, we can narrow the candidates for the neural signature of practical intention.

Further, I will grant a realist view of neural representation. More broadly, that is, I will take it that the localized sets of neural activity being studied are candidates to be the physical vehicles of representation and to be content-bearing. Here I am rejecting the eliminativist and the instrumentalist project whereby the theoretical positing of neural representations cuts no ontological ice.[13] The candidate representational neural states, activity such as electrical potential of a localized population of neurons or firing rates of single neurons, are realized in brain structures.[14] Those representational neural states, moreover, are operated over during causal physical processes that are respecting of their content. That content is fixed by the kinds of information the neural system is exploiting in the service of the task or activity of the organism at hand. These neural states are content-bearing independent of our explanatory goals (e.g., independent of neuroscientific explanations of intentional action in the laboratory and outside the laboratory).[15] Many of the indices of such

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[12] As such, what I say about locating intentions is at odds with an eliminative materialist stance (e.g., Churchland 1981; Stich 1983), at least regarding *some* theoretical entities of folk psychology. Moreover, the attempt to locate intentions in the brain is a stronger realist position on intentions as intentional states than the intentional stance proposed by Dennett (1981, 1991): the real patterns underscoring ascriptions of intentions to systems or agents in the former approach are localized, however, complexly, in neural structures.

[13] For eliminativist accounts, see Chemero (2011); Stich (1983). For a neural representation fictionalist view, see Sprevak (2013). See Ramsey (2007) for a discussion of representation in cognitive science.

[14] For a proposal that synapses and not neurons are the functional units for carrying information in the brain, see Cao (2014).

[15] That is, on my view, representational content is not merely an intentional gloss. I acknowledge, however, that the theoretical positing of neural representations is bound up with the activities of neuroscientists as a community of epistemic agents. Here I take a view in the ballpark of Bechtel's view about the ability of neuroscientists to uncover the reality of the representational states and mechanisms of the brain. The cognitive labor of neuroscientists and their explanatory goals are inextricable aspects of the theoretical positing of neural representations and mechanisms. For instance, Bechtel (2008, 2016) argues that representational contents are attributed to neural states in the service of designing experiments and interpreting results aimed at uncovering mechanistic explanations of the cognitive phenomena. Nonethe-

states—for example, the RP or voxel patterns—are the construct of the neuroscientist, and so are proxy representations. These items are the product of statistical analysis over measured activity and so are not involved themselves in the causal processes of the brain (Roskies forthcoming). However, I take it that the underlying neural activity being measured *is* a vehicle of representational content and that the index of that state, say the RP, aids in our understanding of the representational role of the underlying activity. I'll remain agnostic, though, about the appropriate psychosemantics—how neural states come to have their specific representational content or, more broadly, how the content of representational states is determined.[16]

3 Functions of intention in planning and action

Regardless of the correct account of content determination, epistemic indeterminism about content—what information this state carries or encodes—is likely to be the case to some degree in virtue of neurotechnological limitations.[17] Still, even if content is epistemically indeterministic, an appropriate suitable range of content of those neural states can be inferred given the functional role of the relevant neural activity. In this vein, I'll assess the candidacy for neural realizers of practical intention by the cognitive functions in which they are implicated and whether that role is part of the range of functions ascribed to practical intentions at a psychological or personal level. My aim in this section is to sketch a framework for mapping intentions, functionally defined, to localized neural activity in agency-related cognitive tasks.[18]

Footnote 15 (continued)

less, on his view, those states, as representational vehicles, play a representational role, operated over in neural processes. These states are not representational in the mere useful fiction, or instrumentalist sense.

[16] Hence, what I say here about the representation of intention in the brain remains open with regard to, for instance, the informational approach and teleosemantic accounts. For representative informational semantics about content determination, see Dretske (1981), Dretsky (1988) and Usher (2001), among others. For representative teleosemantic accounts, see Millikan (1984), Papineau (1987), and Nanay (2013). For recent proposals of content determination, especially those related to neural representation, see Cao (2012), Neander (2017), and Shea (2018).

[17] See, for instance, Roskies (2008) on the distance between how epistemically direct neuroimages from fMRI are assumed to be and how epistemically direct those images as indicators of brain activity actually are.

[18] Why look to the proposed functional roles of personal-level intentions as a partial determinant of content of their neural realizers? This is generally the approach taken in neuroscience in some sense. If we are to take seriously that the activation of certain brain regions serves as a neural vehicle of the representational content of intentions, we'll need to know which role of intentions, psychologically speaking, is implicated at which stage of processing for any given task that falls under the domain of volitional agency. Then we'll need to get some sense of how activation in certain neural populations is utilized and affected in the production of such tasks and how that localized activation is connected via networks to the activation of other neural populations in task performance. That is, I'll assume that the functional role of the neural activation in task competence is indicative of the content of the neural representation. The neural realizer of practical intentions should, sensibly speaking, play the same role on a neural-level that practical intentions play on the psychological level of task description.

What are the proposed functional roles of intentions as mental states? Earlier I characterized intentions, per the philosophical literature, as intentional mental states of an agent. Intentional mental states are mental states that are about, or directed at, something. What the state is about, or directed at, is its content. Intentional states have propositional content (Crane 2015). If I believe that it will rain, the content of my belief is *that it will rain*. If I desire that it will rain, my desire has the same content as my belief. What individuates that desire as a (token) mental state from my (token) belief in this case is its distinctive attitude (Searle 1983; Crane 2015): I may believe that it will rain without desiring that it be so. One is an attitude of assent or acceptance and the other of inclination, respectively.

