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Shaped by our thoughts – A new task to assess spontaneous cognition and its associated neural correlates in the default network

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ABSTRACT

Self-generated cognition, or mind wandering, refers to the quintessentially human tendency to withdraw from the immediate external environment and engage in internally driven mentation. This thought activity is suggested to be underpinned by a distributed set of regions in the brain, referred to as the default network. To date, experimental assessment of mind wandering has typically taken place during performance of a concurrent attention-demanding task. The attentional demands of concurrent tasks can influence the emergence of mind wandering, and their application to clinical disorders with reduced cognitive resources is limited. Furthermore, few paradigms have investigated the phenomenological content of mind wandering episodes. Here, we present data from a novel thought sampling task that measures both the frequency and qualitative content of mind wandering, in the absence of a concurrent task to reduce cognitive demand. The task was validated in a non-pathological cohort of 31 older controls and resting-state functional connectivity analyses in a subset of participants ($n = 18$) was conducted to explore the neural bases of mind wandering. Overall, instances of mind wandering were found to occur in 37% of experimental trials. Resting state functional connectivity analyses confirmed that mind wandering frequency was associated with regional patterns of both increased and decreased default network connectivity, namely in the temporal lobe, posterior cingulate cortex and dorsal medial prefrontal cortex. Our findings demonstrate that the novel task provides a context of low cognitive demand, which is conducive to mind wandering. Furthermore, performance on the task is associated with specific patterns of functional connectivity in the default network. Together, this new paradigm offers an important avenue to investigate the frequency and content of mind wandering in the context of low cognitive demands, and has significant potential to be applied in clinical conditions with reduced cognitive resources.

1. Introduction

Spontaneous, self-generative thought – or mind wandering – has been a topic of burgeoning interest for cognitive neuroscientists in recent years. Converging evidence suggests we spend upwards of half of our waking day engaged in mind wandering (Killingsworth & Gilbert, 2010) and that such internal mentation can confer important benefits on our emotional well-being and our ability to engage in forward planning, decision making, self-reflection and social–emotional processing (Immordino-Yang, Christodoulou, & Singh, 2012; Laird et al., 2009; McMillan, Kaufman, & Singer, 2013; Smallwood & Andrews-Hanna, 2013; Uddin, Iacoboni, Lange, & Keenan, 2007).

In task-based assessment, mind wandering has been associated with activity in a distributed set of brain regions known as the default network (DN) (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Mason et al., 2007; Stawarczyk, Majerus, Maquet, & D'Argembeau, 2011b). This anatomically defined brain system comprises regions in the prefrontal, temporal, and parietal cortices, which converge on core midline hubs in the posterior cingulate and anteromedial prefrontal cortex (Andrews-Hanna, 2012). Although the precise functions of the DN remain a matter of debate, mounting evidence points to two distinct DN subsystems that may mediate dissociable aspects of internal mentation,

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namely, memory-based construction/simulation (medial temporal lobe/MTL subsystem) and introspection about mental states (dorsal medial prefrontal cortex/dmPFC subsystem) (Andrews-Hanna, Smallwood, & Spreng, 2014; Buckner, Andrews-Hanna, & Schacter, 2008). Stronger resting state functional connectivity within the DN has been associated with higher frequencies of spontaneous thought and engagement in mind wandering (Andrews-Hanna, Reidler, Huang, & Buckner, 2010a; Wang et al., 2009; Yang, Bossmann, Schiffhauer, Jordan, & Immordino-Yang, 2013). Nevertheless, regions outside the DN have also been implicated in mind wandering, in particular executive control systems (Christoff et al., 2009), yet the exact role these systems play in mind wandering remain to be elucidated (Franklin, Mrazek, Broadway, & Schooler, 2013; McVay & Kane, 2010; Smallwood, 2013).

Given the spontaneous emergence of mind wandering and its internally directed nature, it is a complex phenomenon to assess in an experimental setting. The most common approaches to mind wandering assessment involve participants performing a concurrent attention-demanding task, such as the Sustained Attention to Response Task or text reading, often requiring them to self-identify when "off-task" thoughts occur. Qualitative aspects of mind wandering have been explored, whereby participants may also be trained to classify the "off-task" thoughts – or this is done by the experimenter – into broad categories that reflect the temporal orientation of the thought (Smallwood, Nind, & O'Connor, 2009), the degree of stimulus/task-relatedness (Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011a) or whether it was a form of autobiographical planning (Baird, Smallwood, & Schooler, 2011). Notably, however, this assessment of phenomenological content has been mostly limited to these broad categorisation methods, with limited attempts to map potentially dissociable forms of internal mentation onto established DN subsystems.

