



The attentional switching framework: A dual process account of how the brain switches when attention switches

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ABSTRACT

The capacity to flexibly shift attention between external and internal events is critical for everyday tasks, yet research on how this shifting operates at the cognitive and neural level is still emerging. Here, we examined the question: How does the brain switch when attention switches between external and internal states? We propose the Attentional Switching Framework, which postulates that switching between external and internal attention states involves two seemingly opposing mechanisms subserved by distinct neural bases. First, based on our Resource Dependent Account, the regulation of attentional switching involves a domain-general mechanism that determines when and how the focus of attention shifts between external and internal states. This mainly recruits a similar set of brain regions and pathways when switching to either attention state, suggesting a common neural mechanism that initiates the attentional switch. Second, according to our Resource Independent Account, the maintenance of external and internal attention states involves domain-specific representations. These representations primarily recruit distinct brain regions and pathways, suggesting largely dissociable neural mechanisms that maintain the representation of each attention state. Together, we propose that when attention switches, the brain engages a dual process system involving a common mechanism that supports the *regulation* of switching and dissociable mechanisms that supports the *representation* of attention states. In highlighting the role of distinct operations of various brain regions and pathways underlying attentional switching, our framework reconciles apparent contradictions regarding whether common or distinct mechanisms are involved in switching between external and internal attention and presents important real-world applications and clinical implications.

1. Introduction

The successful implementation of everyday tasks requires the capacity to flexibly shift between focusing on the external environment and internal milieu. Consider reading this manuscript; it requires attending externally to the words on the page and navigating your internal milieu to retrieve prior knowledge to contextualize the manuscript. This experience exemplifies how our attention seamlessly shifts between perceptual inputs (e.g. manuscript) and internal events (e.g. knowledge of past findings). Such fluctuations between external and internal attention states are frequent and necessary aspects of our experiences in daily life, representing a fundamental human function (Cleary et al., 2023; Dixon et al., 2014). In this review, we put forward

the Attentional Switching Framework, which aims to elucidate the neural basis of such attentional switching and proposes that it integrates two mechanisms subserved by distinct neural regions and connections that are involved in regulating and maintaining the switch.

We use the terms "external attention" and "internal attention" as umbrella terms to refer to any form of attention oriented to the external environment or internal representations, respectively. External and internal attention states encompass a wide range of phenomenological content and are implicated in numerous cognitive processes; this review will therefore necessarily capture the diverse cognitive functions framed as external and internal states in the literature. For example, external attention is involved in visual search and auditory perception, whereas internal attention includes spontaneous thought, autobiographical and

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episodic memory retrieval, and mental imagery among others. Considering that attention is deeply embedded in these cognitive functions (Awh et al., 2006; Benedek and Fink, 2019; Chun and Turk-Browne, 2007; Orquin et al., 2021), this review aims to dissociate the underlying mechanism of attention that subserves these functions and the unique cognitive and neural resources that are engaged to support each specific function whenever possible. Recent proposals have already proposed some useful distinctions between external and internal modes, contents, and the source(s) of these signals by offering a framework that differentiates attentional processes from broader cognitive operations (van Ede & Nobre, 2023). In the context of this review, we refer to these processes broadly as external and internal attention states, which serves our goal of proposing an overarching framework that integrates these processes and mechanisms supporting them. We also recognize that the term ‘switching’ might imply a categorical shift rather than a graded transition between attention states; nonetheless, this term is optimal for characterizing the phenomenological experience we aim to capture (i.e., when attention shifts from one set of content to another). We do however acknowledge that, in practice, attentional switching may occur along a continuum.

1.1. External and internal attention

To date, research into attention has emphasized mechanisms underlying a given attention state, focusing on external or internal attention, but largely neglecting the switching between these states. The majority of research has historically centered on selective attention towards external stimuli, which involves selecting relevant information in our physical surroundings while ignoring irrelevant information (Duncan, 1984; Treisman, 1969). This large body of work on external attention has offered comprehensive insights into how we attend to perceptual inputs from the behavioral, neural, molecular and computational perspectives (Fiebelkorn and Kastner, 2019; Petersen and Posner, 2012; Raz and Buhle, 2006; Wickens et al., 2022). It also provided the field with useful taxonomies to characterize different types of external attention (Posner and Petersen, 1990). This includes selective attention (as described above) and sustained attention, which is traditionally defined as the decreasing ability to detect rare stimulus over time in the context of vigilance decrement (Langner and Eickhoff, 2013; Mackworth, 1968; Oken et al., 2006), with contemporary definitions prioritizing the moment-to-moment fluctuations in maintaining focus on an external event (Esterman and Rothlein, 2019; Fortenbaugh et al., 2017).

In recent years, the emphasis on internal attention has steadily increased, highlighting that our attention is not strictly oriented externally; rather, attending to our thoughts and disconnecting from the external world is equally prevalent and important in everyday life (Gilbert et al., 2005; Kam et al., 2024). This line of research has advanced our understanding of the inner milieu, and early reviews suggest they share similar taxonomies that parallel those in external attention (Chun et al., 2011; Kuhl and Wagner, 2009; Long et al., 2018). For example, the dissociation between selective and sustained internal attention is manifested in their association with different cognitive functions: working memory (as characterized by temporarily holding and manipulating information (Baddeley, 1992; Baddeley and Hitch, 1974)) has been increasingly associated with internal selective attention (van Ede and Nobre, 2021; Gresch et al., 2024b; Kiyonaga and Egner, 2013), whereas spontaneous thought and mind wandering are often characterized as sustained periods of internal attention towards our thoughts (Kam et al., 2018a; 2018b; 2025; Stawarczyk et al., 2011; Teasdale et al., 1995).

Although well-established theories and empirical evidence exist for both external and internal attention states separately, the mechanisms that explain how we switch (or transition) from one state to another are still underspecified. Traditionally, attentional switching has been mostly examined in the context of task switching, which typically involves

switching between different features of external stimuli (e.g., Meiran, 1996; Monsell, 2003) or between different internal representations (e.g., De Lissnyder et al., 2012). Consistent with our definition of external and internal attention, we consider switching between different external task stimuli to be external switching (though one could argue that implementing the response rules involves internalizing the rule and therefore switching between rules may be considered as a form of internal switching, even though task stimuli are externally presented). Regardless of whether task switching is considered to be external or internal switching, this line of research has provided insights into switching within attention modalities (often referred to as within-domain switching). However, compared to the established literature on task switching, fewer studies have examined how switching occurs between external and internal attention states (referred to as between-domain switching), despite that the capacity to flexibly shift between domains plays as important a role in cognitive processing as within-domain switching.

An emerging body of work examining the mechanisms of attentional switching has provided a glimpse into the cognitive and neural basis underlying switching between external and internal attention (Calzolari et al., 2022; Gresch et al., 2024a; Hammer et al., 2024; Verschooren et al., 2019a, 2019b). For example, Nobre and Gresch (2025) reviewed the literature on the cognitive basis of switching between external and internal selective attention in the context of working memory and proposed several neural candidates that may control the switch. Servais et al. (2023) also proposed potential candidates for switching between external and internal attention in the context of autobiographical memory. These proposals highlighted the importance of advancing our understanding of the switching between attention states as a core human function.

In this review, we build on prior work to broaden the discussion on attentional switching by including multiple forms of attention and their associated functions and by addressing an apparent contradiction in the literature regarding the neural basis of attentional switching. Specifically, there appears to be opposing evidence regarding whether the brain recruits a similar set of regions or allocates resources to different regions when attention switches from an external to an internal orientation, or vice versa. Our paper integrates this burgeoning literature on the cognitive and neural basis of attentional switching to address the following question: How does the brain switch when attention switches? Specifically, does a common or unique set of brain regions and pathways get recruited when we switch between external and internal attention? To our knowledge, this novel question has not yet been explicitly addressed and most studies from various cognitive domains included in our review have only partially examined this question (Nobre and Gresch, 2025; Servais et al., 2023). Here, we therefore synthesize existing literature from different fields to offer insights into how the brain supports attentional switching through two different mechanisms.

1.2. Two accounts of attentional switching

The key question concerns what happens in the brain when attention switches between external and internal states: does the same set of brain regions and pathways get recruited, suggesting attentional switching is supported by a common mechanism, or does a unique set of brain regions get engaged, suggesting a functionally dissociable mechanism? We propose two accounts that are characterized by whether similar or distinct resources are recruited to support a cognitive process. As the term “resources” is often loosely or not defined in the literature, for the purpose of this paper, we use it to denote the recruitment of specific brain regions and pathways, with increased activity or connectivity interpreted as resources devoted to the ongoing cognitive process.

One scenario in which the brain recruits a common set of regions during attentional switching is represented by our *Resource Dependent Account*. We adapted the term from the Resource Sharing account, first coined by (Verschooren et al., 2019b) and inspired by previous cognitive

frameworks (Baars, 2005; Baddeley and Hitch, 1974; Smallwood, 2013). This account suggests that both external and internal attention depend on the same pool of limited resources and thereby rely on the same general mechanism. Accordingly, the brain recruits the same regions and pathways regardless of whether attention switches to an external or internal state. Research supporting this account has consistently found attenuated responses to external stimuli (Kam et al., 2022; Kam et al., 2018b; Maillet et al., 2020) or the shutting out of external inputs (Salvi et al., 2015; Servais et al., 2023) during internal attention states. In other words, as attention orients internally, resources are directed away from external stimuli and allocated to the internal state, suggesting these states depend on the same limited pool of resources (Smallwood, 2013). At first glance, the notion that a similar set of brain mechanisms can give rise to different conscious experiences (in this case, external and internal attention) may seem contradictory; this does however align with an intriguing proposal purporting a dissociation between the cognitive or neural process and the phenomenological experience tied to that process (Schwartz and Cleary, 2025). One potential neural candidate is the fronto-parietal control network (consisting of dorsolateral prefrontal cortex, anterior prefrontal cortex, dorsal anterior cingulate cortex, inferior parietal lobule, and intraparietal sulcus among others), which is robustly involved in both attention states (Dixon et al., 2017; Spreng et al., 2010) as well as attentional control (Dosenbach et al., 2008; Scolari et al., 2015; Zanto and Gazzaley, 2013). Another candidate implicated in switching to both attention states include the hippocampus, which has been shown to be engaged during both external and internal attention states across several contexts (Barbeau et al., 2017; Poskanzer and Aly, 2023).

An alternative scenario in which the brain engages a distinct set of regions to implement the switch from external to internal attention or vice versa is represented by our *Resource Independent Account*. This account rests on the assumption that external and internal attention states represent distinct processes that rely on different resources (Dixon et al., 2014; Hammer et al., 2024; Spreng et al., 2010). Mounting neuroimaging evidence suggests a different mapping between neural networks and external or internal states (Dixon et al., 2014). The main networks of interest include the dorsal attention network (primarily comprised of the frontal eye fields, intraparietal sulcus, and superior parietal lobule) supporting external attention (Corbetta and Shulman, 2002; Raz and Buhle, 2006) and the default network (primarily comprised of medial prefrontal cortex, posterior cingulate cortex, inferior parietal lobule, and medial temporal lobes) supporting internal attention (Buckner et al., 2008; Raichle, 2015). Therefore, a reasonable conclusion is that the brain engages dissociable mechanisms in recruiting distinct regions when attention switches between different states.

In the present review, we aim to reconcile these seemingly opposing perspectives (i.e., the brain engages a common versus dissociable mechanism) by synthesizing the literature from various cognitive domains in a way that clarifies how both perspectives may be correct, ultimately offering an integrative Attentional Switching Framework grounded in behavioral and neural evidence. The capacity to switch between external and internal attention is a core human capacity and is disrupted in many neurodevelopmental, psychiatric, and neurological disorders. Through our review, we aim to shed light on this fundamental cognitive process of attentional switching and its neural basis, as well as highlight its real-world and clinical implications. We envision that this framework will inspire future research, which in turn will facilitate its continued refinement.

2. An introduction to the attentional switching framework

We propose the Attentional Switching Framework, offering an integrative perspective of switching between external and internal attention states. According to our framework, attentional switching involves two connected processes: 1) *regulating the switch* and 2) *maintaining post-switch attention states*. The first process involves switching the locus of

attention between external and internal states, capturing the movement of attention from external inputs to internal events and vice versa. The second process involves maintaining the attention state itself following the switch, which reflects the outcome of the switch as indexed by the locus of attention wherein attention is focused on a particular external stimulus or internal representation. To exemplify the distinction between these two processes, consider the experience of watching the movie “Midnight in Paris”: a particular scene may trigger the memory of your last trip to Paris (characterizing the switch from external to internal attention), after which you may find yourself spending the next few moments reminiscing the details of that trip (initiating an episode of autobiographical memory retrieval engaging internal attention or simulating a spatial navigation of the streets to situate the scene with your own spatial map of Paris). Our framework is visually summarized in Fig. 1.

These processes correspond to those characterizing classically defined task switching, which involves initiating and orienting attention towards as well as maintaining a new mental set (Rushworth et al., 2002, 2005). This distinction between switching and maintenance has also been recently proposed and empirically tested in the context of working memory, focusing on the maintenance of internal attention as indexed by the gating of irrelevant information from perceptual or long-term memory sources (Verschooren, Kessler, et al., 2021). Importantly, the notion of resource dependence and independence is integral to understanding the distinction between the regulation of the switch and the maintenance of post-switch attention states, as discussed in the next section.

2.1. A dual process account of attentional switching

Our Attentional Switching Framework incorporates the two aforementioned resource accounts by proposing that the regulation of the switch aligns with the Resource Dependent Account whereas the outcome of the switch aligns with the Resource Independent Account. Borrowing the common analogy of a spotlight from traditionally defined selective attention, the switching of attention can be characterized by moving the spotlight of attention between external and internal states, which involves a shift from the current state to the upcoming state. We propose that this process is consistent with the Resource Dependent Account, based on converging evidence indicating that similar mechanisms are involved during switching, suggesting that shared resources facilitate the regulation of the switch. This perspective would suggest that the brain engages a common neural mechanism when switching between external and internal attention. This common mechanism may manifest in the recruitment of a similar set of brain regions and/or their interactions with attention-relevant networks.

In contrast, the outcome of the switch is characterized by the locus of attention, or the content of our conscious experience where the spotlight ends up, in which the brain is involved in maintaining the representation of such content. We propose that this is consistent with the Resource Independent Account, with most of the existing literature implicating different brain regions or networks in a myriad of external and internal states, converging on the notion that the maintenance of these attention states recruit different resources. Common examples of these brain-behavior relationships include the dorsal attention network and external functions (Corbetta and Shulman, 2002; Fiebelkorn and Kastner, 2020) as well as the default network and internal functions (Andrews-Hanna, 2012; Menon, 2023). This suggests that resources supporting the neural representation of external and internal states are largely independent and therefore the brain recruits distinct regions when attention switches.

In our framework, we propose a functional mapping between the two switching processes and resource accounts, rather than an absolute anatomical dissociation. Specifically, the regulation and maintenance processes of attentional switching are distinguishable by their proposed functional roles and corresponding temporal order, rather than through

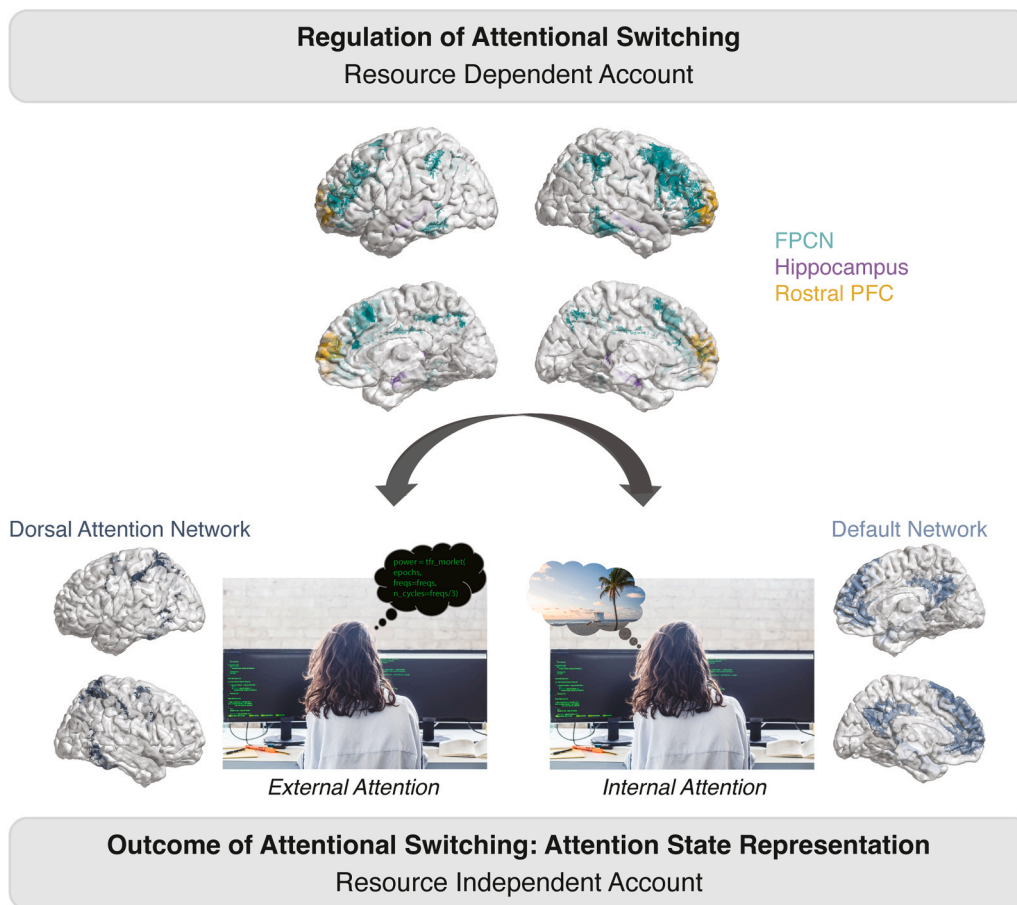


Fig. 1. Attentional Switching Framework: A Dual Process Account. Note: According to the Resource Dependent Account, the regulation of attentional switching determines when and how attention switches by recruiting a similar set of brain regions when switching to external or internal attention. This includes the fronto-parietal control network (FPCN), hippocampus, and rostral prefrontal cortex (PFC). According to the Resource Independent Account, the maintenance of external and internal attention state representations recruits a unique set of brain regions. This includes the dorsal attention network for external attention and default network for internal attention. Therefore, when attention switches, the brain engages a dual process system involving a common mechanism for the regulation of switching and dissociable mechanisms for the representation of attention states. Brain images were generated using the Fieldtrip toolbox and the remaining image is a stock image from Powerpoint.

strictly non-overlapping brain regions. This mapping is most directly supported for experimentally cued, top-down switching between pre-defined external and internal tasks. It remains to be determined whether it will generalize to other forms of switching (see section “Dissociating the Mechanisms of Switching” and Box 3) or tasks that engage concurrent external and internal processes (see Box 1). Under those conditions, it is possible that the regulation of switching may not recruit the same resources and the maintenance of attention states may draw on shared resources. Thus, the notion of resource dependence and independence should be treated as testable properties of attentional switching under specified conditions, not as fixed properties of brain regions or attentional switching processes.

2.2. The necessity of resource dependent and resource independent accounts

Converging behavioral and neural evidence suggests that such a dual process account involving the switch between attention states and the maintenance of these states may be critical for supporting attentional switching. In particular, these two mechanisms prioritize different goals that potentially map onto cognitively and computationally distinct processes. In terms of cognitive processes, the common switching mechanism (in line with the Resource Dependent Account) supports selection and coordination, which operates at a different level as the distinct information processing mechanisms (in line with the Resource

Independent Account) that are primarily involved in attentional state representation.

In the context of computational models, switching may align with flexibility or exploration processes whereas maintenance may align with stability or exploitation processes. These two mechanisms interact along the stability-flexibility or exploitation-exploration dimension that are sensitive to independent parameters (Cohen et al., 2007; Schulz and Gershman, 2019). Specifically, switching between attention states requires sensitivity to relevant signals to subsequently change towards as well as flexibility in state transitions, at the cost of reduced stability, which correspond with an attenuation in goal-relevant information (such as with lower control gain or in exploration mode). Maintenance of attention states requires stability and noise resistance at the cost of inflexibility, which correspond with increases in goal-relevant information (such as with higher control gain or in exploitation mode (Musslick et al., 2019; Ueltzhöffer et al., 2015)). This suggests that separate mechanisms are important for simultaneously being sensitive to potential inputs to rapidly switch to a different state as well as being resistant to perturbation to remain in the current state. Existing theoretical accounts of off-task thoughts have proposed a similar distinction between an exploratory state (also referred to as an intermediate off-focus state) in which the system is more susceptible to distraction thereby facilitating transitions to either an on-task or off-task state as well as a stable state in which attention is focused on an on-task or off-task state (Mittner et al., 2016; Verschooren, Dahl, et al., 2026). In

Box 1**Concurrent External and Internal Attention Engagement.**

Existing literature has devised experimental designs to isolate external and internal attention states to examine these processes alone and the switching between them; yet common functions in everyday life often appear to involve the co-occurrence of both attention modes. In some contexts, they are engaged in pursuit of a common goal (e.g., speaking with a friend while recalling your last conversation with them), whereas in others, they support distinct goals (e.g., driving back home safely while generating plans for the upcoming weekend). How might this seemingly concurrent engagement of both external and internal attention correspond to the neural basis underlying the transition between them?