Practical intentions as intentional states have action plans as their content. What marks out intention as a distinctive type of intentional state from desire or belief is its characteristic attitude: Intentions are states indicative of the agent's attitude of settledness on some action plan (see, e.g., Mele 1992, 2009b). For instance, I might desire to eat a delicious pastry at the French cafe now. However, this desire, or inclination and motivation, to eat the pastry does not necessarily mean that I intend to eat the pastry now: I may be uncertain, deliberating about whether to eat the pastry now or, alternatively, to be more virtuous in my snack choices today. I may also desire to eat the pastry now and yet already be settled on not eating the pastry now. That is, I may simultaneously desire to eat a pastry now, yet intend to not eat the pastry.[19]

Further, intentions can be categorized by their time index. Earlier in the paper, I mentioned two kinds of practical intentions, intention to do something now versus intention to do something later. For example, my intention to run now versus my intention to go to the conference next week. This distinction is one of *proximal* versus *distal* intentions, respectively.[20] Both proximal and distal intentions have as their characteristic content action plans and both indicate an attitude of settledness toward those plans. The difference, then, is the timeframe in which one is settled on enacting those plans—roughly in the next few seconds or minutes versus some time in the more distant future. The majority of the empirical studies discussed here concern proximal intentions.

The role of intentions in the practical life of an agent can be divided into two foci—intentions qua planning agent and intentions qua the agent's bodily movements. Let's call their functions in relation to planning agents *prospective functions*. In this prospective role, intentions are integral to agent's planning agency—allowing coordination of plans and nested subplans both intrapersonally over time and in conjunction with other agents (Bratman 1987). Intentions aid in the coherence of an agent's policies and plans over timeframes ranging from milliseconds to years. They do so via their function of representing those plans as settled. I will focus on proximal intentions. For example, say I'm not sure whether I should turn into bed early or instead meet a friend for a drink now. Having considered the reasons for each

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[19] While there seems to be no rational constraint against an agent's desiring to A and desiring to not A simultaneously, intentions are subject to such rational constraints (Bratman 1987; Mele 2009a).

[20] See Mele (1992, 2009b). A similar distinction is also made by Bratman (1984; present-directed intentions versus future-directed intentions), and Pacherie (2006; P-intentions and F-intentions).

option—that I could use the rest but that I'm deserving of some social time—I come to decide on meeting the friend now. That is, I actively form an intention to meet the friend for a drink.

One role of intention formation, then, is to commit the agent to one option among many.[21] By commitment here I do not mean irrevocably but conditional on the known situation. If new relevant information were to come to light (e.g., I remember that I need to wake up at 4 am tomorrow), the agent may, reasonably, change her plans despite the standing intention formed prior. Further, in committing to this option, say A-ing at t, the agent rejects all other incompatible actional options that she had entertained, such as B-ing at t. In this way, forming an intention inhibits one from forming incompatible intentions to act otherwise (or to not act). Because of my intention to meet a friend just now, I do not intend to shut off the lights and lock up for the night just yet.

In fact, my proximal intention to meet a friend just now in part structures aspects of my psychology beyond this: I will now intend to find the house keys and put on my jacket and shoes, etc. These actions are subplans of my plan to meet a friend. Moreover, my intention aids in structuring others' psychology and agency as well. My intention to meet my friend will contribute to the structure of her planning, and vice versus: That she intends to walk to the restaurant now, etc. This all follows from the settled attitude that marks out intention as a distinctive kind of mental state. Further, the rich ways in which intentions contribute to planning agency, of the agent herself and of those agents with whom she coordinates, demonstrate the significance of intentions in constituting the narrative self of agents over time (Bratman 1987). Intentions are ownership states that reveal something about who I am and my active influence. Insofar as I am a planning agent, I am active in shaping my agency.

Intention is a state of settledness toward a particular action plan. So a further prospective function of intentions is to represent that action plan. This representational content of intentions can be more or less fine-grained and represent different aspects, or parameters, of plans, such as the type of action to be performed (e.g., meet a friend), when and where it is to be performed (e.g., at the restaurant at 8 pm), and how one is to perform it (e.g., walk to the restaurant). That intentions represent various parameters of plans is captured, for instance, in the psychological literature on goal versus implementation intentions (Gollwitzer 1999), in the neuroscience literature as the what-when-how approach to intentional action (Brass and Haggard 2008), and in the philosophy literature with Fridland's (2019) general versus practical intentions, among other places.[22]

Note that intentions can play all of these roles in planning agency *prior to the agent's so acting*. Indeed, depending on the friend you are to meet, you might need

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[21] Mele (1992, 2009b) gives an account of intentions were some intentions can be non-actively acquired. He gives the example of opening one's office door. Although Al's proximal intention to open his office door plays a role in his so opening the door, he needn't have decided to open the office door. For mundane actions like this, the agent typically isn't unsettled about what to do. Hence, the agent need not form an intention though the act of deciding.