While significant advances have been made in the use of cognitive tasks to explore the structure and function of the DN (Andrews-Hanna et al., 2014), a number of issues remain unresolved. Crucially, the extent to which a concurrent task demands attention, and the meta-awareness required to self-identify and self-classify thoughts, restricts its broader application to clinical populations with reduced cognitive resources. Evidence suggests that in the context of low task-demands subjects report more off-task thoughts, compared to reports during more demanding tasks (McVay, Meier, Touron, & Kane, 2013). This highlights that assessment using tasks with low cognitive demands may be more likely to elicit instances of mind wandering. At present, there is a lack of available paradigms to investigate mind wandering in a context free from additional loadings on attention and working memory processes. This renders mind wandering assessment particularly difficult in neurodegenerative diseases or psychiatric conditions, where the integrity of the default network is compromised significantly and progressively, from early in the disease course (Broyd et al., 2009; Damoiseaux, Prater, Miller, & Greicius, 2012; Hafkemeijer, van der Grond, & Rombouts, 2012; Seeley, Crawford, Zhou, Miller, & Greicius, 2009; Whitfield-Gabrieli & Ford, 2012). Developing measures of spontaneous cognition suitable for these populations is critical, in order to establish the functional outcomes of damage to the DN.

To address this gap in the literature we developed a novel thought sampling task designed for the assessment of mind wandering in clinical syndromes, as it is free from the cognitive demands imposed by performing a concurrent task, and from requirements of self-identification and self-classification of thoughts. For the first time, we present a scoring system developed to assess both the frequency of mind wandering, and its qualitative content with respect to potentially dissociable styles of self-generative thought based on a functional–anatomical fractionation of the DN (Andrews-Hanna, 2012). Here, we present behavioural data from a sample of healthy older controls. We specifically chose to validate the task in a cohort that is age-matched to clinical samples in which DN pathology typically manifests (e.g., (Buckner et al., 2008)), with a view to applying the validated task in dementia populations in subsequent studies. We further present resting state functional connectivity imaging analyses to demonstrate that performance on this novel task maps onto specific patterns of functional connectivity in the DN. To our knowledge, this study represents the first attempt to develop a task designed specifically to explore both the frequency and phenomenological content of mind wandering episodes, in the context of minimal cognitive demands.

2. Methods

2.1. Participants

Thirty-one healthy older participants (age range: 53–79, with an average age of 66.9 years and average education of 14.9 years) were recruited from two volunteer research panels and screened for cognitive dysfunction using global assessment scales (the Mini-Mental Status Examination; MMSE (Folstein, Folstein, & McHugh, 1975) and the Montreal Cognitive Assessment; MoCA (Nasreddine et al., 2005)). Participants were deemed suitable for inclusion in the study if they scored above a cut-off score of 26 on the MMSE and MoCA (Ismail, Rajji, & Shulman, 2010; Nasreddine et al., 2005). Exclusion criteria for all participants included prior history of mental illness, significant head injury, movement disorders, cerebrovascular disease, alcohol and other drug abuse, and limited English proficiency. A subset of 18 participants underwent resting state functional magnetic resonance imaging as part of the study. No difference was evident in age, gender, or years of education between the overall sample and the imaging subset (all p values > .2). Table 1 presents demographic details for the overall participant cohort and the subset that underwent imaging.

The study was approved by the Human Ethics Committees of the Central and South Eastern Sydney Area Health Services and the Universities of Sydney and New South Wales. All participants provided informed consent in accordance with the Declaration of Helsinki.

2.2. Shape Expectations task

The task was designed to resemble the conditions in everyday life that are most conducive to mind wandering – that is, minimal external stimulation and free from the constraints of performing a concurrent cognitive task.

A detailed description of the Shape Expectations materials and administration protocol is available from the authors upon request. Briefly, participants were instructed that they would undertake a task in which all they were required to do was to focus on stimuli presented on a computer screen. They were instructed that they did not have to remember the stimuli, and that their only objective

Table 1
Mean (standard deviation) of demographic details for overall sample and subset who underwent neuroimaging.

	Overall sample	Imaging subset	p value
N	31	18	–
Sex (M:F)	10:21	4:14	n.s.
Age	66.9 (6.2)	64.7 (6.1)	n.s.
Education	14.9 (2.8)	15.6 (2.9)	n.s.

n.s. = non significant.