When both attention states are simultaneously engaged, different mechanisms may be at play in the context of the regulation and maintenance of attentional switching. One possible scenario is that the regions corresponding to external and internal attention are concurrently recruited during that particular function in the context of maintenance. While the dominant narrative points to an antagonistic relationship between the dorsal attention network and default network (Fox et al., 2005; Kucyi et al., 2020; Spreng et al., 2013) as proxy for external and internal attention, recent work that employed experimental paradigms capturing more complex functions have indeed found that both networks can be simultaneously engaged or positively correlated (Egan et al., 2024). Although this would seem to suggest a common mechanism at first glance, this possibility simply suggests that external and internal attention would recruit the necessary regions to collectively execute the cognitive function. Notably, a situation in which both attention states are necessary to support the overarching function, which is our focus here, contrasts with a situation in which each attention state is competing to support different functions; therefore, it is plausible that different resources that may have been traditionally anticorrelated can be jointly recruited in service of executing the function.

In the context of regulation, the regions or networks responsible may be similarly engaged regardless of whether one attention state or both attention states are involved; however, they may show differing patterns of connectivity with relevant regions. In situations where a pre-dominant attention state (e.g., internal attention) was engaged, past studies have shown that the fronto-parietal control network is positively correlated with the default network and negatively correlated with the dorsal attention network (Dixon et al., 2014; Spreng et al., 2010). Therefore, in a scenario where both attention states are engaged, it is plausible that the fronto-parietal control network may be positively correlated with both the dorsal attention network and default network. Given the scarcity of research on this topic, a promising future direction involves assessing how the neural basis of switching may be modulated by more complex and naturalistic attention states.

The co-occurrence of external and internal attention during cognitive functions conceptually corresponds to the caveat outlining a more complex relationship between neural networks and attention states than previously suggested (see section "A Caveat"). As an example, the default network has been implicated in both internal (Buckner et al., 2008; Raichle, 2015) and external functions (Sormaz et al., 2018; Steel et al., 2024; Vatansever et al., 2015). This underscores the possibility that the clearly defined attention modes in the literature may not always emerge in isolation, especially in everyday life, both in terms of their cognitive and neural bases. In the context of working memory, behavioral evidence further suggests that when external and internal processes are simultaneously engaged but for different purposes, they tend to recruit and thus compete for the same resources (Oberauer, 2019). We elaborate on how external and internal attention may compete versus cooperate in different contexts through the lens of the resource accounts in Box 3.

Finally, although many functions may appear to require both attention states, an important consideration is the temporal unfolding of the engagement of external and internal attention. For certain functions, it is possible that both external and internal attention may be required to execute the function over time, but only one attention state is engaged in any single given moment in time. For instance, listening to a lecture while activating previous knowledge may involve a rapid switching between external and internal attention, such that each attention state is differentially engaged over successive timepoints. Future studies using methodological approaches with superior temporal resolution would be better suited to address the temporal aspects of the neural underpinnings of attentional switching (as discussed in Box 2).

addition, this dual mechanism of flexibility and stability is central to cognitive control (see Egner, 2023 for a review), which has been associated with dissociable neural markers for switching and maintenance processes (Braver, 2012). Beyond specific cognitive processes, this is broadly consistent with the network control theory that proposes dissociable functions of brain regions that initiate large-scale state transitions across networks and maintain the stability of a given local state (Bassett and Sporns, 2017). Together, these findings highlight the value of a dual mechanism mode to function in a dynamic environment, suggesting that our system requires two separate mechanisms to be sensitive to signals relevant for transitioning between states as well as to maintain focus on a given state. A single unified system cannot support such incompatible goals.

Similarly, the shared control mechanism (Resource Dependent Account) serves an important purpose in coordinating between otherwise independent processing streams (Resource Independent Account). Although external and internal attention states may be supported by largely independent resources, they are closely linked to the same control mechanism as both streams of inputs compete for access to a shared,

capacity-limited system that support the phenomenological content of conscious awareness. In line with the global workspace account of conscious awareness (Baars, 2005) purporting that access to consciousness is limited in capacity, it follows that only a subset of information, in this case presumably from one attention state, may be prioritized and represented at any given moment. Our framework therefore suggests that this shared control mechanism of switching is necessary to coordinate between external and internal inputs to determine which input gains access to downstream systems for representation. By gating which input can access this limited-capacity workspace, this mechanism also serves to resolve competition for goal-relevant actions by ensuring that they are not driven by conflicting external and internal goals. When appropriate, this system may also regulate when gating occurs to protect one state from interference or when integration between external and internal information occurs in situations that require integrating external and internal information (see Boxes 1 and 3). This collectively suggests that the shared control mechanism involved in selection and coordination may be necessary to regulate the independent processes involved in representation.

Box 2**Temporal Dynamics of Attentional Switching.**

Growing evidence converges on the regions and networks involved in attentional switching; however, the temporal dynamics both in terms of the cognitive and neural levels underlying this function remains underexplored. In terms of the cognitive level, one plausible scenario is that the domain-general switching mechanism unfolds over time (analogous to task switching), which is followed by the sustained engagement of domain-specific maintenance processes. In particular, the cognitive and neural reconfiguration required to facilitate the switch takes time. This is evidenced by the behavioral switch costs observed after a switch between external and internal attention (Gresch et al., 2024b; Verschooren et al., 2019a), suggesting the brain may need time to disengage from the previous attention state in order to engage the upcoming one. At first glance, the notion that attentional switch unfolds over time may seem to contradict our phenomenological experience of switching as a discrete, transient event (e.g., the moment that we switch our attention); however, this distinction aligns with the proposition that a dissociation can and do exist between the cognitive or neural process and the phenomenological experience of such process (Schwartz and Cleary, 2025). Following the switch, the maintenance of attention states prolongs for as long as the state lasts until the next switch occurs. As a naturalistic example, in the case of top-down switching to an internal state (e.g., deciding to recall a memorable weekend on the beach when reading), this may involve disengaging from networks required for reading and engaging the fronto-parietal control network, after which activity in the relevant network persists to support episodic memory retrieval. Given our limited understanding of how these mechanisms unfold over time, this represents a key priority for future investigations (see Box 4).

In terms of the neural level, a core aspect of temporal dynamics concerns the oscillatory dynamics that facilitate the large-scale network activity and interactions. Based on robust evidence implicating phase synchrony in high-level cognitive processes (Fries, 2005; Ward, 2003), it is conceivable that phase synchronization facilitates the intra- and inter-network interactions of relevant large-scale networks. The specific frequencies involved will depend on the network's preferred frequency range as well as the relevant cognitive processes. An important avenue for future research therefore is to examine which frequencies or cross-frequency interactions are engaged within and across neural networks to facilitate the switching and the maintenance of external and internal attention states. Given much of the existing literature used fMRI, which does not have sufficient temporal resolution to capture these processes as they unfold, future investigations will need to rely on techniques with better temporal resolution such as scalp or intracranial EEG or MEG to capture the temporal and oscillatory nature of the relationships (e.g., Gresch et al., 2024a; Kam et al., 2019; Verschooren Schindler et al., 2021)

2.3. Dissociating the initiating mechanisms of switching

Although switching may be initiated by distinct mechanisms, the nature of these mechanisms and their underlying neural basis remain largely underexplored. We therefore outline three possible scenarios in which switching may be elicited. Specifically, we propose that attentional switching can occur in a top-down, bottom-up, or spontaneous manner. In outlining these three potential initiating mechanisms of switching below, it is important to note that the existing evidence does not provide equal support across all three mechanisms of switching. The current evidentiary base is strongest for experimentally cued, top-down switching, wherein most studies reviewed here instruct participants to alternate between predefined external and internal tasks, allowing the timing and direction of the switch to be experimentally controlled. Our Resource Dependent Account therefore is primarily informed by the regulation of switching in a top-down manner. Whether bottom-up and spontaneous switches recruit the same domain-general control mechanism remains an open question rather than an established feature of the framework.

Although we conceptualize attentional switching as relying on a domain-general system, the framework does not assume that switching is inherently goal-directed or volitional. Rather, we speculate that attentional switching relies on a common control system that can be initiated by qualitatively distinct sources, including top-down goals, bottom-up salience inputs and spontaneous fluctuations in external and internal representations, thereby allowing for voluntary, involuntary and spontaneous transitions between external and internal attention. In the same way that this has been shown in the context of within-domain switches, such that attention may switch between two external stimuli due to top-down influences such as task demands (Zion Golumbic et al., 2013) and due to bottom-up factors such as speech coherence between stimuli (Dai et al., 2024), switching between external and internal attention may also be elicited by these different factors. For example, top-down control would involve switching attention internally to a thought in a way that subserves an underlying goal (e.g., making a mental note of your to-do list on your commute to work). In contrast, a salient event may capture internal attention in a bottom-up manner (e.

g., an argument with a loved one may seep into your mind throughout work). A given cognitive process may differentially engage top-down and bottom-up across time and different contexts. For example, focusing on reading or movie watching would often involve top-down control in switching our attention externally towards the book or movie; however, an event encountered by the protagonist in the story may elicit a switch to internal attention towards an episode of our childhood memories in a bottom-up manner. We elaborate on these processes below. Establishing whether these proposed mechanisms of attentional switching are supported by distinct neural regions or pathways represents an important direction for future research (as elaborated on in Box 4).

An attentional switch can be modulated by top-down processes, such that the switch in attention is voluntarily engaged. Although this process tends to be described in the context of external attention, top-down control can also be elicited in situations such that attention is shifted towards goal-relevant internal events (Smallwood and Schooler, 2006). The majority of existing studies focus on this mechanism, implicating the fronto-parietal control network (Tamber-Rosenau et al., 2011) and hippocampus (Poskanzer and Aly, 2023), which were recruited during both the switch to external and internal attention. One way to investigate the top-down modulation of switching in the laboratory is to constrain the experiment to a specific external task and internal task that participants switch between. In this context, top-down control is engaged to execute the switch between the external and internal conditions based on task demands. A similar process presumably unfolds in everyday life as we switch between attention states to address our current goals.

Attentional switching can also occur in a bottom-up manner, such that attention switches to an affectively or personally salient external or internal event. For example, Han and Long (2025) found evidence that the switch from external to internal attention can be reactionary to stimuli in the environment, rather than being a strictly top-down process. Along these same lines, (Cleary et al., 2023; 2025) argue that the switch from external to internal attention can be based on detected cue familiarity in the environment. Although the notion of saliency has been primarily conceptualized and investigated in an external attention

context, salient events can also conceivably be internal, both of which have been proposed to involve the salience network, which consists primarily of the anterior insula and dorsal anterior cingulate cortex (Menon and Uddin, 2010; Uddin, 2015). These events tend to be considered as personally relevant and important in our life, which may be exemplified by a conflict with a close friend, the rejection of a manuscript, or an upcoming much-needed vacation. For instance, while engaged in the external environment, our attention may be pulled (or “captured”) by such salient internal event, which then switches our attention inwards towards our thoughts about that event (Christoff et al., 2016). Given the challenge in empirically examining salient internal events, few if any studies have investigated how salient internal events modulate attentional switching and their neural underpinnings, leaving these issues largely unexplored.

Finally, in addition to top-down and bottom-up influences, we speculate that switching may also occur spontaneously, not driven by top-down control or salient events in a bottom-up manner. In other words, the switch does not happen in a way that is strongly influenced by either external or internal goals or saliency; rather, attention spontaneously switches. One potential mechanism by which this occurs is through semantic association. An individual may have seen a mundane visual stimulus, or thought of an internal event, that triggered a memory (e.g., childhood home) by association. Although an attentional switch is often triggered by cues embedded in a task in an experimental setting, making it clear when the switch occurred, it is far more challenging to test spontaneously occurring switches in attention. This is particularly true given the idiosyncrasies in our experiences that craft these associations, which may prompt an attentional switch. Several recent methodological approaches have been used to attempt to capture these associations, including the think-aloud task (Mills et al., 2018; Raffaelli et al., 2021) and the free association semantic task (Andrews-Hanna et al., 2022; Lux et al., 2022). Such tasks allow for participant ratings of each thought that may be crucial for accounting for the occurrence of internally salient events to distinguish them from bottom-up influences. These novel approaches will serve as important tools for future investigations.

Considering that attentional switching can be initiated in these different ways, this raises the possibility that the corresponding neural basis of attentional switching may also differ. For instance, switching that is initiated by top-down mechanisms may engage one set of networks and pathways whereas those triggered by bottom-up mechanisms or that occur spontaneously may involve a different set of networks (see Box 3 for further discussion). Given it has been proposed that external and internal processes engaged in a top-down versus bottom-up manner influences whether or not they recruit the same resources (Dixon et al., 2014), this highlights the value of elucidating the neural basis underlying these three initiating mechanisms of attentional switching. Although the notion of initiating mechanism primarily applies to the regulation of switching, an intriguing possibility is that the two processes of attentional switching may engage different initiating mechanisms, such that the switching of attention may be engaged in a top-down manner (e.g., distracting oneself from a boring scene in a movie) whereas the outcome of the switch may be engaged spontaneously (e.g., recalling a funny conversation). Future research would therefore need to acknowledge the potential interaction between these three initiating mechanisms (i.e., top-down, bottom-up and spontaneous switching) and the two processes of attentional switching. Notably, given the existing evidence exclusively examined attentional switching in a top-down manner, our review only covers its neural basis associated with the top-down mechanism. We outline possible differences associated with bottom-up and spontaneous switching where appropriate and highlight the notion of these three initiating mechanisms of switching engaging distinct neural mechanisms as relevant future directions in Box 4.

2.4. Summary

In summary, our Attentional Switching Framework suggests that attentional switching involves two processes: the regulation of the switch between attention states and the maintenance of attention states. The resources controlling the switching (i.e., movement of the spotlight) are shared, whereas resources that support the outcome of the switch (i.e., representation of the external or internal attention state itself) are not. We elaborate on these two processes along with their neural evidence in the remaining sections. This framework builds on and integrates existing views from disparate bodies of work (Baddeley and Hitch, 1974; Burgess et al., 2007; Chun et al., 2011; Lückmann et al., 2014; Nobre and Gresch, 2025; Smallwood, 2013). This includes perspectives that have dissociated between external and internal representations (Burgess et al., 2007), separated the allocation of attentional resources from the representation of attention states themselves (Lückmann et al., 2014), distinguished between the process and occurrence of self-generated mental activity (Smallwood, 2013), dissociated orienting and sustained selective attention towards space- or feature-based external stimuli (Posner and Petersen, 1990) and the resources supporting the central executive versus the visual and auditory systems (as well as the episodic buffer) in working memory (Baddeley, 2000; Baddeley and Hitch, 1974), drawn parallels between external and internal selective attention (Chun et al., 2011), and, finally, two recent reviews that proposed neural candidates underlying switching between external and internal attention in the context of selective attention and working memory (Nobre and Gresch, 2025) and autobiographical memory (Servais et al., 2023). Although these previous perspectives have often focused on a relatively narrow band of cognitive experience or function (e.g., mind wandering, spontaneous thoughts, working memory, autobiographical memory), we believe that a cohesive review that considers the breadth of these cognitive phenomena offers a unique and robust perspective on attentional switching and its neural basis.

In the next sections, we first explore the perspective that the brain recruits a common set of regions in line with the Resource Dependent Account, followed by a review of evidence supporting the alternative perspective that the brain recruits a unique set of regions as consistent with the Resource Independent Account. To provide support for both accounts, our review draws on existing neural evidence from studies that aimed to experimentally elicit the cognitive processes of interest and examined their corresponding neural activity, facilitating the interpretation of the functional role of the implicated brain regions. Finally, we present our Attentional Switching Framework in bringing together these two accounts and outlining the cognitive and neural mechanisms underlying the switching between external and internal attention states in a way that reconciles two seemingly opposing perspectives suggesting that the brain both engages a common mechanism and functionally dissociable mechanisms during different aspects of attentional switching.

3. Resource dependent account: similar resources are recruited during the regulation of attentional switching

The perspective that the brain recruits a similar set of regions when attention switches to either external or internal states is grounded in the Resource Dependent Account. According to this account, we rely on the same pool of limited resources to support what we currently attend to (i.e., locus of attention), therefore switching from external to internal attention would require that resources be disengaged from external attention to be allocated to internal attention and vice versa. This is an extension of well-established models of consciousness (Baars, 2005; Dehaene and Naccache, 2001) and executive resources (e.g., (Baddeley and Hitch, 1974; Banich, 2009; Smallwood and Schooler, 2006) as well as cognitive frameworks characterized by a finite pool of attentional resources (Kahneman, 1973; Verschooren et al., 2019b), in which attention can only be dedicated to one stream of input at a time, leaving

limited resources for other streams. From a top-down perspective, the presence of a common set of neural regions that can regulate the allocation of resources to both external and internal attention would be a necessary (albeit insufficient) characteristic of a single attentional control mechanism that regulates this switch between these two attention states. Accordingly, a key property of these regions would entail not only its recruitment during switching but also its connectivity with attention-relevant networks during the corresponding state. In addition, activity in these regions and networks have to be temporally linked to the switching itself, engaged during switching to both external and internal states, and cannot be explained solely by general task demands, sensory processing of switch cues, or the maintenance of the emerging attentional state. The mechanism underlying these regions especially when engaged in a top-down manner may therefore be akin to an executive control system (e.g., [Baddeley and Hitch, 1974](#); [Logie et al., 1990](#)), regulating the direction of the attentional spotlight toward an external or internal state and using the same shared pool of resources to implement the switch.

To that end, several neural regions and networks including the hippocampus and the fronto-parietal control network have been shown to be engaged during both external and internal attention states ([Honey et al., 2017](#); [Spreng et al., 2010](#)), suggesting both states are supported by the same regions and thus share the same resources. Additional findings indicate that these regions are engaged during moments of switching ([Tamber-Rosenau et al., 2011](#); [Treder et al., 2021](#)) and flexibly connect with attention relevant networks either during or following the switch ([Poskanzer and Aly, 2023](#); [Spreng et al., 2010](#)), further supporting their involvement in attentional switching. We propose that these regions are likely involved in regulating the switch (or the movement of spotlight of attention), shifting attention from one state to another (or vice versa). Although converging evidence implicates these regions in attentional switching, it is important to point out that domain-general engagement along with connectivity with relevant regions alone do not necessarily entail a domain-general controller ([Nobre & Gresch, 2025](#)). Further evidence establishing its causal involvement, temporal precedence (prior to switching outcome) as well as predictability of subsequent attention-relevant experiences and behavior is needed, which we discuss in [Boxs 2 and 4](#). This section offers an overview of the cognitive and neural mechanism underlying the regulation of attentional switching, drawing on existing literature supporting the Resource Dependent Account.

The switching literature has traditionally focused on switching that occurs within a single attention domain (i.e., external or internal), such as switching between different aspects of external stimuli or between different types of internal representations. In the context of task switching, this research has uncovered the behavioral correlates of switching within the external ([Koch et al., 2018](#); [Monsell, 2003](#); [Vandierendonck et al., 2010](#)) or internal domain ([De Lissnyder et al., 2012](#)). Task switching involves the capacity to learn and implement new rules. Once the new rule has been proceduralized, it has been proposed that there is no longer a need for active maintenance ([Brass et al., 2017](#)). This contrasts with our framework on attentional switching, in which the maintenance of post-switch attention states can be engaged actively or passively. Of relevance, where there may be a parallel between the within-domain switching in the context of task switching and between-domain switching in the context of our framework concerns the notion of flexibility, such that the extent to which one can flexibly implement the new rule may correspond with the extent to which one can flexibly switch attention to an external stimulus or internal representation as needed. Such flexibility in within-domain switching (and arguably between-domain switching) is considered to be an important facet of executive function ([Miyake et al., 2000](#)), and has been reliably shown to be accompanied with a switch cost. A switch cost is a detriment in behavioral performance (often indexed by slower reaction times or increased error rates) linked to switch trials (i.e., a trial preceded by different demands in a previous trial) as compared to repetition trials (i.

e., a trial preceded by the same demands as the previous trial). Theoretical frameworks mainly focusing on switching within the external domain have implicated attentional control mechanisms in switch costs ([Mayr and Kliegl, 2000](#); [Monsell and Mizon, 2006](#); [Waszak et al., 2004](#)), proposing that attentional control is important for shifting the allocation of attention to meet differing task demands. However, its limited resources prevent the concurrent processing of multiple inputs, thereby resulting in worse behavioral performance. A meta-analysis of the fMRI literature examining the brain regions reliably engaged during within-domain external switching has implicated the inferior frontal junction and posterior parietal cortex as domain-general regions that are broadly involved in switching within the external domain, as well as other domain-preferential regions that are differentially involved in switching within specific aspects of the external domain, including perceptual, motor and contextual shifts ([Kim et al., 2012](#)). Given that the dominant approach in these studies emphasized on switching within the external or internal domain, our understanding until recently has been limited to switching within attention domains. If the regions implicated in within-domain switching are also involved in between-domain switching in the context of external and internal attention, this would provide support for a domain-general switching mechanism. Notably, the extent to which a domain-general switch necessarily entails identical neural or behavioral signatures across contexts, information flow between regions ([Honey et al., 2017](#)) and/or a common reconfiguration of brain states ([Gu et al., 2015](#)), remains underexplored and represents an important direction for future research.