[22] Gollwitzer (1999)'s work concerns distal intentions, intentions to do something later, whereas Brass and Haggard (2008)'s account primarily applies to proximal intentions.

to schedule the meet-up well in advance of an hour's time. Some folks like to plan out their days months in advance. But intentions don't just structure how we will act; some formed intentions also have an active hand in bringing it about that we successfully act as planned. Here I qualify this function in action as restricted to some token intentions that fulfill prospective functions, as some agents' 'best' intentions for the future are never executed in action. Think of the annual intentions people form each New Year's to go the gym frequently in the coming year. Yet, the fact that intentions qua the prospective agent represent parameters of future action plans and further signify the agent's settledness on those action plans places intentions in a good position to fulfill various functions in action production itself. For instance, the fact that one has a standing commitment to act in thus-and-so way at this particular time or place enhances success in executing that plan when the specified conditions obtain.[23]

Indeed, in their accounts of the nature of intentions, philosophers and psychologists alike assign online causal roles to intentions in executing bodily movement. According to the causal theory of action, events, such as bodily movements, are actions insofar as they feature mental states among their causes (see, e.g., Brand 1984; Davidson 1980; Mele 1992; Searle 1983; Setiya 2007). Intentions—along with beliefs, desires, and other mental items—are often discussed to be among the candidates for causes of action. This theory is consistent with the view that mental states are realized in physical states, such as neural states, and that those physical states are among the causes of bodily movement. Here by 'cause,' it's often meant an initiating role, as was the focus of Libet's study outlined in section one.

However, importantly, for some causal theorists, the proposed role of intentions in producing bodily movements is not limited to initiating bodily movement. Problematic cases of agency abound for simple causal theories of action that restrict intention (or belief and desire) to merely the initiator of action. Consider the following case of causal deviance: A climber is scaling a mountain. Attached to the climber via rope is another person. The climber is tired and considers that if he were to loosen his grip on the rope, he could rid himself of the weight of the other climber. Imagine that he even comes to intend to rid himself of the weight in a few minutes time. But now just intending to do so so unnerves the climber that he fidgets, and, in the course of fidgeting drops the rope and so drops the other climber (Davidson 1980). Did he intentionally drop the other climber? Was his dropping the other climber an action? Or, rather, should one say that, due to the nerves and fumbling, that movement was involuntary?

Such cases of deviant causal chains suggest that actions are not just events caused by intentions, but more accurately events caused by intentions in the right way. Exactly what this right way is becomes the burden of the causal theorist of action (Mele 1992, 2009a). One oft-defended response is to argue that intentions not only initiate action but also *sustain and guide the execution of intentional actions* (e.g., Mele 2009a). That is, the intention in part controls the unfolding of the bodily

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[23] See Gollwitzer (1999) for an overview of empirical work that supports that implementation intentions do in fact enhance the likeliness of successful execution of planned actions.

movement. If the climber's intention caused the rope to drop via nervous fumbling, then the intermediate nervous fumbling was a more proximal cause of the drop and, moreover, the movement of the climber's hand to drop the rope was not controlled by any intention to do so in this-and-that particular way at this particular time. Spurred by these and other concerns, theorists such as Searle (1983), Mele (1992), and Pacherie (2006) offer accounts of intentions that cover the gamut of both these prospective and in action roles. Shepherd (2019) too delineates a theory of control for intentional action that ascribes intention a complex role in action production. In his account, intention plays a causal role in generating success in action execution (for instance, in circumstances where the agent faces interference in goal pursuit).[24]

A functional profile for the neural realizer of practical intentions emerges from this review. The neural vehicle(s) of intention should be implicated both in planning agency prospective of action and in the ongoing execution of bodily movements constitutive of action. Intentions qua planning agent should (1) indicate settledness among action plan options specified course-grained, (2) represent the action plan settled upon, and (3) relate to the personal-level agency of the actor.

Personal-level agency here is understood as those aspects of agency that are attributable to the agent as a person, in contrast to states or processes of subsystems of the agent. Here I'll follow Dennett's (1969) distinction between personal and sub-personal levels of explanation. I aim to have a wide umbrella in terms of what kinds of agency-related states and processes fall under personal level for the purposes of this inquiry. Work by Libet and colleagues suggests that some of these personal-level states can be phenomenally specified, including conscious states, sense of agency, and active (versus passive) in nature. However, especially given the focus on pre-awareness representation of intention and the role of intention in action, agency-implicated states and processes that are accessible to consciousness or that are integral to guiding agent-level behavior—states and processes that are access conscious (Block 1995)—are not excluded.[25]

Intentions qua acting agent should (4) be among the initiators of action preparation, (5) guide unfolding bodily movement, and (6) sustain unfolding bodily movement. This guiding and sustaining role is dependent upon the representational content match in terms of action outcome and the attitude of commitment that is characteristic of practical intention. Further, this guiding and sustaining role of intentions aids in success in generating action outcomes as planned, even in the face of interference. In the next section I evaluate localized neural activity in the SMA/pre-SMA as candidate representational vehicles according to this standard.

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[24] One notable exception is Fridland's (2019) argument that while practical intentions do play a role in guiding action, other control mechanisms feature more prominently in the unfolding of planned action, at least for skilled actions.

[25] I thank a reviewer for pushing me to be clearer about my characterization of personal level.

4 Assessing the fit of candidate representations

4.1 Prospective functions of intention

Multiple lines of research support that neural activity of the SMA and pre-SMA is implicated in the prospective roles of intention.[26] Recall that one of the functions of intention (1) is to commit the agent to a course of action, thereby ruling out incompatible actional options. One way to understand the attitude of commitment characteristic of intention is to say that if one is committed to an action, then one will carry out that action, unless relevant conditions change. In line with this sense of commitment, philosophers such as Mele (2009b, 2012) and Shepherd (2015) have argued that the activity in the SMA and pre-SMA, captured by the RP, instead might represent preparation for or bias toward an action plan (e.g., a left button press versus a right button press), but stop short of commitment to that action plan in the form of intention.