The between-domain switching of attention from external to internal events (e.g., from watching a video to brainstorming weekend plans) and from internal to external events (e.g., from thinking about a friend to reading a text message from them) reflect the natural fluctuations in our attention in daily life. This capacity to flexibly switch between attention states is critical for our everyday activities, including reading, working, and socializing. Emerging theoretical and empirical work converge on a cognitive mechanism underlying this switch (e.g., [Gresch et al., 2024a](#); [Nobre and Gresch, 2025](#); [Verschooren et al., 2019a](#)). Building off the notion that attentional control plays a role in within-domain switching (i.e., external to external or internal to internal), [Verschooren et al. \(2019b\)](#) suggests that a similar mechanism is at play for between-domain switching. Specifically, a serial control mechanism underlies attentional switching, characterized by a limited pool of resources that supports both external and internal attention states. This has implications for behavioral measures (often characterized by performance deficits when switching to a different state) and neural measures (such that depending on the same pool of resources would entail recruiting similar regions).

The next section offers an overview of the cognitive and neural mechanism underlying attentional switching, incorporating findings from the literature supporting the Resource Dependent Account. We first summarize the switch cost as a behavioral measure of attentional switching, highlighting the cognitive mechanism by which switching occurs. In the section “Neural regions underlying the regulation of attentional switching between domains”, we then review empirical evidence converging on a set of regions and networks along with their corresponding pathways that are recruited during the precise moments of switching and engaged during both external and internal attention states, which are considered to regulate the switching between these states. For the purpose of our review, we will emphasize findings that directly compare and contrast external and internal attention states.

3.1. Behavioral markers of attentional switching between domains: switch cost

The majority of studies examining between-domain attentional switching elicits the switching in a top-down manner, such that the switch in attention is voluntarily engaged. Although top-down control tends to be described in the context of external attention ([Baluch and](#)

Itti, 2011; Corbetta and Shulman, 2002; Katsuki and Constantinidis, 2014), it can also be elicited in situations such that attention is shifted towards goal-relevant internal events (Smallwood and Schooler, 2006). Specifically, a common approach to investigate between-domain attentional switching in the laboratory is to constrain the experiment to a specific external task and internal task that participants switch between. Top-down control is therefore engaged to execute the switch between the external and internal conditions based on task demands.

To capture attentional switching, several studies in the context of working memory have devised highly controlled tasks that required participants to switch between the external condition, which involved a perceptual attention task, and the internal condition, which required them to attend to an internal event in the context of a working memory, long-term memory and self-referential tasks (Calzolari et al., (2022); Gresch et al., 2024a; Gresch et al., (2024b); Verschooren et al., (2019a), (2019b)). The physical properties of the stimuli are identical in both conditions in these tasks, ruling out the potential explanation that changes in the results may be attributable to differing characteristics of the stimuli across two attention states. These studies found that switching between external and internal attention incurred a behavioral cost, either indexed by slower reaction time, increased errors, or both, compared to within-domain switch. Two studies further reported that this cost is asymmetrical though with mixed findings, such that one found switching from external to internal states compared to the other way around incurred a larger switching cost (Verschooren et al., 2019a), and another observed a larger switching cost in the other direction when switching between external and internal content (Gresch et al., 2024a). Using a similar experimental paradigm as (Verschooren et al., 2019a), with a self-referential task for the internal condition, Calzolari et al. (2022) replicated this set of findings of slower reaction time for the between-domain switch compared to a within-domain switch, primarily for the switch from the external to internal domain, with weaker evidence supporting the switch from the internal to external domain.

Extending beyond behavioral measures, a handful of studies further examined the corresponding neurophysiological markers underlying the differences between within-domain and between-domain switches. For example, using scalp EEG, Verschooren et al., (2021) reported greater disruption in early visual processing (as indexed by a larger reduction in the P1 event-related potential) after between-domain compared to within-domain switches. This aligns with the notion of behavioral costs for between-domain switching. In a follow-up study, they reported differences in these attenuated evoked responses to external stimuli during the switching towards internal attention and periods of internal attention, providing evidence for a distinction between the switching and maintenance of attention stages (Verschooren et al., 2025). In contrast, Gresch et al., (2024a) did not find any significant differences through univariate analyses of event-related fields derived from MEG data; using multi-variate decoding, however, they revealed differences in patterns of neural activity that distinguished between-domain and within-domain switches.

Taken together, these studies converge on a behavioral cost to switching between external and internal conditions compared to within-domain switching, though additional evidence is needed to draw definitive conclusions regarding neural differences. Notably, the magnitude of the effect and strength of the behavioral evidence appears to depend on the nature of the external and internal tasks themselves. This set of findings have two important implications. First, this growing evidence of the behavioral costs of between-domain compared to within-domain switching suggests that within-domain switching may provide a baseline against which additional cognitive and neural demands between-domain switching may be quantified. Such behavioral findings provide evidence of quantitative differences, whereas the limited existing neural findings highlight the possibility that these differences may also be qualitative, which underscores the importance of recognizing that between-domain switches may not simply be a more demanding version of within-domain switches. Second, and more

importantly, the behavioral findings underscore the notion that attentional resources, albeit limited, are important for executing the switch. At first glance, this provides support for the Resource Dependent Account, suggesting that both attention states tapping into a single pool of limited resources may explain the behavioral costs associated with the switch. Behavioral measures alone however do not directly address this; therefore, we turn to neuroimaging data.

3.2. Neural regions underlying the regulation of attentional switching between domains

The neural basis of the attentional switching phenomenon has been primarily studied using fMRI, with emerging evidence implicating several potential regions or networks involved in switching between external and internal attention. According to the Resource Dependent Account, both external and internal attention rely on the same pool of limited resources and thereby would recruit similar regions or networks during attentional switching. Our framework suggests that these neural resources are responsible for regulating the switch between external and internal attention. The most direct evidence stems from studies using paradigms that captured the precise moments when attention switches between external and internal states, along with evidence suggesting the control networks interact with attention-relevant networks during both states. However, less direct evidence may also address this issue by examining the neural regions recruited to support both attention states.

One potential network responsible for regulating attentional switching is the fronto-parietal control network. Given its widespread intrinsic connectivity across externally and internally relevant regions (Vincent et al., 2008), as well as its intermediate position between unimodal sensory systems and limbic regions (Mesulam, 1998) or the transmodal default mode regions along the principal cortical gradient (Margulies et al., 2016), the neural architecture of frontoparietal control network makes it well-positioned to enable flexible transitions between external and internal attention states. In a functional neuroimaging study, Tamber-Rosenau et al. (2011) used a switching task that asked participants to shift between visual items (external) and between two numbers held in working memory (internal). Their results indicate that switching between external and internal states involves a domain-general process that recruits overlapping regions in the fronto-parietal control network, as well as domain-specific processes that engage different regions within the same network to carry out the specific shift to external or internal states (Tamber-Rosenau et al., 2011). This is consistent with converging evidence indicating that regions within the fronto-parietal control network support both external and internal attention states (Cabeza et al., 2003; Li et al., 2023a; Nee, 2021; Turnbull et al., 2019), often through their connectivity with the attention relevant networks (Dixon et al., 2017; Spreng et al., 2010). Although these studies did not directly examine attentional switching, their findings suggest this network is important for allocating attention towards both external perceptual stimuli and internal events by flexibly connecting with relevant regions during a given attention state. Since participants in these studies were asked to complete either the external or internal task as instructed, thereby engaging top-down initiating mechanisms, this further aligns with the proposal that external and internal attention engaged in a top-down manner recruit the same resources (Dixon et al., 2014). The involvement of the fronto-parietal control network further supports the view that this network is engaged broadly during the top-down regulation of attention. Specifically, classic primate studies have reported on the role of the lateral prefrontal cortex, as a core region of the fronto-parietal control network, in flexibly switching within domains based on task demands (Duncan, 2001; Freedman et al., 2001; Miller and Cohen, 2001) and a more recent primate study has further implicated this region in shared mechanisms between external and internal attention (Panichello and Buschman, 2021). These findings are also in line with computational models, theoretical frameworks and neuroimaging studies using traditional task

switching paradigms focusing on within-domain shifts, in which the prefrontal cortex is implicated in shifting between external features or tasks (Monsell, 2003; O'Reilly and Frank, 2006; Sakai, 2008). Finally, an EEG study examining both attention states in patients with lesions in the prefrontal cortex established its causal role in both external and internal attention (Kam et al., 2019), thereby further bolstering the involvement of the prefrontal cortex in supporting both attention states.

The hippocampus has also been proposed to play a pivotal role in regulating the switch between external and internal attention. Similar to the frontoparietal control network, the hippocampus is ideally situated to mediate switching between external and internal attention states. Anatomically, this region interacts with higher order sensory regions as well as the default network, allowing it to flexibly process both external and internal information. Functionally, the hippocampus has also been implicated in cognitive processes that map onto external and internal attention, including encoding and retrieval (see Tarder-Stoll et al., 2020 for a review), which we describe below. For example, in a memory task that involved an encoding phase and cued-recall phase, Treder et al. (2021) found increased high frequency activity (55–110 Hz) in the hippocampus using MEG during the moments when activity in extra-hippocampal regions (including temporal, parietal and occipital areas) shifted from representation of the cue (involving external attention) to the mnemonic target (involving internal attention) during successful recall. The authors interpreted these findings to implicate the hippocampus as the switchboard between perceptual (external) and memory (internal) processes. A study with experienced meditators similarly reported that the hippocampus was recruited during the switch to an internal state (as indexed by the emergence of a spontaneous thought) though from an interoceptive state (Ellamil et al., 2016). Specifically, activity in the hippocampus peaked prior to thought emergence and occurred earlier than other regions also implicated in spontaneous thoughts, highlighting distinct temporal profiles of brain regions, which we discuss further in Box 2. These findings are consistent with several studies that albeit did not directly examine attentional switching but have also suggested the involvement of the hippocampus in both external and internal states. For instance, an intracranial EEG study by Barbeau et al. (2017) reported stimulus-evoked responses showing opposite polarity in the same hippocampal contacts within patients during both a novelty detection task (as a proxy for external processing) and a memory recall task (as a proxy for internal processing). These authors suggested that the same hippocampal circuit may reverse in polarity in its response depending on whether the circuit is engaged in an externally oriented encoding mode or an internally oriented retrieval mode. This aligns with fMRI findings of a “flip” or dissociation between encoding (external) and retrieval (internal) processes within the hippocampus; specifically, although the hippocampus is involved in both processes (Greicius et al., 2003), this region shows dissociable patterns either based on the activity in different subfields involved in each process (Eldridge et al., 2005) or the different connectivity patterns it exhibits with other regions (Duncan et al., 2014; McCormick et al., 2010; Raud et al., 2023). Similar conclusions have been drawn in a working memory fMRI study that found the hippocampus was recruited during both external and internal states, showing increased connectivity with different regions in each respective state (Poskanzer and Aly, 2023). The role of the hippocampus in switching between external and internal modes has also been proposed in the context of learning, which involves constructing and refining internal models of the incoming information to facilitate predictions about its environment (Honey et al., 2017). Specifically, a subregion of the hippocampus (CA1) receives inputs from separate regions that differentially engages more externally versus internally biased mode (van Strien et al., 2009) and operates at different phases of theta frequency that play differential functional roles in memory (Fernández-Ruiz et al., 2017; Itskov et al., 2008). Altogether, these studies providing both direct and indirect evidence converge on the hippocampus as a potential region responsible for regulating the switch between external and internal states. Thus far, the most direct

evidence examining the moments of switching have implicated the fronto-parietal control network (Tamber-Rosenau et al., 2011) and hippocampus (Treder et al., 2021). Although other regions have been shown to be recruited during both attention states and are implicated in control processes, they have yet to be examined during the moments of switching.

This includes the rostral prefrontal cortex as another prominent region purported to regulate the switching between attention states. Based on the Gateway Hypothesis (Burgess et al., 2007), this region is involved in regulating the gain between external and internal states, particularly during sustained attention or in ambiguous situations in which there is no clear response. This region is postulated to support the mechanisms that facilitate our conscious representations of both external stimulus and internal events, by regulating the flow of information between different cognitive systems involved in these two states. Specifically, the medial part of the rostral prefrontal cortex is implicated in external attention whereas the lateral part is involved in internal attention (Gilbert et al., 2005). The rostral prefrontal cortex itself is not sensitive to the content of the conscious experience, rather it is primarily engaged to direct attention externally or internally. This aligns with our framework suggesting that the neural resources for switching between attention states may be dissociable from the resources necessary for supporting the representation of these states. Given the lack of direct evidence implicating the rostral prefrontal cortex during switching, this remains speculative and requires further investigation.

3.3. Interim conclusion I

Taken together, emerging literature has suggested that several regions and networks may be involved in regulating the switching of attention between external and internal domains. Direct evidence implicates the fronto-parietal control network and hippocampus during the moments of switching, whereas the rostral prefrontal cortex is supported by less direct evidence. As these regions are recruited during switching and interact with the corresponding attention-relevant networks during both external and internal states, a parsimonious interpretation is that both attention states rely on the same pool of resources to regulate the switch, thereby offering support for the Resource Dependent Account. From this perspective, these regions and networks may operate along the spectrum of an externally oriented mode and an internally oriented mode (Honey et al., 2017) when attention switches. Since these regions and networks are often considered to be involved in higher-order regulatory roles, this aligns with the possibility that a domain-general controller exists that regulates the switch by directing and maintaining the spotlight of attention to an external or internal state. This is reminiscent of an executive control system of the spotlight of attention, which serves to initiate the movement of the spotlight to an external stimuli or internal information and to protect its representations once the switch occurs.

Notably, in light of the limited but emerging direct evidence that implicates these candidate regions and networks during the precise moment of switching, additional evidence is necessary to claim that these regions are causally responsible for attentional switching. Specifically, evidence that a region is active as well as its ability to flexibly connect with attention relevant regions during both attention states does not provide definitive evidence for a between-domain switching controller (Nobre and Gresch, 2025). Further investigation that establishes that the region becomes engaged during (but not after) the switch, that causally links the region with the process of switching, and that demonstrates the functional significance of attentional switching is necessary. This growing body of research nevertheless offers meaningful theoretical implications. Given the region or network is recruited during both attention states and connected to networks supporting external and internal attention during their corresponding attention states, it suggests that both attention states may be linked to a common control signal at least in the context of top-down attentional switching, which would be

inconsistent with models proposing fully independent systems. Moreover, a common control mechanism that modulates both external and internal attention, based on this functional profile, would at least be a plausible candidate that is well-positioned to coordinate between them. To that end, this work informs future investigations that aim to establish more direct evidence for the between-domain controller roles of these potential candidate regions and networks in such transitions.

Based on our current understanding of these regions, we speculate they may be responsible for different sources of attentional switching. For example, the fronto-parietal control network may be preferentially engaged when top-down attentional control is involved in executing the switch (Dosenbach et al., 2008; Scolari et al., 2015; Zanto and Gazzaley, 2013), whereas other regions, such as the hippocampus, may be involved more broadly including when switching occurs in a bottom-up or spontaneous manner (Ellamil et al., 2016; Iwata et al., 2024; Su et al., 2025). Although the precise roles of these aforementioned regions in attentional switching remain to be determined (see Box 4 for future directions), growing interest in this area paves the way for future studies to elucidate their unique, overlapping and interactive contributions. Despite such evidence suggesting that the brain engages a common mechanism however, there is an intuitive appeal to the argument that the brain engages a dissociable mechanism during attentional switching, especially given that our phenomenological experience strongly reflects distinguishable external and internal states. We discuss this perspective next.

4. Resource independent account: distinct resources are recruited during external versus internal attention

Although the evidence reviewed above suggests a common set of regions that consistently support attentional switching, there is also ample evidence suggesting that dissociable neural processes are engaged when attention is redirected. This perspective is supported by robust evidence demonstrating that distinct brain regions or networks support different external and internal states; it logically follows then that when attention switches, the brain switches between different functional configurations that are known to support either external or internal attention. Based on this large body of research, our Resource Independent Account proposes that external and internal attention states involve distinct processes that recruit different resources involving different functional configurations to support the maintenance of the representation of different attention states. Accordingly, when attention switches from an external to an internal state, this could manifest in the recruitment of a unique set of regions or information flow between different regions that support external attention versus internal attention. This perspective may resonate with one's subjective experience of external and internal attention as distinct states, rendering this perspective intuitive and compelling.

According to our framework, different regions or networks are needed to facilitate the representation of different content in a given attention state. For instance, looking for your keys (implicating the frontal eye field, posterior parietal cortex and visual cortex; Donner et al., 2000) as a proxy for external attention and reminiscing your last vacation (implicating medial temporal lobe regions within the default network; Andrews-Hanna, 2012; Buckner et al., 2008) as a proxy for internal attention recruits different brain regions. Even within each attention state, different external or internal attention functions requires different resources. As an example, the implementation of visuospatial attention and navigating a new physical environment are different ways to engage external attention that involve different brain regions (Epstein et al., 2017; Petersen and Posner, 2012; Peylo et al., 2021).

Research on external attention states has dominated the attention

literature, and studies contrasting them with internal attention states have examined various functions including visual attention, visual search and working memory. Notably, contemporary attention studies have gradually expanded the focus to internal attention states. In line with Chun et al. (2011)'s proposition that internal attention can be characterized as transient states, similar to external selective attention, these brief internal selective attention states have been primarily studied in the context of working memory (as a form of attentional bias towards internal representations). Many of these studies use a paradigm involving prospective and retrospective cues for content relevant to the memory test, in order to contrast external and internal focus of attention (Souza and Oberauer, 2016). Both contemporary theoretical frameworks and empirical evidence consider working memory as a form of internal attention (Awh and Jonides, 2001; Gazzaley and Nobre, 2012; Kiyonaga and Egner, 2013; Postle, 2006; though see Myers et al., 2017; Tas et al., 2016). Other studies contrasting external and internal selective attention states have used mental math as a proxy for internal attention (Jiang et al., 2021; Magosso et al., 2021). Notably, internal attention states can also be sustained (Chun et al., 2011), which has been studied in the context of spontaneous thoughts (Christoff et al., 2016; Smallwood and Schooler, 2015). The content of such thoughts can vary along different dimensions (Chitiz et al., 2025; Kam et al., 2025; Mckeown et al., 2025; Wallace et al., 2025), with episodic memory retrieval and autobiographical planning as examples of commonly reported thoughts engaging internal attention in everyday life (Baird et al., 2011; Kvavilashvili and Rummel, 2020; Spreng et al., 2015).

This next section "Neural basis of external vs internal attention states" integrates the cognitive and neural evidence regarding external and internal attention from existing literature to support the Resource Independent Account. In keeping with the spotlight analogy, our framework suggests that distinct resources are recruited as a function of where the attentional spotlight ends up, as characterized by the externally or internally oriented focus of our attention, to maintain the representation of these states.

4.1. Neural basis of external vs internal attention states

Ample evidence has implicated a large number of unique brain regions in external and internal attention states, highlighting largely distinct neural mechanisms underlying the representation of these states. The Resource Independent Account is supported by such evidence, demonstrating that external and internal attention rely on dissociable neural mechanisms, which recruit different regions or networks and operate at different oscillatory frequencies. A summary of the mapping between every function and region is beyond the scope of this review and has been reported in their respective fields (e.g., (Buckner et al., 2008; Corbetta and Shulman, 2002; Menon, 2023; Vossel et al., 2014); instead, we will review the literature focusing on studies that directly contrasted external and internal states, with the aim to highlight the resources needed specifically to maintain the representation of external versus internal attention states.

Although cognitive neuroscience has been historically dominated by external attention, the last few decades have witnessed a surge of interest in understanding the neural basis of internal attention using a variety of techniques including functional neuroimaging and electrophysiology (Dixon et al., 2014; Gresch et al., 2024b; Jiang et al., 2021; Kam et al., 2019, 2021, 2025; Magosso et al., 2021; Spreng et al., 2010; Stawarczyk et al., 2011; Verschooren et al., 2021). Studies using fMRI inform the neuroanatomy of attentional switching with whole-brain coverage, whereas scalp EEG studies inform its neurophysiological signatures with less optimal spatial resolution; intracranial EEG captures local field potentials in the brain that offers insights into neural activity

within and across regions and networks, combining the benefits of both fMRI and scalp EEG despite sparse brain coverage (Johnson et al., 2020; Parvizi and Kastner, 2018). The majority of evidence supporting the Resource Independent Account is primarily based on these three methodological approaches, which provide complementary but distinct information regarding how the brain supports external and internal attention representation. Therefore, we first review fMRI studies, highlighting the two main networks involved in external and internal attention. We then review scalp EEG and MEG studies emphasizing the role of spectral activity in maintaining attention states, followed by iEEG studies that inform both the networks involved and their corresponding spectral signatures.

Consistent with the well-established role of the dorsal attention network, the majority of fMRI studies contrasting external and internal attention states have implicated this network in external attention states (Dixon et al., 2014; Spreng et al., 2010). In contrast, most studies have shown increased default network activity during internal attention (Dixon et al., 2017; Scheibner et al., 2017; Spreng et al., 2010; Stawarczyk et al., 2011). Regions within the default network also showed increased connectivity with each other during a retrieval state (internal attention) compared to a perceptual state (external attention) in the context of a memory task (Li et al., 2023). Given that both working memory (in some contexts) and episodic memory retrieval have been characterized as internal attention (Cabeza et al., 2008; Gazzaley and Nobre, 2012; Kiyonaga and Egner, 2013; Long, 2023), the established role of the default network in working memory (Jensen and Lisman, 2005; Johnson et al., 2018; Laroche et al., 2000) and episodic memory retrieval (Eichenbaum et al., 2012; Nyberg et al., 1996) aligns with these findings implicating the default network in various internal attention states.

Extending beyond the neural structures involved in attention states, electrophysiological studies comparing external and internal attention states have revealed several potential mechanisms that support the representation of such states. To that end, a growing body of literature has examined spectral differences between external and internal states using a variety of tasks, primarily implicating theta and alpha frequency bands. The majority of studies examining theta activity reported increased theta during internal compared to external attention (though see Kam et al., 2019 for an exception). For example, a mental math task has been used to engage internal attention, which was linked to increased frontal midline theta compared to external passive viewing or low demand target detection tasks (Jiang et al., 2021; Magosso et al., 2021). Another study compared a retrospective cue condition (relying on internal attention) with a cue monitoring condition (relying on external attention) in the context of prospective memory (Cona et al., 2020), reporting increased theta activity over widespread regions across the right hemisphere during internal attention compared to external conditions. These studies all required participants to engage in internal attention in a top-down manner. Therefore, theta activity, especially over frontal midline sites, may serve as a marker of goal-directed internal attention processes (Cavanagh and Frank, 2014). Its role in spontaneously occurring internal attention states is less clear and may depend on the source of theta activity and the context within which it occurs.

Previous evidence converges on increased alpha activity during internal compared to external states. This finding was first reported by Cooper et al. (2003), which found increased alpha during mental imagery compared to sensory processing. It has since been replicated across a wide variety of tasks, including a mental math task in which alpha was increased at posterior sites (Magosso et al., 2021) and across the right hemisphere (Jiang et al., 2021); a prospective memory task in which increased alpha was observed across both lateral and medial

posterior sites in a MEG study (Cona et al., 2020); as well as a self-reflection task that showed increased alpha over parietal-occipital sites (Matsuoka et al., 2021). An increase in alpha activity during internal attention compared to external attention was also found in studies that did not restrict the specific types of thoughts participants experienced during the internal condition (Kam et al., 2019; Kam et al., 2026) or the specific types of tasks participants completed during the study (Kam et al., 2025). Although often considered as a measure of cortical inhibition of task-irrelevant events (Cooper et al., 2003; Jensen and Mazaheri, 2010), this recent body of work highlights its value as a direct proxy of internal attention (Kam et al., 2022; Palva and Palva, 2011).

Using iEEG, several studies revealed the electrophysiological activity directly recorded from neural regions involved in external versus internal attention. For instance, Hammer et al. (2024) asked participants to alternate between visual search (external) and episodic memory retrieval (internal) task conditions. They found concurrent patterns of low and high frequency activity interpreted as a proxy for cortical activation (Miller et al., 2014) in the default network during internal attention whereas similar patterns of low and high frequency activity were reported in the dorsal attention network during external attention. These spectral patterns align with existing neuroimaging literature (Dixon et al., 2017; Spreng et al., 2010). In addition to within network activity, another iEEG study reported increased theta band connectivity during internal compared to external attention between the default network and a subsystem of the fronto-parietal control network (Kam et al., 2021) that has been previously linked to the default network across contexts (Dixon et al., 2017; Spreng et al., 2013). These differing low frequency patterns across scalp and intracranial EEG studies highlight its complex relationship with internal attention states. Specifically, increased alpha observed mainly over posterior sites in scalp EEG may serve as a specific marker of internal attention which may be localized to regions outside of the default network. Moreover, unique patterns of activity within the default network may capture domain-specific internal attention processes that are distinct from connectivity patterns observed between large scale networks, which may in this case reflect a domain-general process associated with the control networks regulating internal attention.

Taken together, both fMRI and EEG studies generally converge on the dorsal attention network in the representation of external attention and default network in the representation of internal attention, engaging different patterns of low and high frequency activity within each network. As the primary focus of these studies was on the maintenance of both external and internal attention states, not all included an experimentally induced switch of attention prior to maintaining the attention states themselves. Nevertheless, that these studies converged on the same conclusion, which also corroborates with the existing literature, suggests reliable differences in neural activity supporting the maintenance of external versus internal attention states can be observed regardless of when the attention state was captured (specifically whether the attention state began just moments ago or has been maintained for some time). Yet, a deeper understanding of how neural mechanisms maintaining a given attention state unfolds over time following a switch is an important avenue for future research (see Box 4).

4.2. A caveat: are resources truly independent?

Thus far, the majority of findings appear to converge on the notion of a clear correspondence between neural networks and attention states. However, emerging evidence suggests a more complex relationship, such that the default network plays a role in functions beyond internal attention (Sormaz et al., 2018; Vatansever et al., 2015), and internal

attention states recruit regions beyond this network (Benedek et al., 2016; Fox et al., 2015; Kam et al., 2019). One striking example is the finding that the default network implements a retinotopic code of external visual information (Groen et al., 2022; Steel et al., 2024), suggesting that this network supports the representation of sensory level visual information in the external environment. These observations have been synthesized in a recent review purporting that the default network is directly involved in visual perception (Ujhelyi et al., 2026). The default network also showed increased connectivity with the retrosplenial cortex during a perception state (external) compared to a memory retrieval state (internal; Li et al., 2023). Furthermore, the default network has been implicated in sustained bouts of external attention (Esterman and Rothlein, 2019; Song et al., 2021). Beyond perceptual processing of external stimulus, Yeshurun et al. (2021) purported that the default network incorporates both external and internal information to create a model of the social world to make sense of evolving situation. Although an influential framework places the default network on one end of a gradient space that is one of the farthest away from sensory networks (Margulies et al., 2016), these separate pieces of evidence suggest that this network is nevertheless capable of sensory- and higher-level processing of external information.

Similar complex relationships have been made concerning the link between the dorsal attention network and external attention states. As an example, Poskanzer and Aly (2023) reported that the hippocampus was more strongly connected with the dorsal attention network during internal compared to external attention during a memory task. Although the dorsal attention network is historically linked to external attention, studies have also implicated this network in internal attention functions such as mental imagery, working memory and episodic memory retrieval (Stokes et al., 2012; see Lückmann et al., 2014 for a review). Similarly surprising is that the default network was not recruited during internal attention (Poskanzer and Aly, 2023); this may be due to both experimental conditions involving some level of internal attention thereby “cancelling out” the effect or that the specific function that engaged internal attention in this task did not recruit default network. Altogether, these separate lines of research suggest that the dorsal attention network is engaged during internal processes as well.

In addition to the dorsal attention network, some sensory regions have been shown to be similarly engaged or rely on a common neural mechanism during both external and internal attention (Zhou et al., 2022). Although sensory regions are traditionally implicated in external perceptual processes, they have also been recruited during mental imagery which engages internal attention. For example, Yu et al. (2021) reported that there is an internally generated neural code (based on participant-generated visual grating) in the early visual cortex. This aligns with studies suggesting that the visual cortex is recruited during the mental construction of visual images (Kosslyn, 2005; Wheeler et al., 2000; Yu and Postle, 2021). Similarly, auditory regions have also been implicated in auditory mental imagery (Bunzeck et al., 2005; Hubbard, 2010).

Collectively, these studies suggest that these regions and networks have the capacity to maintain both external and internal attention states. This represents a caveat to our framework from two related perspectives. First, our framework suggests that the maintenance of attention states engages different resources, yet the above evidence indicates that external and internal attention may recruit the same neural regions thereby depend on the same resources. Second, based on our framework, the regulation of attentional switching recruits the same neural regions and thus depends on the same resources; however, this line of evidence indicates that the maintenance of attention states may also rely on the same resources, suggesting the resource dependent account may not exclusively characterize the regulation of attentional switching. These findings align with the proposal that both attention states can recruit the same resources when both involved top-down control (Dixon et al., 2014), underscoring the importance of considering the initiating mechanism of switching, specifically whether a given process of

attentional switching engages top-down control.

Can these findings be reconciled with the perspective that the brain recruits distinct regions when attention switches between external and internal states? Indeed, it is possible that all the aforementioned regions are equally capable of maintaining external and internal attention states, but research simply biased the findings towards one attention domain with evidence supporting their involvement in the other domain gradually emerging. In this case, these domain-specific regions may have the capacity to represent information that can occur in both external and internal contexts. In fact, their role may be to represent that information (e.g., a redwood tree); yet whether they represent the tree in the context of external attention (i.e., visually perceiving it) versus internal attention (i.e., imagining it) may depend less on the recruitment of this region itself but rather depend on its connectivity with other regions or the circuits that are engaged (Barbeau et al., 2017; Honey et al., 2017; McIntosh, 2000). If this proves to be the case, it suggests that the brain may recruit a common set of regions after all to maintain the representations of external and internal attention; importantly, it is their connections with other regions that change when attention switches. To the extent that recruitment of these regions change between external and internal attention in the absence of control regions or network engagement, this would also provide some clues regarding whether a controller region or network is necessary for switching (Nobre and Gresch, 2025; Verschooren et al., 2019b). In particular, this may serve as a potential mechanism supporting attentional switching in a bottom-up or spontaneous manner.

Notably, two observations challenge this possibility. First, given that a task condition may elicit the intended attention state as well as other attention states, it is plausible that networks may be engaged during experimental conditions that unintentionally involve more than one attention state. For example, emerging evidence suggests that movie watching (primarily used to engage external attention) often elicits internal thoughts (Wallace et al., 2025) such as the construction of representations that help understand the events as they unfold in the story (Zacks et al., 2010), thereby recruiting not only the dorsal attention network but also the default network (Yang et al., 2023). Moreover, episodes of task-unrelated, stimulus-independent thought, whereby attention is shifted away from an external task towards inner thoughts, is common during sustained external attention tasks (Kam et al., 2022). In these cases, although these findings may be interpreted as the default network being involved in external attention, it is conceivable that this network was engaged to support the internal thoughts that happened to occur during movie watching or during a mundane external task. In the same way that some experimental conditions may inadvertently elicit more than one attention state, numerous functions in everyday life engage both attention states. We further speculate on how the brain switches in these cases in Box 1 and elaborate on the complex interactions between external and internal attention states through a resource account lens in Box 3.

Second, another plausible explanation is that these regions are indeed responsible for distinct functions, but current studies have yet to examine these regions in a sufficiently fine-grained spatial resolution to determine their roles at the neuronal level. For instance, there may be neurons within the dorsal attention network or default network that are differentially responsible for externally versus internally oriented functions. This has been previously demonstrated using iEEG, with neighbouring electrodes showing differential effects and markers of target detection (Kam et al., 2018c). With functional neuroimaging, these may be similarly captured by the BOLD signal and therefore appear as though the same “region” is involved in both attention states. Although fMRI may therefore not be able to address this possibility, approaches that capture signals of individual neurons such as iEEG with microelectrodes would be appropriate for directly examining whether selectivity for external and internal attention states exist at the level of single neurons within a region. Currently, one study has found that the same macroelectrodes in the hippocampus responded during both

novelty detection (engaging external attention) and memory recall (engaging internal attention) but with the opposite polarity in their stimulus-evoked responses (Barbeau et al., 2017). As this is the only study to our knowledge to suggest that the same electrode representing a group of underlying neurons in a given area responded to both external and internal attention, further research examining activity of single neurons is necessary to provide additional insight.

Accordingly, the claim that the exact same region and more specifically neurons may be recruited to support both the representation of external and internal information would need to reconcile with the two aforementioned observations. Future investigations would need to test this claim using rigorous experimental designs and methodological techniques that capture neuronal activity at a sufficiently fine spatial scale. Notably, such a claim does not necessarily contradict the Resource Independent Account, as the mere recruitment of a single region or network alone does not preclude the notion that resources are independent. Rather, there are other ways that distinct functional configurations may manifest, such as in terms of information flow (Honey et al., 2017; McIntosh, 2000) or computational processes (Park and Friston, 2013). An important direction for future work therefore necessitates clarifying the various manifestations of functional configurations that support external and internal attention.

4.3. Interim conclusion II

In summary, robust evidence has implicated distinct networks in

external and internal attention states. Notwithstanding the main caveat discussed above, this suggests that the brain does generally engage dissociable mechanisms that involve recruiting a unique set of regions when attention switches to maintain the representations of external versus internal information. For example, the dorsal attention network primarily supports processes involving external attention (Corbetta and Shulman, 2002) whereas the default network primarily maintains representations involving internal attention (Buckner et al., 2008). Notably, emerging evidence questions the established notion of these brain-to-behavior relationships, suggesting that these regions meant to support domain-specific representations may be involved in both external and internal attention. Considering the potentially questionable purity of attention states engaged in experimental tasks and the dominant use of fMRI in past findings however, the extent to which these regions are truly engaged during both attention states at the neuronal level remains an open question. Integrating such evidence into a more contemporary view, some authors further suggest that external and internal networks may work together depending on task demands (Dixon et al., 2017; Steel et al., 2024). This is also consistent with a proposal in the context of learning suggesting that external and internal attention states are not determined by the anatomy itself, but rather by the information flow (Honey et al., 2017; McIntosh, 2000). This context- and information flow-dependent approach to understanding the roles of neural networks in complex human behavior marks an important direction for future research.

Box 3

An Important Consideration on the Dual Resource Accounts.

Our framework presents a parsimonious account that maps resource dependence onto the regulation of switching and resource independence onto the maintenance of the post-switch attention state, based on existing neural evidence that primarily examined attentional switching in a top-down manner. Notably, behavioral studies examining resource dependence and independence within and beyond the context of attentional switching may point to a more complex relationship.

One proposed factor that may modulate this relationship, focusing on the maintenance of attention states, is the notion of top-down control. In their framework, Dixon et al., (2014) introduced the notion of top-down control (referred to as intentionality by the authors[†]) in distinguishing when external and internal processes compete versus co-occur. Subsequent proposals further suggest that when both external and internal processes involve top-down control, they will depend on and compete for the same resources, whereas the same processes engaged in a bottom-up (and possibly spontaneous) manner allows for co-occurrence or cooperation (Verschooren, Egner, and Aly, 2026; Verschooren and Egner, 2023). This highlights a condition in which the maintenance of external and internal attention (i.e., when both involve top-down control) in the absence of attentional switching may depend on the same resources, which is reminiscent of the recruitment of similar regions and networks during both external and internal processes (as discussed in the section A Caveat).

Another potential factor concerns whether external and internal attention are concurrently needed to achieve the same goal (see Box 1). This has been examined extensively in the context of working memory, wherein behavioral evidence suggests that external and internal attention may depend on the same resources (thus interfere with each other) in some situations or rely on different resources (and cooperate with each other) in others. For instance, external attention to perceptual events and internal attention to stimuli kept in mind have been shown to interfere with each other during working memory tasks (Kiyonaga and Egner, 2014; Olivers et al., 2011; Soto et al., 2008). Integrating this evidence, a subsequent review concluded that this interference between external and internal information may only emerge in specific conditions, for example when both processes are simultaneously engaged (in a top-down manner) in service of different goals (Oberauer, 2019), suggesting additional conditions in which resource dependence may occur during the maintenance of these two attention states thereby resulting in competition and interference. Further delineating these conditions, one study indicates the timing in a task (in particular whether retrieval was rapid versus prolonged) dictates whether competition or cooperation is more likely among external and internal streams (Poskanzer et al., 2025). External and internal attention has also been shown to cooperate and develop concurrently (while relying on different neural resources) in service of a common goal in the context of visual search (Liu and van Ede, 2025). Finally, the complexity of this relationship is further exemplified by a recent observation that external events can draw attention to certain internal representations in a bottom-up manner that is irrelevant to the ongoing task (van Harmelen et al., 2026), suggesting that the facilitation of internal attention by external attention may also occur in the absence of a common goal.

Together, this theoretical and empirical work highlight an important consideration concerning the relationship between the resource accounts and the two mechanisms of attentional switching – to what extent does the mapping proposed in this framework generalize to different ways in which switching is elicited (top-down, bottom-up and spontaneous), across different triggers (external and internal events) and contexts (working memory, long-term memory, visual search, and spontaneous thought)? This is an important avenue for future research (see Box 4).

[†] Footnote: Given the original terms “intentional” and “spontaneous” in Dixon et al., 2014 carry strong preconceived notions in the field of mind wandering and given that the top-down and bottom-up terminology has already been introduced in other parts of this review (which Dixon et al., 2014 considers as synonymous with intentional and spontaneous), we used the terms top-down and bottom-up in our reference to their paper.

5. Attentional switching framework: how the brain switches when attention switches

In addressing the question “How does the brain switch when attention switches?”, our Attentional Switching Framework presents an integrated neuroscience account proposing that the brain engages a common mechanism (recruiting the same regions and pathways) and dissociable mechanisms (recruiting unique regions and pathways) during different aspects of attentional switching. According to our framework, a distinct set of resources support two different yet related processes: 1) the regulation of switching the attentional spotlight from one domain to another (external vs. internal) and 2) the maintenance of representation of the locus of attention. A common set of regions and pathways is primarily involved in the process of switching to both external and internal attention states and is recruited regardless of the content of the conscious experience, suggesting a common mechanism is engaged regardless of whether attention switches to an external or internal state. Another set of regions and pathways is involved in representing the attention state itself, with distinct regions being recruited to maintain the representation of externally or internally oriented content, suggesting the brain engages a functionally dissociable mechanism supporting external and internal attention. A visual summary of the framework is shown in Fig. 1. Below, we bring together the existing literature on the neural basis underlying these two concurrent processes within the context of our hypothesis. Our goal with this framework is to stimulate future research, whether to support or refute the propositions, in order to advance our understanding of the neural basis of attentional switching.

First, the regulation of attentional switching implicates a similar set of regions and pathways that are involved during the initiation of switching between external and internal attention states, supporting the perspective that the brain engages a common mechanism when attention switches. This includes the fronto-parietal control network and hippocampus, which have been shown to be involved during the precise moments of switching and to interact with attention-relevant networks during both attention states (Dixon et al., 2017; Honey et al., 2017; Poskanzer and Aly, 2023; Spreng et al., 2010; Tamber-Rosenau et al., 2011; Treder et al., 2021), and purported to play a regulatory role in attentional switching. We propose that these regions move along a singular process that can be more biased towards external or internal modes of operation. Accordingly, the same resources are recruited regardless of whether attention is oriented externally or internally, in order to regulate the shifting of the spotlight of attention to any given location, at least in the context of top-down attentional switching. Since these regions and networks have been recruited during both external and internal attention but have been differentially engaged across different task contexts, this may reflect a domain-general attentional switching mechanism in which different regions become engaged as a function of the source of the switching.

Given that these attentional resources are limited but necessary to support what we attend to, they must be shared between attention states. Grounded in the Resource Dependent Account, our framework therefore suggests that there is constant competition for the same limited pool of resources concerning which stream gains access to our conscious experience. Consistent with this notion of the scarcity of resources (Baars, 2005; Smallwood, 2013), the aforementioned regions all connect with distinct regions when supporting external attention states, which they disengage from to connect with another set of regions when supporting internal attention states, and vice versa (e.g., Dixon et al., 2017; Spreng et al., 2010). In summary, our framework highlights a common set of regions and networks that are engaged during the

top-down regulation of both external and internal attention states, highlighting their involvement in attentional switching and support the notion that the brain recruits a similar set of regions when attention switches.

Second, the process of maintaining the representation of a given attention state as the outcome of the switch implicates a distinct set of regions that are differentially involved in external and internal attention states, supporting the notion that the brain engages dissociable mechanisms when attention switches. Grounded in the Resource Independent Account, our framework suggests that different brain regions are recruited to support external or internal states as a function of whether the spotlight ends up in an external or internal ‘location’. Accordingly, the functional configuration in the brain changes, when switching from representing external to internal attention states and vice versa. Although earlier research conveys a more straightforward mapping between brain regions and external versus internal attention states (for example, with the default network supporting internal attention states), recent work portrays a more complex mapping. Clarifying the relationship between all external and internal functions and their corresponding regions is beyond the scope of the current review; nevertheless, these findings highlight the complexity of the brain-to-behavior mapping, suggesting that further research with appropriate methodology accounting for context (Chitiz et al., 2025; Chun, 2000), individual differences (Frischen et al., 2007; Kucyi et al., 2021; Zanesco et al., 2025) and other factors will be necessary to unravel these relationships.