Here I'd like to introduce a distinct notion of the attitude of commitment that is central to practical intentions. To be committed to a course of action is to rule out incompatible actional options. To rule out competing actional options is, in part, to not act on those competing action plans. That is, to commit oneself to one action plan is, in part, to inhibit oneself from performing incompatible actions. Hence a neural representation of intention should be implicated in action inhibition. And, indeed, across both neurotypical and patient populations, the SMA and pre-SMA are linked to behavioral inhibition capacities. For instance, patients with microlesions partly localized in the SMA demonstrate impaired automatic inhibition response to masked prime action cues as compared to neurotypical participants and patients with differentially-localized lesions (Sumner et al. 2007). Independent follow-up fMRI studies of the same paradigm with healthy participants show activation in SMA modulates response in inhibition trials (Boy et al. 2010). Further, one reported patient with bilateral damage to the SMA demonstrated strong utilization behavior, a tendency to grab and use objects in one's environment in an appropriate manner but at inappropriate times (Boccardi et al. 2002).

In addition, the pre-SMA, as part of a control network along with the inferior frontal gyrus (IFG), has been implicated in action inhibition. Participants display degrading response inhibition when single TMS is applied to the pre-SMA before and during a stop-switch task (Obeso et al. 2013). Repetitive TMS (rTMS) of the right pre-SMA interferes with inhibitory control on a stop-switch task, with the effect of an increase in regional cerebral blood flow in the pre-SMA, and IFG, among other areas, as measured by positron emission topography scans (Obeso et al. 2013). Indeed, participants with problematic hyper-sexual behavior display reduced functional connectivity between the IFG and pre-SMA in a fMRI scanner in a go-no go task with sexual distractors (Seok and Sohn 2020). The importance of the pre-SMA for behavioral inhibition in the face of conflicting actional responses has been

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[26] A large experimental literature exists on the SMA and pre-SMA. Here I provide only a snapshot of studies for each proposed function of intention.

further underscored by the finding that grey matter density in pre-SMA is predictive of response inhibition for both conscious prime and masked prime tasks, as measured using structural MRI (Van Gaal et al. 2011).

Neural activity in the SMA and pre-SMA may carry out this inhibitory function in virtue of its representing the settled action plan, prospective function (2). Indeed, in inhibiting automatic movements that might otherwise be triggered by sensory stimuli, the activity of the SMA rules out action execution not matching the planned action outcome represented. Beyond the early work from Libet et al. (1983) and replications of that paradigm, related agency studies suggest activity in the SMA encodes action plans. Which parameters of action plans are encoded by the SMA? Patients with lesions to the SMA evidence impaired ability to carry out sequential motor sequences, such as sequential arm movements, sequential eye saccades, and reach-grasping motions (Dick et al. 1986; Gaymard et al. 1993; Gentilucci et al. 2000, respectively). This behavioral deficit associated with SMA damage may aid in explaining some of the behavioral markers of Parkinson's (Dick et al. 1986). In particular, this work supports that the SMA plays a role in assembling motor programs. This is suggestive of two possible interpretations: Either SMA activation triggers motor representations, an initiating role, *or* activation in the SMA itself represents the assembled motor programs. If the latter, this action plan type match encoding is likely due, in part, to the SMA's involvement in the anatomical motor circuit comprised further of the basal ganglia and thalamus (Alexander and Crutcher 1990; Hoover and Strick 1993). Other studies support that the planned time of action, not the action type, is encoded in SMA activity (multivariate pattern analysis of fMRI; Soon et al. 2008).

Importantly, though, it is not clear whether activity in the SMA encodes for motoric-specific plans or other parameters of the task. For instance, the motoric-specific content view is contested by recent findings in broadly defined Libet studies that the RP, measurable over the SMA and pre-SMA, is also implicated in preparation for non-motor tasks: When participants engage in movement tasks (e.g., cued button pushes) versus non-movement tasks (e.g., mental addition and subtraction), the analogue of the RP is present for both kinds of tasks (Alexander et al. 2015, 2016). In line with these results, RPs have been measured prior to purely mental tasks, such as imagined movement and—importantly—mental addition, in addition to its presence prior to overt bodily movements (Raś et al. 2019). The researchers characterize the role of neural activity measured by the RP as follows: "the readiness potential represents a universal process of unconscious preparatory brain activity preceding any, including mental, voluntary action" (Raś et al. 2019, p. 386). Taken together, recent studies suggest that activity in the SMA may not be movement-specific in function. Importantly, if correct, this conclusion would further undermine claims that SMA activity serves as the initiator of action preparation, role (4) in the service of action execution. But recall that it is this initiating role that grounds some articulated challenges to free will on the basis of Libet et al. (1983).

A role in *voluntary* mental activity, though, preserves a link to personal-level agency, function (3) of intention. The SMA and pre-SMA has a mixed record, however, when it comes to fitting the prospective role of connection to personal-level agency. On the one hand, several pathological conditions of agency, marked by

involuntary movements, are associated with abnormal functioning of the SMA and pre-SMA, including agents with Tourette's syndrome and chronic tics (van der Salm et al. 2012 [RPs precede tics]; Hampson et al. 2009), anarchic hand syndrome (Boccardi et al. 2002), alien limb syndrome (Wolpe et al. 2020), and Parkinson's patients (Hanoğlu et al. 2020). Further, electrical stimulation of the SMA in neurotypical agents produces a reportable urge to move (Fried et al. 1991; Lim et al. 1994). And, the amplitude of the RP has been linked to the strength of the intentional binding effect, an implicit marker of sense of agency in the lab (Moore et al. 2010; Jo et al. 2014).

If the neural activity in the SMA and pre-SMA are related to personal-level agency, though, we would expect a relationship between the RP and W-time, the reported time of first awareness of intention to move in Libet studies. Here matters become more complicated. If an agent's brain exhibits an RP prior to voluntary movement and that RP is intention-specific, then a conscious intention will result. One way to test whether RPs are related to conscious intentions is to see if there is a relationship between the time of onset, or initial ramp up, of the RP and W, the average reported time of first awareness of intention to act. However, several studies have questioned the link between RP and conscious intentions in Libet studies. An earlier experiment by Haggard and Eimer (1999) supported that the timing of the RP is not correlated with W time, but that timing of the LRP is. Recent work that has attempted to replicate Haggard and Eimer's findings is not univocal, with Jo et al. (2015) finding that the RP covaries with W time for a particular subpopulation, committed meditators,[27] but others finding no covariance of either the RP or the LRP with W (Schlegel et al. 2013; Alexander et al. 2015).

On a weaker interpretation of the link between the neural realizer of intention and personal-level agency, we might expect that the activation of the neural vehicle of intention will be accompanied by *some* experience of agency for the relevant actions. That is, in terms of RP studies, when there is a detectable RP, there ought to be an accompanying conscious intention (or some other subjective phenomenology of agency). In an intriguing test of this claim, Schlegel et al. (2015) investigated what these neural markers of agency look like when agents act under post-hypnotic suggestion. The researchers compared participants who performed a series of simple movement tasks—a cued stress ball squeeze with the left or right hand—either under hypnotic suggestion or under normal instruction. The hypnotized participants had no awareness of any intention—no conscious intention—to squeeze the ball (and were told a cover story for the "twitching" of their hands). Schlegel and collaborators found no significant differences in both RP and LRP profiles for the two conditions.

New methodology in the neuroscience of agency, though, has reestablished a connection between the RP and personal-level intentions. The original Libet paradigm asks participants to report the timing of their awareness of intention to move after completing the relevant movement. That is, the report method is retrospective.

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[27] Committed meditators, the experimental group in Jo et al. (2015), were those who had at least three years of experience practicing mindfulness meditation.

Parés-Pujolràs et al. (2019) employed an online measure of report of awareness of intention and argue that online reports of awareness of intention are tied to detectable RPs. Specifically, an analysis of the EEG data shows RP-like ramp-ups prior to the button presses that served as the participants' online report of in-progress preparation to move. Adding to the support for the RP's link to pesonal-level agency, in particular endogenously generated action, externally triggered movements fail to produce an RP (Jahanshahi et al. 1995).

There are other worrying results, though, that challenge the assumed active nature of the neural activity of the SMA and pre-SMA. For instance, Schurger et al. (2012) have proposed the Integration to Bound model of RP. This model holds that, roughly, random walk type fluctuation leads to neural activity crossing the threshold for motor response (i.e., movement). On this model RP does not reflect any true (i.e., active) cognitive preparation. The debate is ongoing as to whether the Integration to Bound model accurately deflates the active, voluntary nature of the RP. Recently, Khalighinejad et al. (2018) found that the Integration to Bound model fits the recorded EEG signature of neural activity during endogenously generated movements. However, they also demonstrated that neural noise reduction precedes self-initiated action but not externally generated action. This neural noise reduction aids in preserving an active nature to intentional actions, albeit a thin one. More recently, the evidence against the active view of the SMA/pre-SMA activity has grown, with striking new results that the initiation of endogenously generated action—but not externally generated action—in the lab is correlated with expiration in breathing rhythms and further that the RP is modulated by low-level and involuntary respiratory patterns (Park et al. 2020).[28]

4.2 Functions of intention in action

This last outlined line of evidence still implicates neural activity in the SMA and pre-SMA in one further function, the initiation of action (4). That is, even if activation in these regions is not univocally linked to personal-level, active agency, still such activation may be instrumental in initiating action preparation. Certainly, this is the crucial role that Libet et al. (1983), and others before them (Kornhuber and Deecke 1965), assign to the onset of the RP. Work on abulia further suggest this functional role of the activation of the SMA: Abulia is a condition characterized by a patient's lack of spontaneity, drive, and initiative. Abulia is associated with numerous neurological conditions, including, non-exhaustively, Parkinson's and stroke. One of the sites complexly implicated in persistent abulia is bilateral lesions to the SMA, among several affected regions. In more severe cases, termed akinetic

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[28] Recall that the impetus for looking at SMA and pre-SMA activity as a neural representation of intention came from earlier work on the RP and its role in the production of voluntary actions. Given the equivocal nature of the evidence for the RP as motoric in content or as tied to conscious and active states, what ought we to conclude about the RP as a proxy representation of prospective intention? That activity in the SMA and pre-SMA has been implicated in inhibiting competing action plans and that the RP has been found to reliably precede self-initiated tasks and self-reports of intention is still strongly suggestive of the RP measuring (at the least) a partial realizer of intention pre-action.

mutism, patients do not initiate even common diurnal behavior such as speaking or eating. In more minor cases, patients participate in the plans that others make but will not initiate plans of their own, despite still forming them (Das and Saadabadi 2020). Moreover, SMA syndrome, a condition arising from unilateral SMA resectioning, is characterized by akinesia (Potgieser et al. 2014). However, other work supports that activation in the SMA is neither sufficient for initiation of action in monkeys (Scangos and Stuphorn 2010) nor necessary for initiation in the form of RPs for intentional action in patients with psychogenetic jerks (van der Salm et al. 2012).