Finally, these two processes do not occur in isolation; rather, they work together to collectively support our phenomenological experience. Converging evidence suggest that the domain-general control regions and networks interact with relevant regions to maintain the domain-specific representations during a given attention state. For example, the fronto-parietal control network has been shown to connect with the default network during internal attention and working memory tasks that engage internal selective attention (Diveica et al., 2026) and with the dorsal attention network during external attention tasks (Dixon et al., 2017; Spreng et al., 2010), as well as during resting state, highlighting their intrinsic functional architecture (Spreng et al., 2013). Recent studies have also found the hippocampus to interact with different networks in support of external and internal attention in the context of working memory (Poskanzer and Aly, 2023). Although these studies did not examine the moments of the switch, such findings suggest that the control regions and networks may regulate attentional switching by connecting with other regions to initiate the switching process in addition to maintaining the representations for the upcoming attention state. They also provide evidence that the two processes of attentional switching proposed in our framework are connected and operate interdependently. Although this interpretation aligns with our framework, whether this inter-network interaction plays a critical role in initiating the switch remains to be directly tested (see Box 4 for future directions).

Our framework presents a parsimonious account that offers a mapping between the two attentional switching processes and dual resource accounts. Notably, given the complexity of these processes, such mapping is likely context-dependent, such that there are situations in which this framework is applicable or not. As the majority of support for this framework thus far comes from experimentally cued, top-down switching, generalization beyond this specific context remains to be determined. For instance, whether this framework holds for bottom-up or spontaneous switching remains to be established. Furthermore, existing neural evidence of the same neural regions supporting both external and internal attention states (as outlined in the “A Caveat”

section) suggests that the maintenance of attention states may also be resource dependent, particularly when both involve top-down control and are engaged to support different goals (see Box 3). The proposed mapping in our framework therefore provides a parsimonious starting point, leaving open critical questions regarding the conditions in which the main tenets of this framework hold true or not that serves as important avenues for future investigation (see Box 4).

Taken together, our attentional switching framework aims to reconcile an apparent contradiction in the literature by proposing that when attention switches, our brain both engages in a common mechanism as well as a dissociable mechanism. This dual process account of attentional switching brings together several lines of research to establish two interconnected mechanisms, namely a common mechanism involved in the regulation of (top-down) attentional switching as well as dissociable mechanisms supporting the outcome of the switch reflected in the representation of attention states. Despite the considerable surge of scientific interest that has emerged over the past decade, there is still much to understand about the neural basis of switching between attention states. We outline these future directions in Box 4.

6. Real-world and clinical implications

Our attentional switching framework has important real-world applications and clinical implications. One primary real-world application concerns disruptions in attention to the task-at-hand, often referred to as off-task thought (or mind wandering); it is highly prevalent and occupies 30–50% of awake hours in daily life (Kane et al., 2007; Kawashima et al., 2023). These disruptions can be harmful particularly when attention turns inward away from an external task in certain contexts, such as driving (Burdett et al., 2016; Yanko and Spalek, 2014) or in an educational or occupational setting (Ibáñez et al., 2024; Szpunar et al., 2013; Wong et al., 2022). Although attentional training programs exist and have dominated research in terms of improving attention span (Peng and Miller, 2016; Tang and Posner, 2009), our framework would suggest that targeting the regulation of attentional switching may be equally important. Specifically, attention training programs may benefit from focusing on the regulation of switching, not simply in maintaining an attention state following a switch. Such training would aim to not only increase attention span but also to increase one's capacity to disengage from attention states and phenomenological content that are maladaptive in order to switch towards an adaptive, goal-relevant state. At the same time, the capacity to regulate the shift between different attention states may also help individuals achieve multiple goals concurrently (e.g., preparing a meal and brainstorming ideas for a project). Moreover, this capacity may also play an important role in creativity, by flexibly switching between different states during both the generation and evaluation stages of creative processes (Lu et al., 2017). Although such training programs have the potential to improve the regulation of attentional switching, future research needs to address common limitations in their experimental designs. This includes designing a program that accounts for individual differences, generalizes to real-world functions (given that such training programs tend to demonstrate near-transfer effects but do not necessarily generalize to other functions (Melby-Lervåg and Hulme, 2013; Sala et al., 2019)), and yields long term benefits (as training benefits are not consistently sustained at follow-up assessments (Melby-Lervåg and Hulme, 2013; Schwaighofer et al., 2015)).

Furthermore, disruptions in switching between attention states is observed in numerous clinical conditions. This includes excessive levels of switching in attention deficit/hyperactivity disorder (Martz et al., 2021; Raffaelli et al., 2025) or minimal switching in mood disorders (as manifested as rumination in depression or anxiety; McLaughlin and Nolen-Hoeksema, 2011; Nolen-Hoeksema, 2000; Yang and van Vugt,

2025) as well as autism spectrum disorder (as manifested as intense focus on a topic; Thom and McDougle, 2023). This highlights the potential for clinically relevant forms of attentional switching to be a transdiagnostic process that is manifested in different ways across conditions. Thus far, most existing interventions for these clinical conditions tend to focus on the content of the attention states (e.g., rumination in mood disorders). However, given the dual processes involved in switching, targeting disruptions in attentional switching itself may involve interventions that improve the capacity for regulating the transition between external and internal attention. In other words, training individuals on gaining control over when attention switches (in a top-down manner) may help regulate the frequency of switching between states to optimally maintain goal-relevant behavior.

There are several potential ways to enhance the regulation of attentional switching. Although mindfulness is often considered a tool for improving different aspects of selective external attention (Jha et al., 2007; Semple, 2010), a similar benefit that can be derived from mindfulness training is to gain control over one's attention (Anderson et al., 2007; Chambers et al., 2008). To the extent that similar mechanisms underlie the control of external attention and internal attention, as proposed in our framework, mindfulness training may facilitate improvement in regulating when attention switches and what becomes the locus of attention. In addition, this type of training may also increase one's awareness of the current attention state, which plays an crucial role in the regulation of attention states (Schooler et al., 2011).

Another potential method for improving the control of attention is neuromodulation. The last few decades have witnessed increased interest in non-invasive brain stimulation methods, which has been purported to have the potential to improve different types of cognitive functions (Polanía et al., 2018). These techniques involve non-invasively modulating neural activity to determine its causal impact on behavior. Although neuromodulation findings have offered important insights into the brain-behavior relationship, establishing the foundation for enhancing function in the general and clinical populations, this methodology has its limitations (Bestmann et al., 2015) and has often been characterized by mixed findings (Guerra et al., 2020). For example, in the context of off-task thoughts, often referred to as mind wandering a number of high-powered, pre-registered studies applying transcranial direct current stimulation over the dorsolateral prefrontal cortex have reported positive (Filmer et al., 2019), negative (Boayue et al., 2021), and null effects (Alexandersen et al., 2022; Boayue et al., 2020) and those applying continuous transcranial magnetic stimulation over the left angular gyrus has reported negative effects (Alexandersen et al., 2025). Several plausible explanations for mixed findings include the variability in parameters that can be selected by users or that are limited by the specific technique (such as location, spatial precision, frequency, duration and intensity of the stimulation, constant versus alternating current or repeated pulses) as well as intra- and inter-individual variability (such as age, gender, brain anatomy, cortical excitability, physical and cognitive states; Guerra et al., 2020; Kam et al., 2021). Despite these considerations, neuromodulation have led to more consistent findings in other domains including motor functions (Jacobson et al., 2012) as well as sensory and pain thresholds (Vaseghi et al., 2014). Given increased complexity in high-level cognitive functions, such as attentional switching, additional research may be necessary to determine the ideal parameters for robust modulation of this cognitive function. With a better understanding of the physiology and neural dynamics underlying the stimulation (Dayan et al., 2013), neuromodulation remains a technique that holds potential for facilitating the enhancement of regulation of attentional switching in the general population and restoration in clinical conditions. We discuss other forms of neuromodulation in Box 4.

Box 4**Future Directions.**

The recent increased interest in attentional switching has provided fundamental insights into a core human function. Yet, it also leaves many unanswered questions that serve as important avenues for future research.

1. The timing of attentional switching remains unexplored. Does attention switch gradually (such that the pre-switch attentional state fades away as the post-switch attentional state comes into focus) or abruptly (such that the pre-switch attentional state is immediately followed by the post-switch attentional state on the order of milliseconds)? If attentional switching can unfold across different time windows, do these faster or slower processes engage similar neural mechanisms? A better understanding of the timing of attentional switching through combining experimental manipulations and methodological approaches such as scalp EEG, MEG or intracranial EEG may inform future investigations on the ideal approach for regulating this process.
2. Relatedly, do the neural mechanisms underlying the maintenance of external and internal attention states unfold differently over time? In other words, are the neural signatures of those initial moments of entering into an attention state versus later moments of having been in an attention state for some time similar or different in a quantitative or qualitative way, and importantly, do these processes unfold differently for external versus internal attention?
3. Little is known about the interactions between the regulation of attentional switching and the maintenance of the representation of attention states at the cognitive and neural level, as well as how these mechanisms unfold over time. How do these two processes interact and what are their corresponding neural patterns? In particular, if attentional switching proves to unfold over time, does the initiation phase operate concurrently as the maintenance phase (e.g., when attention switching is initiated, does representation of the current attention state linger or cease immediately)? Similarly, does the initiation phase entail both switching to the next attention state and disengaging from the current one?
4. Our framework proposed several regions and networks that are engaged during both external and internal attention states. However, evidence is lacking in establishing their causal role in regulating the switching between attention states. Are these regions (e.g., hippocampus) or networks (e.g., fronto-parietal control network) causally involved in regulating attentional switching? A related question concerns the functional significance of these regions: to what extent does activity in these regions correspond with self-report experiences or behavioral markers of switching?
5. In addition to brain stimulation, another promising avenue concerning neuromodulation is pharmacological neuromodulation. Does altering neural activity through pharmacological agents regulate the experience of attentional switching? With theoretical proposals implicating the cholinergic system in internal attention (Verschooren et al., 2026) and growing evidence implicating dopaminergic and noradrenergic systems in related processes such as off-task thought (Mittner et al., 2014; Rasmussen et al., 2025), pharmacological neuromodulation and possibly in combination with non-invasive brain stimulation (Rasmussen et al., 2025) holds promise in exerting causal impact on attentional switching.
6. Existing evidence implicates the fronto-parietal control network in attentional switching engaged in a top-down manner, consistent with the literature linking this network to top-down control processes. When top-down control is not involved however, it remains unknown whether a domain-general control system is still necessary and if not, how the competition between external and internal content to reach conscious access gets resolved from a neural perspective. In particular, does the neural basis underlying attentional switching depend on the process initiating the switch (e.g., top-down, bottom-up or spontaneous)? Relatedly, does this initiation process interact with the direction of switching (i.e., switching to external versus switching to internal attention) and if so, how? An important future direction therefore concerns understanding the distinct neural networks and their neurophysiological basis when switching is initiated through different means and towards different attention states.
7. Our framework proposed several brain regions and networks that may be responsible for regulating attentional switching. However, how these regions decide which stream of information to switch towards remains unknown. One account proposed that this decision is based on the weighting of all possible external and internal inputs and comparing such information in a way that aligns with our goals, thereby informing which external or internal stream to attend at any given moment (Narhi-Martinez et al., 2023). In line with this proposal, a potential avenue for future research therefore involves examining whether and how these regions or networks computes these weights, selects the most highly weighted stream to prioritize, and implements the switch to the chosen stream as needed.
8. Interoception is largely neglected in studies examining external and internal attention states. Does focusing on interoceptive stimuli (e.g., the sensation of hunger or warmth or itch) constitute a state that is distinct from external and internal attention states? If so, does switching between these three states involve similar cognitive and neural mechanisms?
9. Thus far, attentional switching has been conceptualized as a domain-general process. However, content- or state-specific neural patterns are also conceivable. For example, could switching to a specific type of internal attention state engage a switching mechanism that is different from switching to a given external attention state? Specifically, could sub-regions within a network be differentially responsible for switching to different states?
10. The developmental course of attentional switching is essentially not known, at both ends of the lifespan. How does the development of attentional switching during childhood and aging map onto structural and functional changes in the implicated neural networks?
11. The regions and networks of interest, including the hippocampus and fronto-parietal control network, are implicated in numerous clinical conditions, including attention deficit/hyperactivity disorder, mood disorders, dementia, among others. How do abnormalities in the structure or function of these regions correspond with the impairments in attentional switching in different populations?

7. Conclusion

Through our dual process account of the Attentional Switching Framework, we proposed that this fundamental high-level cognitive function consists of two concurrent processes subserved by two distinct sets of neural regions and networks. We postulate that during the switching between external and internal attention, our brain engages a common mechanism to support the regulation of the switch (based on

the Resource Dependent Account) as well as dissociable mechanisms to support the outcome of the switch in maintaining the representations of external and internal attention (based on the Resource Independent Account). This framework has important implications for theoretical accounts of cognitive functions as well as everyday life and clinical practice. As switching between attention states has been implicated in numerous cognitive domains, including working memory, episodic memory, and cognitive flexibility, our framework may provide one

overarching principle for understanding the dual processes of the brain that apply to a wide range of cognitive functions. Finally, at present, this framework is most directly supported for top-down switching between distinct external and internal states; its applicability to other initiating mechanisms of switching (i.e., bottom-up and spontaneous), concurrently engaged attention states, and attention states that serve a common goal are key directions for future research.

Taken together, our paper puts forward a novel framework that aims to further our understanding of the neural basis underlying attentional switching. The recent scientific advances synthesized in this paper positions the field to offer foundational insights into a broad spectrum of high-level cognition as well as clinical conditions linked to such functions and may ultimately transform our understanding of how attention switches in the brain.

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Declaration of Competing Interest

The authors declare no competing interests.

References

- Alexandersen, A., Aasen, S.R., Csifcsák, G., Mittner, M., 2025. Evidence for the efficacy of theta-burst stimulation above the angular gyrus for reducing mind wandering propensity: a successful pre-registered study. *Cortex* 191, 25–40. <https://doi.org/10.1016/j.cortex.2025.07.006>.
- Alexandersen, A., Csifcsák, G., Groot, J., Mittner, M., 2022. The effect of transcranial direct current stimulation on the interplay between executive control, behavioral variability and mind wandering: a registered report. *Neuroimage Rep.* 2 (3), 100109. <https://doi.org/10.1016/j.jnirp.2022.100109>.
- Anderson, N.D., Lau, M.A., Segal, Z.V., Bishop, S.R., 2007. Mindfulness-based stress reduction and attentional control. *Clin. Psychol. & Psychother.* 14 (6), 449–463. <https://doi.org/10.1002/cpp.544>.
- Andrews-Hanna, J.R., 2012. The Brain's Default Network and Its Adaptive Role in Internal Mentation. *Neuroscientist* 18 (3), 251–270. <https://doi.org/10.1177/1073858411403316>.
- Andrews-Hanna, J.R., Woo, C.-W., Wilcox, R., Eisenbarth, H., Kim, B., Han, J., Losin, E.A., Wager, T.D., 2022. The conceptual building blocks of everyday thought: Tracking the emergence and dynamics of ruminative and nonruminative thinking. *J. Exp. Psychol. General.* 151 (3), 628–642. <https://doi.org/10.1037/xge0001096>.
- Awh, E., Jonides, J., 2001. Overlapping mechanisms of attention and spatial working memory. *Trends Cogn. Sci.* 5 (3), 119–126. [https://doi.org/10.1016/S1364-6613\(00\)01593-X](https://doi.org/10.1016/S1364-6613(00)01593-X).
- Awh, E., Vogel, E.K., Oh, S.-H., 2006. Interactions between attention and working memory. *Neurosci. Cogn. Neurosci. Work. Mem.* 139 (1), 201–208. <https://doi.org/10.1016/j.neuroscience.2005.08.023>.
- Baars, B.J., 2005. Global workspace theory of consciousness: Toward a cognitive neuroscience of human experience. In: *Progress in Brain Research*, 150. Elsevier, pp. 45–53. [https://doi.org/10.1016/S0079-6123\(05\)50004-9](https://doi.org/10.1016/S0079-6123(05)50004-9).
- Baddeley, A., 1992. Working Memory. *Science* 255 (5044), 556–559. <https://doi.org/10.1126/science.1736359>.
- Baddeley, A., 2000. The episodic buffer: A new component of working memory? *Trends Cogn. Sci.* 4 (11), 417–423. [https://doi.org/10.1016/S1364-6613\(00\)01538-2](https://doi.org/10.1016/S1364-6613(00)01538-2).
- Baddeley, Hitch, G., J., 1974. Working Memory. In: *Psychology of Learning and Motivation* (G. A. Bower, 8. Academic Press, pp. 47–89. [https://doi.org/10.1016/S0079-7421\(08\)60452-1](https://doi.org/10.1016/S0079-7421(08)60452-1).
- Baird, B., Smallwood, J., Schooler, J.W., 2011. Back to the future: Autobiographical planning and the functionality of mind-wandering. *Consciousness Cognition Dreams Psychosis A European Science Foundation Exploratory Workshop* 20 (4), 1604–1611. <https://doi.org/10.1016/j.concog.2011.08.007>.
- Baluch, F., Itti, L., 2011. Mechanisms of top-down attention. *Trends Neurosci.* 34 (4), 210–224. <https://doi.org/10.1016/j.tins.2011.02.003>.
- Banich, M.T., 2009. Executive Function: The Search for an Integrated Account. *Curr. Dir. Psychol. Sci.* 18 (2), 89–94. <https://doi.org/10.1111/j.1467-8721.2009.01615.x>.
- Barbeau, E.J., Chauvel, P., Moulin, C.J.A., Regis, J., Liégeois-Chauvel, C., 2017. Hippocampus duality: Memory and novelty detection are subserved by distinct mechanisms. *Hippocampus* 27 (4), 405–416. <https://doi.org/10.1002/hipo.22699>.
- Bassett, D.S., Sporns, O., 2017. Network neuroscience. *Nat. Neurosci.* 20 (3), 353–364. <https://doi.org/10.1038/nn.4502>.
- Benedek, M., Fink, A., 2019. Toward a neurocognitive framework of creative cognition: The role of memory, attention, and cognitive control. *Curr. Opin. Behav. Sci. Creat.* 27, 116–122. <https://doi.org/10.1016/j.cobeha.2018.11.002>.
- Benedek, M., Jauk, E., Beaty, R.E., Fink, A., Koschutnig, K., Neubauer, A.C., 2016. Brain mechanisms associated with internally directed attention and self-generated thought. *Sci. Rep.* 6 (1), 22959. <https://doi.org/10.1038/srep22959>.
- Bestmann, S., de Berker, A.O., Bonaiuto, J., 2015. Understanding the behavioural consequences of noninvasive brain stimulation. *Trends Cogn. Sci.* 19 (1), 13–20. <https://doi.org/10.1016/j.tics.2014.10.003>.
- Boayue, N.M., Csifcsák, G., Aslaksen, P., Turi, Z., Antal, A., Groot, J., Hawkins, G.E., Forstmann, B., Opitz, A., Thielscher, A., Mittner, M., 2020. Increasing propensity to mind-wander by transcranial direct current stimulation? A registered report. *Eur. J. Neurosci.* 51 (3), 755–780. <https://doi.org/10.1111/ejn.14347>.
- Boayue, N.M., Csifcsák, G., Kreis, I.V., Schmidt, C., Finn, I., Hovde Vollsund, A.E., Mittner, M., 2021. The interplay between executive control, behavioural variability and mind wandering: Insights from a high-definition transcranial direct-current stimulation study. *Eur. J. Neurosci.* 53 (5), 1498–1516. <https://doi.org/10.1111/ejn.15049>.
- Brass, M., Liefoghe, B., Braem, S., De Houwer, J., 2017. Following new task instructions: Evidence for a dissociation between knowing and doing. *Neurosci. & Biobehav. Rev.* 81, 16–28. <https://doi.org/10.1016/j.neubiorev.2017.02.012>.
- Braver, T.S., 2012. The variable nature of cognitive control: A dual mechanisms framework. *Trends Cogn. Sci.* 16 (2), 106–113. <https://doi.org/10.1016/j.tics.2011.12.010>.
- Buckner, R.L., Andrews-Hanna, J.R., Schacter, D.L., 2008. The Brain's Default Network. *Ann. New. Y. Acad. Sci.* 1124 (1), 1–38. <https://doi.org/10.1196/annals.1440.011>.
- Bunzeck, N., Wuestenberg, T., Lutz, K., Heinze, H.-J., Jancke, L., 2005. Scanning silence: Mental imagery of complex sounds. *Neuroimage* 26 (4), 1119–1127. <https://doi.org/10.1016/j.neuroimage.2005.03.013>.
- Burdett, B.R.D., Charlton, S.G., Starkey, N.J., 2016. Not all minds wander equally: The influence of traits, states and road environment factors on self-reported mind wandering during everyday driving. *Accid. Anal. & Prev.* 95, 1–7. <https://doi.org/10.1016/j.aap.2016.06.012>.
- Burgess, P.W., Dumontheil, I., Gilbert, S.J., 2007. The gateway hypothesis of rostral prefrontal cortex (area 10) function. *Trends Cogn. Sci.* 11 (7), 290–298. <https://doi.org/10.1016/j.tics.2007.05.004>.
- Cabeza, R., Ciaramelli, E., Olson, I.R., Moscovitch, M., 2008. The parietal cortex and episodic memory: An attentional account. *Nat. Rev. Neurosci.* 9 (8), 613–625. <https://doi.org/10.1038/nrn2459>.
- Cabeza, R., Dolcos, F., Prince, S.E., Rice, H.J., Weissman, D.H., Nyberg, L., 2003. Attention-related activity during episodic memory retrieval: A cross-function fMRI study. *Neuropsychol. Funct. Neuroimaging Mem.* 41 (3), 390–399. [https://doi.org/10.1016/S0028-3932\(02\)00170-7](https://doi.org/10.1016/S0028-3932(02)00170-7).
- Calzolari, S., Boneva, S., Fernández-Espejo, D., 2022. Investigating the shift between externally and internally oriented cognition: A novel task-switching paradigm. *Neurosci. Conscious.* 2022 (1), nia016. <https://doi.org/10.1093/nc/nia016>.
- Cavanagh, J.F., Frank, M.J., 2014. Frontal theta as a mechanism for cognitive control. *Trends Cogn. Sci.* 18 (8), 414–421. <https://doi.org/10.1016/j.tics.2014.04.012>.
- Chambers, R., Lo, B.C.Y., Allen, N.B., 2008. The Impact of Intensive Mindfulness Training on Attentional Control, Cognitive Style, and Affect. *Cogn. Ther. Res.* 32 (3), 303–322. <https://doi.org/10.1007/s10608-007-9119-0>.
- Chitiz, L., Mckeown, B., Mulholland, B., Wallace, R., Goodall-Halliwel, I., Ping-Ho, N.S., Konu, D., Poerio, G.L., Wammes, J., Milham, M., Klein, A., Jefferies, E., Leech, R., Smallwood, J., 2025. Mapping cognition across lab and daily life using Experience-Sampling. *Conscious. Cogn.* 131, 103853. <https://doi.org/10.1016/j.concog.2025.103853>.
- Christoff, K., Irving, Z.C., Fox, K.C.R., Spreng, R.N., Andrews-Hanna, J.R., 2016. Mind-wandering as spontaneous thought: A dynamic framework. *Nat. Rev. Neurosci.* 17 (11), 718–731. <https://doi.org/10.1038/nrn.2016.113>.
- Chun, M.M., 2000. Contextual cueing of visual attention. *Trends Cogn. Sci.* 4 (5), 170–178. [https://doi.org/10.1016/S1364-6613\(00\)01476-5](https://doi.org/10.1016/S1364-6613(00)01476-5).
- Chun, M.M., Golomb, J.D., Turk-Browne, N.B., 2011. A Taxonomy of External and Internal Attention. *Annu. Rev. Psychol.* 62 (62, 2011), 73–101. <https://doi.org/10.1146/annurev.psych.093008.100427>.
- Chun, M.M., Turk-Browne, N.B., 2007. Interactions between attention and memory. *Curr. Opin. Neurobiol. Cogn. Neurosci.* 17 (2), 177–184. <https://doi.org/10.1016/j.conb.2007.03.005>.
- Cleary, A.M., Irving, Z.C., Mills, C., 2023. What Flips Attention? *Cogn. Sci.* 47 (4), e13274. <https://doi.org/10.1111/cogs.13274>.
- Cleary, A.M., McNeely-White, K.L., Neisser, J., Drane, D.L., Liégeois-Chauvel, C., P. Pedersen, N., 2025. Does familiarity-detection flip attention inward? The familiarity-flip-of-attention account of the primacy effect in memory for repetitions. *Mem. & Cogn.* 53 (5), 1622–1635. <https://doi.org/10.3758/s13421-024-01673-x>.
- Cohen, J.D., McClure, S.M., Angela, J.Y., 2007. Should I stay or should I go? How the human brain manages the trade-off between exploitation and exploration. *Philos. Trans. R. Soc. B: Biol. Sci.* 362 (1481), 933.
- Cona, G., Chiocci, F., Di Tomasso, S., Pellegrino, G., Piccione, F., Bisiacchi, P., Arcara, G., 2020. Theta and alpha oscillations as signatures of internal and external attention to delayed intentions: A magnetoencephalography (MEG) study. *NeuroImage* 205, 116295. <https://doi.org/10.1016/j.neuroimage.2019.116295>.
- Cooper, N.R., Croft, R.J., Dominey, S.J., Burgess, A.P., Gruzelier, J.H., 2003. Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses. *Int. J. Psychophysiol.* 47 (1), 65–74. [https://doi.org/10.1016/S0167-8760\(02\)00107-1](https://doi.org/10.1016/S0167-8760(02)00107-1).

- Corbetta, M., Shulman, G.L., 2002. Control of goal-directed and stimulus-driven attention in the brain. *Nat. Rev. Neurosci.* 3 (3), 201–215. <https://doi.org/10.1038/nrn755>.
- Dai, B., Zhai, Y., Long, Y., Lu, C., 2024. How the Listener's Attention Dynamically Switches Between Different Speakers During a Natural Conversation. *Psychol. Sci.* 35 (6), 635–652. <https://doi.org/10.1177/09567976241243367>.
- Dayan, E., Censor, N., Buch, E.R., Sandrini, M., Cohen, L.G., 2013. Noninvasive brain stimulation: From physiology to network dynamics and back. *Nat. Neurosci.* 16 (7), 838–844. <https://doi.org/10.1038/nn.3422>.
- De Lissnyder, E., Koster, E.H.W., Goubert, L., Onraedt, T., Vanderhasselt, M.-A., De Raedt, R., 2012. Cognitive control moderates the association between stress and rumination. *J. Behav. Ther. Exp. Psychiatry* 43 (1), 519–525. <https://doi.org/10.1016/j.jbtep.2011.07.004>.
- Dehaene, S., Naccache, L., 2001. Towards a cognitive neuroscience of consciousness: Basic evidence and a workspace framework. *Cogn. Cogn. Neurosci. Conscious.* 79 (1), 1–37. [https://doi.org/10.1016/S0010-0277\(00\)00123-2](https://doi.org/10.1016/S0010-0277(00)00123-2).
- Diveica, V., Setton, R., Turner, G.R., Spreng, R.N., 2026. Goal-directed modulation of the default network supports interactions between selective attention, working memory, and prior knowledge. *Proc. Natl. Acad. Sci.* 123 (29), e2605179123. <https://doi.org/10.1073/pnas.2605179123>.
- Dixon, M.L., Andrews-Hanna, J.R., Spreng, R.N., Irving, Z.C., Mills, C., Girn, M., Christoff, K., 2017. Interactions between the default network and dorsal attention network vary across default subsystems, time, and cognitive states. *NeuroImage* 147, 632–649. <https://doi.org/10.1016/j.neuroimage.2016.12.073>.
- Dixon, M.L., Fox, K.C.R., Christoff, K., 2014. A framework for understanding the relationship between externally and internally directed cognition. *Neuropsychologia* 62, 321–330. <https://doi.org/10.1016/j.neuropsychologia.2014.05.024>.
- Donner, T., Kettermann, A., Diesch, E., Ostendorf, F., Villringer, A., Brandt, S.A., 2000. Involvement of the human frontal eye field and multiple parietal areas in covert visual selection during conjunction search. *Eur. J. Neurosci.* 12 (9), 3407–3414. <https://doi.org/10.1046/j.1460-9568.2000.00223.x>.
- Dosenbach, N.U.F., Fair, D.A., Cohen, A.L., Schlaggar, B.L., Petersen, S.E., 2008. A dual-networks architecture of top-down control. *Trends Cogn. Sci.* 12 (3), 99–105. <https://doi.org/10.1016/j.tics.2008.01.001>.
- Duncan, J., 1984. Selective Attention and the Organization of Visual Information, 113 (4), 501–517. <https://doi.org/10.1037/0096-3445.113.4.501>.
- Duncan, J., 2001. An adaptive coding model of neural function in prefrontal cortex. *Nat. Rev. Neurosci.* 2 (11), 820–829. <https://doi.org/10.1038/35097575>.
- Duncan, K., Tompary, A., Davachi, L., 2014. Associative encoding and retrieval are predicted by functional connectivity in distinct hippocampal area CA1 pathways. *J. Neurosci.* 34 (34), 11188–11198. <https://doi.org/10.1523/JNEUROSCI.0521-14.2014>.
- Egan, N.F., Costines, C., D'Esposito, M., Sadaghiani, S., 2024. Endogenous preparatory control is associated with increased interaction between default mode and dorsal attention networks. *imag-2-00124 Imaging Neurosci. (Cambridge Mass.)* 2. https://doi.org/10.1162/imag_a.00124.
- Egner, T., 2023. Principles of cognitive control over task focus and task switching. *Nat. Rev. Psychol.* 2 (11), 702–714. <https://doi.org/10.1038/s44159-023-00234-4>.
- Eichenbaum, H., Sauvage, M., Fortin, N., Komorowski, R., Lipton, P., 2012. Towards a functional organization of episodic memory in the medial temporal lobe. *Neurosci. & Biobehav. Rev. Mem. Form.* 36 (7), 1597–1608. <https://doi.org/10.1016/j.neubiorev.2011.07.006>.
- Eldridge, L.L., Engel, S.A., Zeineh, M.M., Bookheimer, S.Y., Knowlton, B.J., 2005. A Dissociation of Encoding and Retrieval Processes in the Human Hippocampus. *J. Neurosci.* 25 (13), 3280–3286. <https://doi.org/10.1523/JNEUROSCI.3420-04.2005>.
- Ellamil, M., Fox, K.C.R., Dixon, M.L., Pritchard, S., Todd, R.M., Thompson, E., Christoff, K., 2016. Dynamics of neural recruitment surrounding the spontaneous arising of thoughts in experienced mindfulness practitioners. *NeuroImage* 136, 186–196. <https://doi.org/10.1016/j.neuroimage.2016.04.034>.
- Epstein, R.A., Patai, E.Z., Julian, J.B., Spiers, H.J., 2017. The cognitive map in humans: Spatial navigation and beyond. *Nat. Neurosci.* 20 (11), 1504–1513. <https://doi.org/10.1038/nn.4656>.
- Esterman, M., Rothlein, D., 2019. Models of sustained attention. *Curr. Opin. Psychol. Atten. & Percept.* 29, 174–180. <https://doi.org/10.1016/j.copsyc.2019.03.005>.
- Fernández-Ruiz, A., Oliva, A., Nagy, G.A., Maurer, A.P., Berényi, A., Buzsáki, G., 2017. Entorhinal-CA3 Dual-Input Control of Spike Timing in the Hippocampus by Theta-Gamma Coupling. *Neuron* 93 (5), 1213–1226.e5. <https://doi.org/10.1016/j.neuron.2017.02.017>.
- Fiebelkorn, I.C., Kastner, S., 2019. A rhythmic theory of attention. *Trends Cogn. Sci.* 23 (2), 87–101. <https://doi.org/10.1016/j.tics.2018.11.009>.
- Fiebelkorn, I.C., Kastner, S., 2020. Functional specialization in the attention network. *Annu. Rev. Psychol.* 71 (71, 2020), 221–249. <https://doi.org/10.1146/annurev-psych-010418-103429>.
- Filmer, H.L., Griffin, A., Dux, P.E., 2019. For a minute there, I lost myself ... dosage dependent increases in mind wandering via prefrontal tDCS. *Neuropsychologia* 129, 379–384. <https://doi.org/10.1016/j.neuropsychologia.2019.04.013>.
- Fortenbaugh, F.C., DeGutis, J., Esterman, M., 2017. Recent theoretical, neural, and clinical advances in sustained attention research. *Ann. New. Y. Acad. Sci.* 1396 (1), 70–91. <https://doi.org/10.1111/nyas.13318>.
- Fox, M.D., Snyder, A.Z., Vincent, J.L., Corbetta, M., Van Essen, D.C., Raichle, M.E., 2005. The human brain is intrinsically organized into dynamic, anticorrelated functional networks. *Proc. Natl. Acad. Sci.* 102 (27), 9673–9678. <https://doi.org/10.1073/pnas.0504136102>.
- Fox, K.C.R., Spreng, R.N., Ellamil, M., Andrews-Hanna, J.R., Christoff, K., 2015. The wandering brain: Meta-analysis of functional neuroimaging studies of mind-wandering and related spontaneous thought processes. *NeuroImage* 111, 611–621. <https://doi.org/10.1016/j.neuroimage.2015.02.039>.
- Freedman, D.J., Riesenhuber, M., Poggio, T., Miller, E.K., 2001. Categorical Representation of Visual Stimuli in the Primate Prefrontal Cortex. *Science* 291 (5502), 312–316. <https://doi.org/10.1126/science.291.5502.312>.
- Fries, P., 2005. A mechanism for cognitive dynamics: neuronal communication through neuronal coherence. *Trends Cogn. Sci.* 9 (10), 474–480. <https://doi.org/10.1016/j.tics.2005.08.011>. PMID: 16150631.
- Frischen, A., Bayliss, A.P., Tipper, S.P., 2007. Gaze cueing of attention: Visual attention, social cognition, and individual differences. *Psychol. Bull.* 133 (4), 694–724. <https://doi.org/10.1037/0033-2909.133.4.694>.
- Gazzaley, A., Nobre, A.C., 2012. Top-down modulation: Bridging selective attention and working memory. *Trends Cogn. Sci.* 16 (2), 129–135. <https://doi.org/10.1016/j.tics.2011.11.014>.
- Gilbert, S.J., Frith, C.D., Burgess, P.W., 2005. Involvement of rostral prefrontal cortex in selection between stimulus-oriented and stimulus-independent thought. *Eur. J. Neurosci.* 21 (5), 1423–1431. <https://doi.org/10.1111/j.1460-9568.2005.03981.x>.
- Greicius, M.D., Krasnow, B., Boyett-Anderson, J.M., Eliez, S., Schatzberg, A.F., Reiss, A. L., Menon, V., 2003. Regional analysis of hippocampal activation during memory encoding and retrieval: fMRI study. *Hippocampus* 13 (1), 164–174. <https://doi.org/10.1002/hipo.10064>.
- Gresch, D., Boettcher, S.E.P., Gohil, C., Van Ede, F., Nobre, A.C., 2024a. Neural dynamics of shifting attention between perception and working-memory contents. *Proc. Natl. Acad. Sci.* 121 (47), e2406061121. <https://doi.org/10.1073/pnas.2406061121>.
- Gresch, D., Boettcher, S.E.P., Van Ede, F., Nobre, A.C., 2024b. Shifting attention between perception and working memory. *Cognition* 245, 105731. <https://doi.org/10.1016/j.cognition.2024.105731>.
- Groen, I.I.A., Dekker, T.M., Knapen, T., Silson, E.H., 2022. Visuospatial coding as ubiquitous scaffolding for human cognition. *Trends Cogn. Sci.* 26 (1), 81–96. <https://doi.org/10.1016/j.tics.2021.10.011>.
- Gu, S., Pasqualetti, F., Cieslak, M., Telesford, Q.K., Yu, A.B., Kahn, A.E., Medaglia, J.D., Vettel, J.M., Miller, M.B., Grafton, S.T., Bassett, D.S., 2015. Controllability of structural brain networks. *Nat. Commun.* 6, 8414. <https://doi.org/10.1038/ncomms9414>.
- Guerra, A., López-Alonso, V., Cheeran, B., Suppa, A., 2020. Variability in non-invasive brain stimulation studies: Reasons and results. *Neurosci. Lett. Non Invasive Brain Stimul.* 719, 133330. <https://doi.org/10.1016/j.neulet.2017.12.058>.
- Hammer, J., Kajsosa, M., Kalina, A., Krysl, D., Fabera, P., Kudr, M., Jezdik, P., Janca, R., Krsek, P., Marusic, P., 2024. Antagonistic behavior of brain networks mediated by low-frequency oscillations: Electrophysiological dynamics during internal-external attention switching. *Commun. Biol.* 7 (1), 1105. <https://doi.org/10.1038/s42003-024-06732-2>.
- Han, S., Long, N.M., 2025. Evidence for a reactionary account of retrieval state initiation. *Imaging Neurosci.* 3, IMAG.a.1023. <https://doi.org/10.1162/IMAG.a.1023>.
- Honey, C.J., Newman, E.L., Schapiro, A.C., 2017. Switching between internal and external modes: A multiscale learning principle. *Netw. Neurosci.* 1 (4), 339–356. <https://doi.org/10.1162/NETN.a.00024>.
- Hubbard, T.L., 2010. Auditory imagery: Empirical findings. *Psychol. Bull.* 136 (2), 302–329. <https://doi.org/10.1037/a0018436>.
- Ibáñez, M., Holman, D., Niven, K., 2024. Mind-wandering contents and characteristics: An exploratory study comparing between work and non-work contexts. *Eur. J. Work. Organ. Psychol.* 33 (4), 503–516. <https://doi.org/10.1080/1359432X.2024.2328373>.
- Itskov, V., Pastalkova, E., Mizuseki, K., Buzsáki, G., Harris, K.D., 2008. Theta-Mediated Dynamics of Spatial Information in Hippocampus. *J. Neurosci.* 28 (23), 5959–5964. <https://doi.org/10.1523/JNEUROSCI.5262-07.2008>.
- Iwata, T., Yanagisawa, T., Ikegaya, Y., Smallwood, J., Fukuma, R., Oshino, S., Tani, N., Khoo, H.M., Kishima, H., 2024. Hippocampal sharp-wave ripples correlate with periods of naturally occurring self-generated thoughts in humans. *Nat. Commun.* 15 (1), 4078. <https://doi.org/10.1038/s41467-024-48367-1>.
- Jacobson, L., Koslowsky, M., Lavidor, M., 2012. tDCS polarity effects in motor and cognitive domains: A meta-analytical review. *Exp. Brain Res.* 216 (1), 1–10. <https://doi.org/10.1007/s00221-011-2891-9>.
- Jensen, O., Lisman, J.E., 2005. Hippocampal sequence-encoding driven by a cortical multi-item working memory buffer. *Trends Neurosci.* 28 (2), 67–72. <https://doi.org/10.1016/j.tins.2004.12.001>.
- Jensen, O., Mazaheri, A., 2010. Shaping functional architecture by oscillatory alpha activity: Gating by inhibition. *Front. Human. Neurosci.* 4, 186. <https://doi.org/10.3389/fnhum.2010.00186>.
- Jha, A.P., Krompinger, J., Baime, M.J., 2007. Mindfulness training modifies subsystems of attention. *Cogn. Affect. & Behav. Neurosci.* 7 (2), 109–119. <https://doi.org/10.3758/CABN.7.2.109>.
- Jiang, Y., Zhang, H., Yu, S., 2021. Changes in delta and theta oscillations in the brain indicate dynamic switching of attention between internal and external processing. *4th Int. Conf. Biom. Eng. Appl.* 25–31. <https://doi.org/10.1145/3476779.3476784>.
- Johnson, E.L., Adams, J.N., Solbakk, A.-K., Endestad, T., Larsson, P.G., Ivanovic, J., Meling, T.R., Lin, J.J., Knight, R.T., 2018. Dynamic frontotemporal systems process space and time in working memory. *PLOS Biol.* 16 (3), e2004274. <https://doi.org/10.1371/journal.pbio.2004274>.
- Johnson, E.L., Kam, J.W.Y., Tzovara, A., Knight, R.T., 2020. Insights into human cognition from intracranial EEG: A review of audition, memory, internal cognition, and causality. *J. Neural Eng.* 17 (5), 051001. <https://doi.org/10.1088/1741-2552/abb7a5>.
- Kahneman, D., 1973. *Attention and effort*. Prentice-Hall.