Of note, Fridland (2019) has recently raised doubts as to whether personal-level practical intentions initiate action, at least in the case of skilled actions.[29] She argues that the content of practical intentions sets the conditions for action initiation but that distinct initiation mechanisms initiate action when those conditions obtain and are detected (e.g., environmental cues). She gives for support the example of elite swimmers and sprinters who all share the intention to move in this precise way at the sound of the starter gun. Fridland (2019) argues, however, that

> …actually implementing that intention, that is initiating the action, can be done more or less effectively, more or less successfully, depending on the skill of the athlete. As such, because the initiation of the action and the intention to initiate the action can come apart in this way, it seems to be that the initiation of the action is not best construed as a function of intention.

Elsewhere she observes that "[n]ormally, we just begin acting at more or less the appropriate time—we don't explicitly, intentionally, initiate our action at all" (Fridland 2019).

I am not committed to the activity in the SMA and pre-SMA being the sole initiator of action. Other initiation mechanisms may indeed play a role. However, I also do not accept the assumption, operative above, that we would have to "explicitly, intentionally, initiate our action" in the sense of *intend to initiate action (A)*. There is an important difference between an intention to initiate A and an intention to A. An intention to A can initiate A-ing and further one can intentionally initiate A-ing even if one does not intend to initiate A-ing. To suggest otherwise embraces the so-termed 'Simple View': That intentionally A-ing requires intending to A (see, for example, Bratman 1987), a view not uncontroversial in action theory.

But then if we can clear the way for intentions to A to initiate A-ing, then why not allow that one intentionally initiates A-ing due to a standing intention to A in partnership with other mechanisms? The agent's detection of the conditions (e.g., starter gun) may activate the intention to A in virtue of its having those conditions among its representational content. The commitment to this action plan (e.g., commitment to diving into the pool) in these conditions (e.g., at the starter gun), which define that token intention, rules out competing actions (e.g., staying put). That intention to A in concert with other initiation mechanisms, some of which may be

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[29] I thank the reviewer who drew my attention to this important view regarding the role of practical intention in action initiation.

better trained up in certain athletes, plausibly initiate action. This is much like how I intentionally walk to the library, and I intentionally take the first step toward the library, not because I intend specifically to take the first step, but because of my governing intention to walk to the library. As such, even if the evidence doesn't support that neural activity in the SMA and pre-SMA plays this initiating role of intention, a neural realizer of practical intention otherwise located is still well suited to do so.

Earlier I noted that many causal theorists of action are not content to restrict the role of intention in action execution to an antecedent cause or initiator of action though. Intentions, as functional states, are implicated in the (5) sustaining and (6) guiding of action execution. If this is right, by extension, the neural realizers of intention should be implicated in those online roles during action. There are two plausible ways in which activation in the SMA/pre-SMA could feature in online action control.

One possibility is that the SMA and pre-SMA participate qua realizers of intention in action execution indirectly, or distally, via feedforward connections to other regions more directly involved in the ongoing execution of action. And, further, that activity in those latter neural structures play the representational role of intention during action execution post-initiation. Pacherie (2006) proposes the category of M-intentions, motor-related fine-grained representations of action plans that can be governed by P-intentions (e.g., proximal intentions). M-intentions are motor representations that are causally involved downstream in action execution and differ from P-intentions in their operative timescale and (lack of) rationality constraints. If so, then perhaps M-intentions, as distinctly neurally realized, carry out the work of sustaining and guiding unfolding bodily movement, but their doing so is triggered, or initiated, by activity in the SMA/pre-SMA.

Indeed, work on motor representations and their role in online bodily movement is comparatively well understood: for instance, work on sub-personal motor representations during object-oriented action (e.g., Jeannerod 1994) and work on computational models of physiological sensorimotor control (see, e.g., review of these models in Franklin and Wolpert 2011). Recent work in neuroscience has explicitly connected neural underpinnings of decision-making to the neural mechanisms of sensorimotor control (see, e.g., review of this effort in Gallivan et al. 2018). In particular, philosophers and neuroscientists alike have drawn on empirical work on perceptual and sensorimotor systems to delineate characterizations of these low-level pragmatic representations and motor representations that represent action goals (e.g., Ferrari et al. 2003; Rizzolatti and Craighero 2004; Nanay 2013; Pacherie 2000; Ferretti 2016 for a review of this literature).

Drawing on this research, the most promising candidates for neural realizer of intention qua sustaining and guiding action are activity in the primary motor cortex (M1) and to a lesser degree in the premotor cortex (PMC). SMA and pre-SMA project to M1 as part of the motor control circuit. The work of representing action plans at a fine-grained level during online action execution is distributed across multiple brain regions, including M1 (Shibasaki et al. 1993) and PMC (Weinrich & Wise 1982; Desmurget and Sirigu 2009), in addition to activation in the SMA. Both M1 and PMC have been identified as generating LRPs (Coles 1989; De Jong et al. 1988; Eimer 1998; Miller and Hackley 1992 for M1; van Vugt et al. 2014 for PMC). LRPs,

as proxy representations, stand for a particular action plan, specified at a fine-grain level (e.g., which hand to move), just prior to and during action execution.

Indeed, as noted above, although RPs are present prior to both motor and non-motor cognitive tasks in the lab, LRPs are only present for motor tasks, suggesting that the underlying neural activity of the LRP is motoric-specific in content but the neural activity measured by the RP is not (Alexander et al. 2015). If the SMA/pre-SMA activity underlying the RP is not motor-specific in content, then those neural states are not suitable for sustaining and guiding action execution. Further, since M1 activity underlying the LRP is motoric in nature, it is well placed, in contrast, to coordinate and oversee the complex unfolding of action. In support of this online and motoric-specific role, participants who observe their own hand movements demonstrate measurable LRPs (Touzalin-Chretien et al. 2010). Moreover, in line with M1's proposed role in motor activation, the ramp up of LRP occurs temporally after selection of a particular motor response but at the start of motor programming (Masaki et al. 2004). Direct electrical stimulation to the PMC triggers overt movements (Desmurget and Sirigu 2009).