- Kam, J.W.Y., Irving, Z.C., Mills, C., Patel, S., Gopnik, A., Knight, R.T., 2021. Distinct electrophysiological signatures of task-unrelated and dynamic thoughts. *Proc. Natl. Acad. Sci.* 118 (4), e2011796118. <https://doi.org/10.1073/pnas.2011796118>.
- Kam, J.W.Y., Lin, J.J., Solbakk, A.-K., Endestad, T., Larsson, P.G., Knight, R.T., 2019. Default network and frontoparietal control network theta connectivity supports internal attention. *Nat. Human. Behav.* 3 (12), 1263–1270. <https://doi.org/10.1038/s41562-019-0717-0>.
- Kam, J.W.Y., Rahnuma, T., Nanjappan Jothiraj, S., Ouellette-Zuk, A.A., Knight, R.T., 2025. Electrophysiological signatures of ongoing thoughts during naturalistic behavior. *Imaging Neuroscience* (Cambridge Mass.) 3, IMAG.a.20. <https://doi.org/10.1162/IMAG.a.20>.
- Kam, J.W.Y., Rahnuma, T., Park, Y.E., Hart, C.M., 2022. Electrophysiological markers of mind wandering: A systematic review. *NeuroImage* 258, 119372. <https://doi.org/10.1016/j.neuroimage.2022.119372>.
- Kam, J.W.Y., Rai, S., Jothiraj, S.N., Lender, J., 2026. Aperiodic and oscillatory neural activity underlying external and internal attention. *Biol. Psychol.* 209, 109307.
- Kam, J.W.Y., Solbakk, A.-K., Endestad, T., Meling, T.R., Knight, R.T., 2018a. Lateral prefrontal cortex lesion impairs regulation of internally and externally directed attention. *NeuroImage* 175, 91–99. <https://doi.org/10.1016/j.neuroimage.2018.03.063>.
- Kam, J.W.Y., Solbakk, A.-K., Funderud, I., Endestad, T., Meling, T.R., Knight, R.T., 2018b. Orbitofrontal damage reduces auditory sensory response in humans. *Cortex* 101, 309–312. <https://doi.org/10.1016/j.cortex.2017.12.023>.
- Kam, J.W.Y., Szczepanski, S.M., Canolty, R.T., Flinker, A., Auguste, K.I., Crone, N.E., Kirsch, H.E., Kuperman, R.A., Lin, J.J., Parvizi, J., Knight, R.T., 2018c. Differential Sources for 2 Neural Signatures of Target Detection: An Electroconvitography Study. *Cereb. Cortex* 28 (1), 9–20. <https://doi.org/10.1093/cercor/bhw343>.
- Kam, J.W.Y., Wong, A.Y., Thiemann, R.F., Hasan, F., Andrews-Hanna, J.R., Mills, C., 2024. On the relationship between unprompted thought and affective well-being: A systematic review and meta-analysis. *Psychol. Bull.* 150 (5), 621–641. <https://doi.org/10.1037/bul0000428>.
- Kane, M.J., Brown, L.H., McVay, J.C., Silvia, P.J., Myin-Germeys, I., Kwapil, T.R., 2007. For Whom the Mind Wanders, and When: An Experience-Sampling Study of Working Memory and Executive Control in Daily Life. *Psychol. Sci.* 18 (7), 614–621. <https://doi.org/10.1111/j.1467-9280.2007.01948.x>.
- Katsuki, F., Constantinidis, C., 2014. Bottom-Up and Top-Down Attention: Different Processes and Overlapping Neural Systems. *Neuroscientist* 20 (5), 509–521. <https://doi.org/10.1177/1073858413514136>.
- Kawashima, I., Hinuma, T., Tanaka, S.C., 2023. Ecological momentary assessment of mind-wandering: Meta-analysis and systematic review. *Sci. Rep.* 13 (1), 2873. <https://doi.org/10.1038/s41598-023-29854-9>.
- Kim, C., Cilles, S.E., Johnson, N.F., Gold, B.T., 2012. Domain general and domain preferential brain regions associated with different types of task switching: A Meta-Analysis. *Human. Brain Mapp.* 33 (1), 130–142. <https://doi.org/10.1002/hbm.21199>.
- Kiyonaga, A., Egner, T., 2013. Working memory as internal attention: Toward an integrative account of internal and external selection processes. *Psychon. Bull. & Rev.* 20 (2), 228–242. <https://doi.org/10.3758/s13423-012-0359-y>.
- Kiyonaga, A., Egner, T., 2014. The Working Memory Stroop Effect: When Internal Representations Clash With External Stimuli. *Psychol. Sci.* 25 (8), 1619–1629. <https://doi.org/10.1177/0956797614536739>.
- Koch, I., Poljac, E., Müller, H., Kiesel, A., 2018. Cognitive structure, flexibility, and plasticity in human multitasking—An integrative review of dual-task and task-switching research. *Psychol. Bull.* 144 (6), 557–583. <https://doi.org/10.1037/bul0000144>.
- Kosslyn, S.M., 2005. Mental images and the Brain. *Cogn. Neuropsychol.* 22 (3–4), 333–347. <https://doi.org/10.1080/02643290442000130>.
- Kuciy, A., Daitch, A., Raccach, O., Zhao, B., Zhang, C., Esterman, M., Zeineh, M., Halpern, C.H., Zhang, K., Zhang, J., Parvizi, J., 2020. Electrophysiological dynamics of antagonistic brain networks reflect attentional fluctuations. *Nat. Commun.* 11 (1), 325. <https://doi.org/10.1038/s41467-019-14166-2>.
- Kuciy, A., Esterman, M., Capella, J., Green, A., Uchida, M., Biederman, J., Gabrieli, J.D., E., Valera, E.M., Whitfield-Gabrieli, S., 2021. Prediction of stimulus-independent and task-unrelated thought from functional brain networks. *Nat. Commun.* 12, 1793. <https://doi.org/10.1038/s41038-021-22027-0>.
- Kuhl, B.A., Wagner, A.D., 2009. Forgetting and retrieval. In: *Handbook of neuroscience for the behavioral sciences*, 1. John Wiley & Sons, Inc, pp. 586–605. <https://doi.org/10.1002/9780470478509.neubb001031>.
- Kvavilashvili, L., Rummel, J., 2020. On the Nature of Everyday Prospection: A Review and Theoretical Integration of Research on Mind-Wandering, Future Thinking, and Prospective Memory. *Rev. General. Psychol.* 24 (3), 210–237. <https://doi.org/10.1177/1089268020918843>.
- Langner, R., Eickhoff, S.B., 2013. Sustaining attention to simple tasks: A meta-analytic review of the neural mechanisms of vigilant attention. *Psychol. Bull.* 139 (4), 870–900. <https://doi.org/10.1037/a0030694>.
- Laroche, S., Davis, S., Jay, T.M., 2000. Plasticity at hippocampal to prefrontal cortex synapses: Dual roles in working memory and consolidation. *Hippocampus* 10 (4), 438–446. [https://doi.org/10.1002/1098-1063\(2000\)10:4%3C438::AID-HIPO10%3E3.0.CO;2-3](https://doi.org/10.1002/1098-1063(2000)10:4%3C438::AID-HIPO10%3E3.0.CO;2-3).
- Li, Y.P., Wang, Y., Turk-Browne, N.B., Kuhl, B.A., Hutchinson, J.B., 2023. Perception and memory retrieval states are reflected in distributed patterns of background functional connectivity. *NeuroImage* 276, 120221. <https://doi.org/10.1016/j.neuroimage.2023.120221>.
- Liu, B., van Ede, F., 2025. Concurrent selection of internal goals and external sensations during visual search. *Sci. Adv.* 11 (45), ead8191. <https://doi.org/10.1126/sciadv.ad8191>.
- Logie, R.H., Zucco, G.M., Baddeley, A.D., 1990. Interference with visual short-term memory. *Acta Psychol.* 75 (1), 55–74. [https://doi.org/10.1016/0001-6918\(90\)90066-0](https://doi.org/10.1016/0001-6918(90)90066-0).
- Long, N.M., 2023. The intersection of the retrieval state and internal attention. *Nat. Commun.* 14 (1), 3861. <https://doi.org/10.1038/s41467-023-39609-9>.
- Long, N.M., Kuhl, B.A., Chun, M.M., 2018. Memory and Attention. *Stevens' Handbook of Experimental Psychology and Cognitive Neuroscience*. John Wiley & Sons, Ltd, pp. 1–37. <https://doi.org/10.1002/9781119170174.epcn109>.
- Lu, J.G., Akinola, M., Mason, M.F., 2017. Switching On" creativity: Task switching can increase creativity by reducing cognitive fixation. *Organ. Behav. Human. Decis. Process.* 139, 63–75. <https://doi.org/10.1016/j.obhdp.2017.01.005>.
- Lückmann, H.C., Jacobs, H.L., Sack, A.T., 2014. The cross-functional role of frontoparietal regions in cognition: Internal attention as the overarching mechanism. *Progress. Neurobiol.* 116, 66–86. <https://doi.org/10.1016/j.pneurobio.2014.02.002>.
- Lux, B.K., Andrews-Hanna, J.R., Han, J., Lee, E., Woo, C.-W., 2022. When self comes to a wandering mind: Brain representations and dynamics of self-generated concepts in spontaneous thought. *Sci. Adv.* 8 (35), eabn8616. <https://doi.org/10.1126/sciadv.abn8616>.
- Mackworth, J.F., 1968. Vigilance, arousal, and habituation. *Psychol. Rev.* 75 (4), 308–322. <https://doi.org/10.1037/h0025896>.
- Magosso, E., Ricci, G., Ursino, M., 2021. Alpha and theta mechanisms operating in frontal-external regions in cognition: Internal attention as the overarching mechanism. *J. Integr. Neurosci.* 20 (1), 1. <https://doi.org/10.31083/j.jin.2021.01.422>.
- Maillet, D., Yu, L., Lau, B., Chow, R., Alain, C., Grady, C.L., 2020. Differential effects of mind-wandering and visual distraction on age-related changes in neuro-electric brain activity and variability. *Neuropsychologia* 146, 107565. <https://doi.org/10.1016/j.neuropsychologia.2020.107565>.
- Margulies, D.S., Ghosh, S.S., Goulas, A., Falkiewicz, M., Huntenburg, J.M., Langs, G., Bezin, G., Eickhoff, S.B., Castellanos, F.X., Petrides, M., Jefferies, E., Smallwood, J., 2016. Situating the default-mode network along a principal gradient of macroscale cortical organization. *Proc. Natl. Acad. Sci.* 113 (44), 12574–12579. <https://doi.org/10.1073/pnas.1608282113>.
- Martz, E., Bertschy, G., Kraemer, C., Weibel, S., Weiner, L., 2021. Beyond motor hyperactivity: Racing thoughts are an integral symptom of adult attention deficit hyperactivity disorder. *Psychiatry Res.* 301, 113988. <https://doi.org/10.1016/j.psychres.2021.113988>.
- Matsuoka, T., Shimode, T., Ota, T., Matsuo, K., 2021. Event-related alpha-band power changes during self-reflection and working memory tasks in healthy individuals. *Front. Human. Neurosci.* 14, 570279. <https://doi.org/10.3389/fnhum.2020.570279>.
- Mayr, U., Kliegl, R., 2000. Task-set switching and long-term memory retrieval. *J. Exp. Psychol. Learn. Mem. Cogn.* 26 (5), 1124–1140. <https://doi.org/10.1037/0278-7393.26.5.1124>.
- McCormick, C., Moscovitch, M., Protzner, A.B., Huber, C.G., McAndrews, M.P., 2010. Hippocampal-neocortical networks differ during encoding and retrieval of relational memory: Functional and effective connectivity analyses. *Neuropsychologia* 48 (11), 3272–3281. <https://doi.org/10.1016/j.neuropsychologia.2010.07.010>.
- McIntosh, A.R., 2000. Towards a network theory of cognition. *Neural Netw.* 13 (8), 861–870. [https://doi.org/10.1016/S0893-6080\(00\)00059-9](https://doi.org/10.1016/S0893-6080(00)00059-9).
- Mckeown, B., Goodall-Halliwel, I., Wallace, R., Chitiz, L., Mulholland, B., Karapanagiotidis, T., Hardikar, S., Strawson, W., Turnbull, A., Vanderwal, T., Ho, N., Wang, H.-T., Xu, T., Milham, M., Wang, X., Zhang, M., Gonzalez Alam, T.R., Vos de Wael, R., Bernhardt, B., Smallwood, J., 2025. Self-reports map the landscape of task states derived from brain imaging. *Commun. Psychol.* 3, 8. <https://doi.org/10.1038/s44271-025-00184-y>.
- McLaughlin, K.A., Nolen-Hoeksema, S., 2011. Rumination as a Transdiagnostic Factor in Depression and Anxiety. *Behav. Res. Ther.* 49 (3), 186–193. <https://doi.org/10.1016/j.brat.2010.12.006>.
- Meiran, N., 1996. Reconfiguration of processing mode prior to task performance. *J. Exp. Psychol. Learn. Mem. Cogn.* 22 (6), 1423–1442. <https://doi.org/10.1037/0278-7393.22.6.1423>.
- Melby-Lervåg, M., Hulme, C., 2013. Is Working Memory Training Effective? A Meta-Analytic Review. *Dev. Psychol.* 49 (2), 270–291. <https://doi.org/10.1037/a0028228>.
- Menon, V., 2023. 20 years of the default mode network: A review and synthesis. *Neuron* 111 (16), 2469–2487. <https://doi.org/10.1016/j.neuron.2023.04.023>.
- Menon, V., Uddin, L.Q., 2010. Saliency, switching, attention and control: a network model of insula function. *Brain Struct. Funct.* 214 (5), 655–667. <https://doi.org/10.1007/s00429-010-0262-0>.
- Mesulam, M., 1998. From sensation to cognition. *Brain* 121 (6), 1013–1052. <https://doi.org/10.1093/brain/121.6.1013>.
- Miller, E.K., Cohen, J.D., 2001. An Integrative Theory of Prefrontal Cortex Function. *Annu. Rev. Neurosci.* 24 (24, 2001), 167–202. <https://doi.org/10.1146/annurev.neuro.24.1.167>.
- Miller, K.J., Honey, C.J., Hermes, D., Rao, R.P., denNijs, M., Ojemann, J.G., 2014. Broadband changes in the cortical surface potential track activation of functionally diverse neuronal populations. *NeuroImage New. Horiz. Neural Oscil.* 85, 711–720. <https://doi.org/10.1016/j.neuroimage.2013.08.070>.
- Mills, C., Raffaelli, Q., Irving, Z.C., Stan, D., Christoff, K., 2018. Is an off-task mind a freely-moving mind? Examining the relationship between different dimensions of thought. *Conscious. Cogn.* 58, 20–33. <https://doi.org/10.1016/j.concog.2017.10.003>.
- Mittner, M., Boekel, W., Tucker, A.M., Turner, B.M., Heathcote, A., Forstmann, B.U., 2014. When the brain takes a break: a model-based analysis of mind wandering. *J. Neurosci.* 34 (49), 16286–16295. <https://doi.org/10.1523/JNEUROSCI.2062-14.2014>.

- Mittner, M., Hawkins, G.E., Boekel, W., Forstmann, B.U., 2016. A neural model of mind wandering. *Trends Cogn. Sci.* 20 (8), 570–578. <https://doi.org/10.1016/j.tics.2016.06.004>.
- Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., Wager, T.D., 2000. The Unity and Diversity of Executive Functions and Their Contributions to Complex “Frontal Lobe” Tasks: A Latent Variable Analysis. *Cogn. Psychol.* 41 (1), 49–100. <https://doi.org/10.1006/cogp.1999.0734>.
- Monsell, S., 2003. Task switching. *Trends Cogn. Sci.* 7 (3), 134–140. [https://doi.org/10.1016/S1364-6613\(03\)00028-7](https://doi.org/10.1016/S1364-6613(03)00028-7).
- Monsell, S., Mizon, G.A., 2006. Can the task-cuing paradigm measure an endogenous task-set reconfiguration process? *J. Exp. Psychol. Human. Percept. Perform.* 32 (3), 493–516. <https://doi.org/10.1037/0096-1523.32.3.493>.
- Musslick, S., Bizyaeva, A., Agaron, S., Leonard, N., Cohen, J.D., 2019. Stability-Flexibility Dilemma. *Cogn. Control. A Dyn. Syst. Perspect.*
- Myers, N.E., Stokes, M.G., Nobre, A.C., 2017. Prioritizing information during working memory: beyond sustained internal attention. *Trends Cogn. Sci.* 21 (6), 449–461. <https://doi.org/10.1016/j.tics.2017.03.010>.
- Narhi-Martinez, W., Dube, B., Golomb, J.D., 2023. Attention as a multi-level system of weights and balances. *WIREs Cogn. Sci.* 14 (1), e1633. <https://doi.org/10.1002/wcs.1633>.
- Nee, D.E., 2021. Integrative frontal-parietal dynamics supporting cognitive control. *eLife* 10, e57244. <https://doi.org/10.7554/eLife.57244>.
- Nobre, A.C., Gresch, D., 2025. How the brain shifts between external and internal attention. *Neuron* 113 (15), 2382–2398. <https://doi.org/10.1016/j.neuron.2025.06.013>.
- Nolen-Hoeksema, S., 2000. The role of rumination in depressive disorders and mixed anxiety/depressive symptoms, 109 (3), 504–511. <https://doi.org/10.1037/0021-843X.109.3.504>.
- Nyberg, L., McIntosh, A.R., Houle, S., Nilsson, L.-G., Tulving, E., 1996. Activation of medial temporal structures during episodic memory retrieval. *Nature* 380 (6576), 715–717. <https://doi.org/10.1038/380715a0>.
- O'Reilly, R.C., Frank, M.J., 2006. Making working memory work: a computational model of learning in the prefrontal cortex and basal ganglia, 19099466 *Neural Comput.* 18 (2), 283–328. <https://doi.org/10.1162/089976606775093909>.
- Oberauer, K., 2019. Working memory and attention – a conceptual analysis and review. *J. Cogn.* 2 (1), 36. <https://doi.org/10.5334/joc.58>.
- Oken, B.S., Salinsky, M.C., Elsas, S.M., 2006. Vigilance, alertness, or sustained attention: Physiological basis and measurement. *Clin. Neurophysiol.* 117 (9), 1885–1901. <https://doi.org/10.1016/j.clinph.2006.01.017>.
- Olivers, C.N.L., Peters, J., Houtkamp, R., Roelfsema, P.R., 2011. Different states in visual working memory: When it guides attention and when it does not. *Trends Cogn. Sci.* S1364661311000854 <https://doi.org/10.1016/j.tics.2011.05.004>.
- Orquin, J.L., Lahm, E.S., Stojic, H., 2021. The visual environment and attention in decision making. *Psychol. Bull.* 147 (6), 597–617. <https://doi.org/10.1037/bul0000328>.
- Palva, S., Palva, J.M., 2011. Functional roles of alpha-band phase synchronization in local and large-scale cortical networks. *Front. Psychol.* 2, 204. <https://doi.org/10.3389/fpsyg.2011.00204>.
- Panichello, M.F., Buschman, T.J., 2021. Shared mechanisms underlie the control of working memory and attention. *Nature* 592 (7855), 601–605. <https://doi.org/10.1038/s41586-021-03390-w>.
- Park, H.-J., Friston, K., 2013. Structural and functional brain networks: from connections to cognition. *Science* 342 (6158), 1238411. <https://doi.org/10.1126/science.1238411>.
- Parvizi, J., Kastner, S., 2018. Promises and limitations of human intracranial electroencephalography. *Nat. Neurosci.* 21 (4), 474–483. <https://doi.org/10.1038/s41593-018-0108-2>.
- Peng, P., Miller, A.C., 2016. Does attention training work? A selective meta-analysis to explore the effects of attention training and moderators. *Learn. Individ. Differ.* 45, 77–87. <https://doi.org/10.1016/j.lindif.2015.11.012>.
- Petersen, S.E., Posner, M.I., 2012. The attention system of the human brain: 20 years after. *Annu. Rev. Neurosci.* 35 (1), 73–89. <https://doi.org/10.1146/annurev-neuro-062111-150525>.
- Peylo, C., Hilla, Y., Sauseng, P., 2021. Cause or consequence? Alpha oscillations in visuospatial attention. *Trends Neurosci.* 44 (9), 705–713. <https://doi.org/10.1016/j.tics.2021.05.004>.
- Polanía, R., Nitsche, M.A., Ruff, C.C., 2018. Studying and modifying brain function with non-invasive brain stimulation. *Nat. Neurosci.* 21 (2), 174–187. <https://doi.org/10.1038/s41593-017-0054-4>.
- Poskanzer, C., Aly, M., 2023. Switching between External and Internal Attention in Hippocampal Networks. *J. Neurosci.* 43 (38), 6538–6552. <https://doi.org/10.1523/JNEUROSCI.0029-23.2023>.
- Poskanzer, C., Tarder-Stoll, H., Javid, R., Spolaore, E., Aly, M., 2025. Successful prediction is associated with enhanced encoding. *Open. Mind* 9, 959–991. <https://doi.org/10.1162/opmi.a.15>.
- Posner, M.I., Petersen, S.E., 1990. The attention system of the human brain. *Annu. Rev. Neurosci.* 13 (13, 1990), 25–42. <https://doi.org/10.1146/annurev.ne.13.030190.000325>.
- Postle, B.R., 2006. Working memory as an emergent property of the mind and brain. *Neuroscience* 139 (1), 23–38. <https://doi.org/10.1016/j.neuroscience.2005.06.005>.
- Raffaelli, Q., Mills, C., de Stefano, N.-A., Mehl, M.R., Chambers, K., Fitzgerald, S.A., Wilcox, R., Christoff, K., Andrews, E.S., Grilli, M.D., O'Connor, M.-F., Andrews-Hanna, J.R., 2021. The think aloud paradigm reveals differences in the content, dynamics and conceptual scope of resting state thought in trait brooding. *Sci. Rep.* 11 (1), 19362. <https://doi.org/10.1038/s41598-021-98138-x>.
- Raffaelli, Q., Rai, S., Galbraith, A., Krupa, A., Buerkner, J., Andrews-Hanna, J.R., Callahan, B.L., Kam, J.W.Y., 2025. Hyperactive ADHD symptoms are associated with increased variability in thought content in less constrained contexts. *Sci. Rep.* 15 (1), 9792. <https://doi.org/10.1038/s41598-025-93053-x>.
- Raichle, M.E., 2015. The brain's default mode network. *Annu. Rev. Neurosci.* 38 (38, 2015), 433–447. <https://doi.org/10.1146/annurev-neuro-071013-014030>.
- Rasmussen, T., Dux, P.E., Filmer, H., 2025. On the neural substrates of mind wandering and dynamic thought: a drug and brain stimulation study. *Neuroscience*. <https://doi.org/10.1101/2024.11.02.620526>.
- Raud, L., Sneve, M.H., Vidal-Piñero, D., Sørensen, Ø., Folvik, L., Ness, H.T., Mowinckel, A.M., Grydeland, H., Walhovd, K.B., Fjell, A.M., 2023. Hippocampal-cortical functional connectivity during memory encoding and retrieval. *NeuroImage* 279, 120309. <https://doi.org/10.1016/j.neuroimage.2023.120309>.
- Raz, A., Buhle, J., 2006. Typologies of attentional networks. *Nat. Rev. Neurosci.* 7 (5), 367–379. <https://doi.org/10.1038/nrn1903>.
- Rushworth, M.F.S., Passingham, R.E., Nobre, A.C., 2002. Components of switching intentional set. *J. Cogn. Neurosci.* 14 (8), 1139–1150. <https://doi.org/10.1162/089892902760807159>.
- Rushworth, M.F.S., Passingham, R.E., Nobre, A.C., 2005. Components of attentional set-switching. *Exp. Psychol.* 52 (2), 83–98. <https://doi.org/10.1027/1618-3169.52.2.83>.
- Sakai, K., 2008. Task set and prefrontal cortex. *Annu. Rev. Neurosci.* 31 (31, 2008), 219–245. <https://doi.org/10.1146/annurev-neuro.31.060407.125642>.
- Sala, G., Aksayli, N.D., Tatlidil, K.S., Tatsumi, T., Gondo, Y., Gobet, F., 2019. Near and far transfer in cognitive training: a second-order meta-analysis. *Collabra Psychol.* 5 (1), 18. <https://doi.org/10.1525/collabra.203>.
- Salvi, C., Bricolo, E., Franconeri, S.L., Kounios, J., Beeman, M., 2015. Sudden insight is associated with shutting out visual inputs. *Psychon. Bull. & Rev.* 22 (6), 1814–1819. <https://doi.org/10.3758/s13423-015-0845-0>.
- Scheibner, H.J., Bogler, C., Gleich, T., Haynes, J.-D., Bermpohl, F., 2017. Internal and external attention and the default mode network. *NeuroImage* 148, 381–389. <https://doi.org/10.1016/j.neuroimage.2017.01.044>.
- Schooler, J.W., Smallwood, J., Christoff, K., Handy, T.C., Reichle, E.D., Sayette, M.A., 2011. Meta-awareness, perceptual decoupling and the wandering mind. *Trends Cogn. Sci.* 15 (7), 319–326. <https://doi.org/10.1016/j.tics.2011.05.006>.
- Schulz, E., Gershman, S.J., 2019. The algorithmic architecture of exploration in the human brain. *Curr. Opin. Neurobiol.* 55, 7–14.
- Schwaighofer, M., Fischer, F., Bühner, M., 2015. Does working memory training transfer? A meta-analysis including training conditions as moderators. *Educ. Psychol.* 50 (2), 138–166. <https://doi.org/10.1080/00461520.2015.1036274>.
- Schwartz, B.L., Cleary, A.M., 2025. Tulving's (1989) Doctrine of Concordance Revisited. *J. Cogn.* 8 (1), 36. <https://doi.org/10.5334/joc.447>.
- Scolari, M., Seidl-Rathkopf, K.N., Kastner, S., 2015. Functions of the human frontoparietal attention network: Evidence from neuroimaging. *Curr. Opin. Behav. Sci. Cogn. Control.* 1, 32–39. <https://doi.org/10.1016/j.cobeha.2014.08.003>.
- Semple, R.J., 2010. Does mindfulness meditation enhance attention? a randomized controlled trial. *Mindfulness* 1 (2), 121–130. <https://doi.org/10.1007/s12671-010-0017-2>.
- Servais, A., Hurter, C., Barbeau, E.J., 2023. Attentional switch to memory: an early and critical phase of the cognitive cascade allowing autobiographical memory retrieval. *Psychon. Bull. & Rev.* 30 (5), 1707–1721. <https://doi.org/10.3758/s13423-023-02270-w>.
- Smallwood, J., 2013. Distinguishing how from why the mind wanders: a process-occurrence framework for self-generated mental activity. *Psychol. Bull.* 139 (3), 519–535. <https://doi.org/10.1037/a0030010>.
- Smallwood, J., Schooler, J.W., 2006. The restless mind. *Psychol. Bull.* 132 (6), 946–958. <https://doi.org/10.1037/0033-2909.132.6.946>.
- Smallwood, J., Schooler, J.W., 2015. The science of mind wandering: empirically navigating the stream of consciousness. *Annu. Rev. Psychol.* 66 (66, 2015), 487–518. <https://doi.org/10.1146/annurev-psych-010814-015331>.
- Song, H., Finn, E.S., Rosenberg, M.D., 2021. Neural signatures of attentional engagement during narratives and its consequences for event memory. *Proc. Natl. Acad. Sci. USA* 118 (33), e2021905118. <https://doi.org/10.1073/pnas.2021905118>.
- Sormaz, M., Murphy, C., Wang, H., Hymers, M., Karapanagiotidis, T., Poerio, G., Margulies, D.S., Jefferies, E., Smallwood, J., 2018. Default mode network can support the level of detail in experience during active task states. *Proc. Natl. Acad. Sci.* 115 (37), 9318–9323. <https://doi.org/10.1073/pnas.1721259115>.
- Soto, D., Hodson, J., Rotshtein, P., Humphreys, G.W., 2008. Automatic guidance of attention from working memory. *Trends Cogn. Sci.* 12 (9), 342–348. <https://doi.org/10.1016/j.tics.2008.05.007>.
- Souza, A.S., Oberauer, K., 2016. search of the focus of attention in working memory: 13 years of the retro-cue effect. *Atten. Percept. & Psychophys.* 78 (7), 1839–1860. <https://doi.org/10.3758/s13414-016-1108-5>.
- Spreng, R.N., Gerlach, K.D., Turner, G.R., Schacter, D.L., 2015. Autobiographical planning and the brain: activation and its modulation by qualitative features, 110074434 *J. Cogn. Neurosci.* 27 (11), 2147–2157. https://doi.org/10.1162/jocn_a.00846.
- Spreng, R.N., Sepulcre, J., Turner, G.R., Stevens, W.D., Schacter, D.L., 2013. Intrinsic Architecture Underlying the Relations among the Default, Dorsal Attention, and Frontoparietal Control Networks of the Human Brain, 83866607 *J. Cogn. Neurosci.* 25 (1), 74–86. https://doi.org/10.1162/jocn_a.00281.
- Spreng, R.N., Stevens, W.D., Chamberlain, J.P., Gilmore, A.W., Schacter, D.L., 2010. Default network activity, coupled with the frontoparietal control network, supports goal-directed cognition. *NeuroImage* 53 (1), 303–317. <https://doi.org/10.1016/j.neuroimage.2010.06.016>.