Taken as a whole, this research suggests that more proximal representations of intention during action execution are structurally dissociable from the SMA/pre-SMA or at the least are of a more distributed nature neurally. This neuroimaging and behavioral evidence lends support, in addition to Schröder et al. (2014) simulation data, to the view that the neural representation of practical intention is distributed widely, both spatially and temporally, and of a multimodal nature during action execution. To Schröder et al's (2014) proposed sites of intention (i.e., sensory areas, PFC, basal ganglia, amygdala, anterior cingulate, and SMA), we can offer both further support for the inclusion of SMA as well as support for adding activity in the M1 and PMC. Indeed, this is consistent with work that suggests that activity in the PFC encodes conscious prospective intentions to act (see, e.g., Momennejad and Haynes 2012).[30]

Practical intentions, though, as philosophers typically discuss them, are personal-level states. How can low-level motor representations play the representational role of intention? Low-level motor representations have motoric format and are not consciously accessible. Intentions are taken to have propositional content, which is consciously accessible. This propositional content allows for involvement of intention in agent-level practical reasoning. Hence, part of the answer lies in explicating the connection between personal-level intentions and motor representations. Butterfill and Sinigaglia (2014) have posed this issue as the 'interface challenge'. The challenge is, roughly, how practical intentions and motor representations, distinct in representational format, are able to coordinate so that the action outcome specified by each systematically match in the normal case.[31] Brozzo (2017) argues that motor representations can be consciously accessible under certain conditions (e.g. motor imagery), and so subject to constraints that hold for personal-level intentions. If

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[30] I thank a reviewer for drawing my attention to these accounts of intention.

[31] See Mylopoulos and Pacherie (2017) for a competing proposed response to the interface challenge; see Levy (2017) for motor representations in relation to know-how.

motor intentions are neurally realized, at least in part by activity in the M1 for example, then in cases in which motor representations are present, activity in M1 serves as the neural representation of intention in guiding and sustaining the movements that constitute action. However, the circumstances in which motor representations are consciously accessible may be too narrowly prescribed to cover all of the cases of intentional action production at issue here. If correct, we ought to explore further whether neural activity more paradigmatically linked to personal-level states, such as pre-SMA and SMA activation, could serve the representational role of intention in action execution.

One helpful place to look in this regard is the discussion of skilled action and the online influence of personal-level states. Fridland (2017), addresses the challenge of how low-level sensorimotor execution is sensitive to personal-level states in the special case of skilled action. Some accounts of skilled action explain the execution of fine-grained bodily movements constitutive of skilled action, such as sporting skill (e.g., the major leaguer's hitting a pitched baseball), as more or less an exercise of automatic learned motor routines (Stanley and Krakauer 2013; Papineau 2013). On this view, conscious intentions and other personal-level states can be among the initiators of motor preparation, but the execution of the bodily movements that constitute skilled action are automatically dispersed once learned. Citing optimal control theory (Todorov and Jordan 2002; Liu and Todorov 2007; Todorov 2004), Fridland argues that skilled action execution is "intelligence all the way down" (2017). She poses the 'dynamic interface problem' to denote the challenge of how personal-level intentions don't just trigger motor representations for action but how intentions are also continuously in communication with motor representations during skilled action execution. Shepherd (2018) similarly argues that personal-level states and processes play a role in the guidance of constitutive bodily movements of intentional action. One helpful piece of this puzzle might be, as Shepherd (2019) suggests, that intentions do not exclusively have propositional content but also can have representational content formatted motorically.

If intention and other personal-level states do intelligently guide action execution—via connections to motor representations or more directly, then one apt test for the candidate neural representations of intention in these functional capacities would be in the context of a task that requires online flexibility subsequent to and during action execution.[32] Work on stop-switch paradigms, however, indicate a mixed message regarding whether activity in the pre-SMA plays this proposed representational role of intention during action execution. In stop-switch tasks, participants are asked to press a left or right button as quickly as possible after receiving a left or right arrow cue. In go trials of the task, participants press the button cued. In stop trials, participants start to prepare to press the button, but are instructed to veto the press (e.g., see an X over the arrow). In switch trials, participants start to prepare to press the button but are instructed to switch to a spacebar press pre-completion (e.g., via a change in color of the cue). Here the cues are conscious-level cues, not subliminal

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[32] See Waller (2012) for a proposal that a skilled action paradigm would aid in uncovering initiator of action for broadly conceived Libet tasks.

primes. One should charitably infer that regions implicated in sustaining and guiding action preparation will be operative in switching tasks based on dynamic task demands, such as environmental cues. However, TMS over the pre-SMA during the trial impairs performance on the stop task but not the switch task (Obeso et al. 2013). These results suggest that even if activity in the pre-SMA is implicated in the initial preparation to move, guidance and sustaining of the preparation is downstream of that activity. Indeed, regions such as PMC have been implicated in updating action plans pre-movement (Wise and Mauritz 1985) and during action execution (Pastor-Bernier et al. 2012). Other work is seemingly at odds with this result, though: One patient with a pre-SMA localized lesion did evidence impaired performance on a switch task but with no impairment on a stop task (Roberts and Husain 2015). The researchers discuss this contrary result with previous work as consistent with an intact SMA and further suggestive of inhibition being governed by multiple systems. If so, then the role of pre-SMA qua intention during online action in sustaining and guiding is a negative one, one of potential for action inhibition in the event that plans need to be updated.

Dynamic task demands coupled with object-oriented tasks are further suggestive of which aspects of the sensorimotor system are crucial to sustaining and guiding action. In one paradigm participants perform a reaching movement with their hand toward a target object. In some trials the target is displaced after movement onset and online correction of hand pathway is measured. This displacement can occur just following movement onset (Hinton 1984) or later in the movement execution process (Liu and Todorov 2007). This kind of task has been previously discussed in the context of whether action execution is subject to intelligent control (Fridland 2017; Shepherd 2019) but, in the context of the current concern, could helpfully inform which neural states realize intention. Note that the intentional action studies related to SMA activation canvassed in sections one and two are simple endogenously generated movements or action sequences without perturbations.

SMA activation has been implicated in reaching movements (Picard and Strick 2003). What happens if activation of the SMA is affected via TMS after movement onset in a reaching paradigm with object displacement? If task performance is impaired, then SMA may be necessary for successful ongoing execution of the fine-grained movements constitutive of action in a dynamic environment. If task performance is maintained, that the affected regions may not be necessary for successful movement execution in such conditions. One intriguing early study showed that when the SMA in monkeys was temporarily inhibited with muscimol micro infusion, the subjects failed to initiate self-paced reaching tasks during trials. However, when the researchers initiated the start of the trial, the monkeys executed the reaching tasks successfully. In contrast, inactivation of other regions, such as M1, did not impair initiation but did impair grasping (Kermadi et al. 1997). A plausible claim, then, is that, if the SMA serves any online function of intention in action, it is that of initiating action in the sense of a trigger and perhaps also in the negative capacity of inhibiting in-progress action plans given task demands. Further downstream motor representations are better candidates for online sustaining and guiding of movement execution.

5 Concluding remarks

My aim in this article was to assess proposals for representation of practical intention pre-awareness in the brain. I focused on proposals that activation in the SMA/pre-SMA, a precursor of awareness of intention to act for voluntary agency, is a key neural realizer of intention. I then constructed a framework for evaluating the fit of those localized neural states as sites of practical intentions: The neural vehicle of intention should play a role in both planning agency prospective of action and during in-progress action. Qua planning agent, intentions indicate a settled attitude toward an action plan, represent the action plan selected, and form part of the fabric of the agent's personal-level psychology. Qua intentional action execution, intentions initiate motor preparation as well as sustain and guide the bodily movements constitutive of action.

Overall, the candidate representation of intention demonstrates fit—with some qualification—with the prospective functions of intention. The SMA/pre-SMA captures the settled attitude of intention, at least with respect to the role of inhibiting other action options, as well as encodes select parameters of the selected action plan. One worry, though, is that it is still a topic of much debate as to whether the representational content of the SMA/pre-SMA activity reflects motoric-specific information and whether the mechanism governing its generation is active in nature. If neural firing of SMA/pre-SMA neurons during action execution does not encode motoric-specific content, then such neural activity is not a good candidate to be (one of) the initiators of action.

Hence, turning to the neural representation of intention in action, activity in SMA and pre-SMA has been implicated in the initiation of action, one critical role of intention in action production. However, what emerges from the broader empirical literature is that these regions are not implicated, at least directly, in the online execution of fine-grained bodily movements that constitute action. Motor representations, based in PMC and M1, are better candidates for the neural realizer of (aspects of) intention in action. But this further role of sustaining and guiding action execution is a key role attributed to practical intention in action. Finally in light of proposals that intention should play a role in the unfolding of skilled bodily movement towards a goal action, I suggested that attention to paradigms requiring flexibility and conscious monitoring during task execution might further aid in uncovering neural representations of intention in action execution.

Given these conclusions, the prospects for localizing both the prospective and in-action functions of intention in the activity of a relatively restricted set of regions, such as the SMA and pre-SMA, are not promising. To capture the full range of proposed roles of practical intention, both qua planning agency and qua acting agent, would entail embracing that practical intention is represented in a distributed fashion over the neural activities over time of functionally connected areas, from the PFC to the PMC and M1 in addition to the SMA and pre-SMA. Notice, though, that if the SMA/pre-SMA activity during Libet-like tasks is not performing functions of intention-in-action, such as initiation of action, contra certain models of the Libet paradigm, then old questions require revisiting. In

particular, this opens the door to non-bypassed conscious intentions, perhaps via activation in the PFC in free choice contexts, as playing a top-down causal role in action initiation. Further if the neural realizer of intention is distributed, the question of the format of the content of motor representations and their relation to personal-level states is now of enhanced importance. A multimodal distributed representation encoding the content of practical intention would contribute to, among other issues, the resolution of the interface problem. As such, a stronger dialogue between the neuroscience of intention for volitional action and the neuroscience of motor control would facilitate these inquiries.

Agential control is a closely linked notion to that of moral responsibility for actions and outcomes. As such, the accuracy of our conception of ourselves as self-governing and responsible agents turns on what we should infer from the neuroscience of agency about agential control. That the brain decides or intends what we do well before we know it is a striking claim. That the brain prepares for voluntary activity is not. A proper assessment of these claims rests on the representational story that best explains the causal neural mechanisms implicated in intentional action. Here I have argued that the best representational explanation is less sensational than the former claim and, yet, more exciting that the latter.

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