- Stawarczyk, D., Majerus, S., Maquet, P., D'Argembeau, A., 2011. Neural correlates of ongoing conscious experience: both task-unrelatedness and stimulus-independence are related to default network activity. *PLOS ONE* 6 (2), e16997. <https://doi.org/10.1371/journal.pone.0016997>.
- Steel, A., Silson, E.H., Garcia, B.D., Robertson, C.E., 2024. A retinotopic code structures the interaction between perception and memory systems. *Nat. Neurosci.* 27 (2), 339–347. <https://doi.org/10.1038/s41593-023-01512-3>.
- Stokes, M.G., Atherton, K., Patai, E.Z., Nobre, A.C., 2012. Long-term memory prepares neural activity for perception. *Proc. Natl. Acad. Sci.* 109 (6), E360–E367. <https://doi.org/10.1073/pnas.110855108>.
- Su, H., Li, X., Born, S., Honey, C.J., Chen, J., Lee, H., 2025. Neural dynamics of spontaneous memory recall and future thinking in the continuous flow of thoughts. *Nat. Commun.* 16, 6433. <https://doi.org/10.1038/s41467-025-61807-w>.
- Szpunar, K.K., Moulton, S.T., Schacter, D.L., 2013. Mind wandering and education: From the classroom to online learning. *Front. Psychol.* 4, 495. <https://doi.org/10.3389/fpsyg.2013.00495>.
- Tamber-Rosenau, B.J., Esterman, M., Chiu, Y.-C., Yantis, S., 2011. Cortical mechanisms of cognitive control for shifting attention in vision and working memory. *J. Cogn. Neurosci.* 23 (10), 2905–2919. <https://doi.org/10.1162/jocn.2011.21608>.
- Tang, Y.-Y., Posner, M.I., 2009. Attention training and attention state training. *Trends Cogn. Sci.* 13 (5), 222–227. <https://doi.org/10.1016/j.tics.2009.01.009>.
- Tarder-Stoll, H., Jayakumar, M., Dimsdale-Zucker, H.R., Günseli, E., Aly, M., 2020. Dynamic internal states shape memory retrieval. *Neuropsychologia* 138, 107328. <https://doi.org/10.1016/j.neuropsychologia.2019.107328>.
- Tas, A.C., Luck, S.J., Hollingworth, A., 2016. The relationship between visual attention and visual working memory encoding: A dissociation between covert and overt orienting. *J. Exp. Psychol. Human. Percept. Perform.* 42 (8), 1121–1138. <https://doi.org/10.1037/xhp0000212>.
- Teasdale, J.D., Dritschel, B.H., Taylor, M.J., Proctor, L., Lloyd, C.A., Nimmo-Smith, I., Baddeley, A.D., 1995. Stimulus-independent thought depends on central executive resources. *Mem. & Cogn.* 23 (5), 551–559. <https://doi.org/10.3758/BF03197257>.
- Thom, R.P., McDougle, C.J., 2023. Repetitive thoughts and behaviors in autism spectrum disorder: a symptom-based framework for novel therapeutics. *ACS Chem. Neurosci.* 14 (6), 1007–1016. <https://doi.org/10.1021/acscchemneuro.2c00731>.
- Treder, M.S., Charest, I., Michelmann, S., Martín-Buro, M.C., Roux, F., Carceller-Benito, F., Ugalde-Canitrot, A., Rollings, D.T., Sawlani, V., Chelvarajah, R., Wimber, M., Hanslmayr, S., Staresina, B.P., 2021. The hippocampus as the switchboard between perception and memory. *Proc. Natl. Acad. Sci.* 118 (50), e2114711118. <https://doi.org/10.1073/pnas.2114711118>.
- Treisman, A.M., 1969. *Strateg. MODEL SELECTIVE Atten.* 76 (3), 282–299. <https://doi.org/10.1037/h0027242>.
- Turnbull, A., Wang, H.T., Murphy, C., Ho, N.S.P., Wang, X., Sormaz, M., Karapanagiotidis, T., Leech, R.M., Bernhardt, B., Margulies, D.S., Vatansever, D., Jefferies, E., Smallwood, J., 2019. Left dorsolateral prefrontal cortex supports context-dependent prioritisation of off-task thought. *Nat. Commun.* 10, 3816. <https://doi.org/10.1038/s41467-019-11764-y>.
- Uddin, L.Q., 2015. Salience processing and insular cortical function and dysfunction. *Nat. Rev. Neurosci.* 16 (1), 55–61. <https://doi.org/10.1038/nrn3857>.
- Ueltzhöffer, K., Armbruster-Genç, D.J.N., Fiebach, C.J., 2015. Stochastic dynamics underlying cognitive stability and flexibility. *PLOS Comput. Biol.* 11 (6), e1004331. <https://doi.org/10.1371/journal.pcbi.1004331>.
- Ujhelyi, B., Korda, Z., Zaretskaya, N., 2026. The contribution of default mode network areas to visual perception. *Trends Neurosci.* 49 (6), 450–463. <https://doi.org/10.1016/j.tins.2026.03.009>.
- van Ede, F., Nobre, A.C., 2023. Turning attention inside out: how working memory serves behavior. *Annu. Rev. Psychol.* 74 (74, 2023), 137–165. <https://doi.org/10.1146/annurev-psych-021422-041757>.
- Van Ede, F., Nobre, A.C., 2021. Toward a neurobiology of internal selective attention. *Trends Neurosci.* 44 (7), 513–515. <https://doi.org/10.1016/j.tins.2021.04.010>.
- van Harmelen, A.M., Rol, L., van Ede, F., 2026. *bioRxiv*, 04.08.717206. Extern. driven Atten. Intern. Work. Mem. Content 2026. <https://doi.org/10.64898/2026.04.08.717206>.
- van Strien, N.M., Cappaert, N.L.M., Witter, M.P., 2009. The anatomy of memory: An interactive overview of the parahippocampal–hippocampal network. *Nat. Rev. Neurosci.* 10 (4), 272–282. <https://doi.org/10.1038/nrn2614>.
- Vandierendonck, A., Liefvooghe, B., Verbruggen, F., 2010. Task switching: Interplay of reconfiguration and interference control. *Psychol. Bull.* 136 (4), 601–626. <https://doi.org/10.1037/a0019791>.
- Vaseghi, B., Zoghi, M., Jaberzadeh, S., 2014. Does anodal transcranial direct current stimulation modulate sensory perception and pain? A meta-analysis study. *Clin. Neurophysiol.* 125 (9), 1847–1858. <https://doi.org/10.1016/j.clinph.2014.01.020>.
- Vatansever, D., Menon, D.K., Manktelow, A.E., Sahakian, B.J., Stamatakis, E.A., 2015. Default mode network connectivity during task execution. *NeuroImage* 122, 96–104. <https://doi.org/10.1016/j.neuroimage.2015.07.053>.
- Verschooren, S., Dahl, M.J., Aly, M., Mittner, M., 2026. Transition dynamics of external and internal attention across on-task and off-task states. *Nat. Rev. Psychol.* 5 (7), 493–509. <https://doi.org/10.1038/s44159-026-00578-7>.
- Verschooren, S., Egner, T., Aly, M., 2026. Competition, concurrence, and cooperation between external and internal attention. In: *Psychology & Psychiatry Journal*, 462. Psychology, Gale OneFile.
- Verschooren, S., Egner, T., 2023. When the mind's eye prevails: The Internal Dominance over External Attention (IDEA) hypothesis. *Psychon. Bull. & Rev.* 30 (5), 1668–1688. <https://doi.org/10.3758/s13423-023-02272-8>.
- Verschooren, S., Kessler, Y., Egner, T., 2021. Evidence for a single mechanism gating perceptual and long-term memory information into working memory. *Cognition* 212, 104668. <https://doi.org/10.1016/j.cognition.2021.104668>.
- Verschooren, S., Liefvooghe, B., Brass, M., & Pourtois, G. (2019a). Attentional Flexibility Is Imbalanced: Asymmetric Cost for Switches Between External and Internal Attention.
- Verschooren, S., Schindler, S., De Raedt, R., Pourtois, G., 2019b. Switching attention from internal to external information processing: A review of the literature and empirical support of the resource sharing account. *Psychon. Bull. & Rev.* 26 (2), 468–490. <https://doi.org/10.3758/s13423-019-01568-y>.
- Verschooren, S., Schindler, S., De Raedt, R., Pourtois, G., 2021. Early reduction of sensory processing within the visual cortex when switching from internal to external attention. *Biol. Psychol.* 163, 108119. <https://doi.org/10.1016/j.biopsycho.2021.108119>.
- Verschooren, S., Vermeyl, L., Boeve, S., Pourtois, G., 2025. Perceptual decoupling underlies internal shielding benefit during switches between external and internal attention: Evidence from early sensory ERP components. *J. Cogn. Neurosci.* 37 (10), 1666–1684. <https://doi.org/10.1162/jocn.a.02329>.
- Vincent, J.L., Kahn, I., Snyder, A.Z., Raichle, M.E., Buckner, R.L., 2008. Evidence for a Frontoparietal Control System Revealed by Intrinsic Functional Connectivity. *J. Neurophysiol.* 100 (6), 3328–3342. <https://doi.org/10.1152/jn.90355.2008>.
- Vossel, S., Geng, J.J., Fink, G.R., 2014. Dorsal and Ventral Attention Systems: Distinct Neural Circuits but Collaborative Roles. *Neuroscientist* 20 (2), 150–159. <https://doi.org/10.1177/1073858413494269>.
- Wallace, R.S., Mckeown, B., Goodall-Halliwel, I., Chitiz, L., Forest, P., Karapanagiotidis, T., Mulholland, B., Turnbull, A., Vanderwal, T., Hardikar, S., Gonzalez Alam, T.R., Bernhardt, B.C., Wang, H.-T., Strawson, W., Milham, M., Xu, T., Margulies, D.S., Poerio, G.L., Jefferies, E., Smallwood, J., 2025. Mapping patterns of thought onto brain activity during movie-watching. *eLife* 13, RP97731. <https://doi.org/10.7554/eLife.97731>.
- Ward, L.M., 2003. Synchronous neural oscillations and cognitive processes. *Trends Cogn. Sci.* 7 (12), 553–559. <https://doi.org/10.1016/j.tics.2003.10.012>.
- Waszak, F., Hommel, B., Allport, A., 2004. Semantic generalization of stimulus-task bindings. *Psychon. Bull. & Rev.* 11 (6), 1027–1033. <https://doi.org/10.3758/BF03196732>.
- Wheeler, M.E., Petersen, S.E., Buckner, R.L., 2000. Memory's echo: Vivid remembering reactivates sensory-specific cortex. *Proc. Natl. Acad. Sci.* 97 (20), 11125–11129. <https://doi.org/10.1073/pnas.97.20.11125>.
- Wickens, C.D., McCarley, J.S., & Gutzwiller, R.S. (2022). *Applied Attention Theory* (2nd ed.). CRC Press. <https://doi.org/10.1201/9781003081579>.
- Wong, A.Y., Smith, S.L., McGrath, C.A., Flynn, L.E., Mills, C., 2022. Task-unrelated thought during educational activities: a meta-analysis of its occurrence and relationship with learning. *Contemp. Educ. Psychol.* 71, 102098. <https://doi.org/10.1016/j.cedpsych.2022.102098>.
- Yang, E., Milisav, F., Kopal, J., Holmes, A.J., Mitsis, G.D., Misic, B., Finn, E.S., Bzdok, D., 2023. The default network dominates neural responses to evolving movie stories. *Nat. Commun.* 14, 4197. <https://doi.org/10.1038/s41467-023-39862-y>.
- Yang, H., van Vugt, M., 2025. Sticky" thinking disrupts decision making for individuals with a tendency toward worry and depression. *Emotion* 25 (4), 997–1010. <https://doi.org/10.1037/emo0001449>.
- Yanko, M.R., Spalek, T.M., 2014. Driving with the wandering mind: the effect that mind-wandering has on driving performance. *Human. Factors* 56 (2), 260–269. <https://doi.org/10.1177/0018720813495280>.
- Yeshurun, Y., Nguyen, M., Hasson, U., 2021. The default mode network: Where the idiosyncratic self meets the shared social world. *Nat. Rev. Neurosci.* 22 (3), 181–192. <https://doi.org/10.1038/s41583-020-00420-w>.
- Yu, L., Hu, J., Shi, C., Zhou, L., Tian, M., Zhang, J., Xu, J., 2021. The causal role of auditory cortex in auditory working memory. *eLife* 10, e64457. <https://doi.org/10.7554/eLife.64457>.
- Yu, Q., Postle, B.R., 2021. The Neural Codes Underlying Internally Generated Representations in Visual Working Memory. *J. Cogn. Neurosci.* 33 (6), 1142–1157. <https://doi.org/10.1162/jocn.a.01702>.
- Zacks, J.M., Speer, N.K., Swallow, K.M., 2010. The brain's cutting-room floor: segmentation of narrative cinema. *Front. Hum. Neurosci.* 4, 168. <https://doi.org/10.3389/fnhum.2010.00168>.
- Zanenko, A.P., Denkova, E., Jha, A.P., 2025. Mind-wandering increases in frequency over time during task performance: an individual-participant meta-analytic review. *Psychol. Bull.* 151 (2), 217–239. <https://doi.org/10.1037/bul0000424>.
- Zanto, T.P., Gazzaley, A., 2013. Fronto-parietal network: flexible hub of cognitive control (Special Issue: The Connectome). *Trends Cogn. Sci.* 17 (12), 602–603. <https://doi.org/10.1016/j.tics.2013.10.001>.
- Zhou, Y., Curtis, C.E., Sreenivasan, K.K., Fougny, D., 2022. Common neural mechanisms control attention and working memory. *J. Neurosci.* 42 (37), 7110–7120. <https://doi.org/10.1523/JNEUROSCI.0443-22.2022>.
- Zion Golumbic, E.M., Ding, N., Bickel, S., Lakatos, P., Schevon, C.A., McKhann, G.M., Goodman, R.R., Emerson, R., Mehta, A.D., Simon, J.Z., Poeppel, D., Schroeder, C.E., 2013. Mechanisms underlying selective neuronal tracking of attended speech at a "cocktail party. *Neuron* 77 (5), 980–991. <https://doi.org/10.1016/j.neuron.2012.12.037>.