Mind-Wandering Experiences in Ageing: Neurocognitive Processes and Other Influencing Factors

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Mind-Wandering Experiences in Ageing: Neurocognitive Processes and Other Influencing Factors

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Abstract

The ability to self-generate thoughts in imagination is a central aspect of the human experience. Mind-wandering episodes are multifaceted and are heterogeneous in terms of their content, form (e.g. modality, level of detail), and behavioural outcomes. Older adults' neurocognitive profile shows impairments in functions highly linked to the generation and management of such episodes, namely episodic memory, attentional control, and abilities associated with the recruitment of the default mode network (DMN). Robust findings have documented a decrease in the frequency of mind-wandering with increasing age. However, age-related changes in thought content, and how this is related to the cerebral organisation of the brain, has largely been neglected. This PhD project aimed to: (i) investigate older adults' neurocognitive profile alongside the complexities of mind-wandering, and importantly (ii) explore the impact of moderating factors on thought content as we grow older. Converging behavioural and neuroimaging methods were employed to provide a comprehensive account of self-generated thoughts. The first two chapters combined self-reports with electrophysiological and fMRI connectivity data, and demonstrated associations between changes in the recruitment of the DMN and age-related changes in self-generated thoughts. Subsequent experimental chapters considered the influence of key factors believed to impact on the content of thoughts. Examining the influence of culture revealed that native French speakers favoured self-reflection and engaged in more positively oriented thoughts, in comparison to English native speakers. In addition, the manipulation of task difficulty encouraged verbal rehearsal, and meta-awareness mainly targeted the temporal characteristics of thoughts. Finally, after a 4-week meditation intervention, there was a reduction in both negative and past-oriented thoughts. Throughout, behavioural measures demonstrated older adults' bias toward deliberate on-task thoughts, with evidence of a decrease of negatively oriented thoughts, stable rates of positively oriented thoughts, and an increase of visual thoughts, and task-related interference. Overall, the systematic use of convergent behavioural and neuroimaging methodology has provided a more in-depth understanding of mind-wandering experiences in ageing where previously the frequency of these episodes has only been considered.

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Published work

Chapter 5 is published as:

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The following scientific communications have also arisen from this project:

Martinon, L. M., Smallwood, J., Mitchell M., Hamilton, C., Riby, L. M. (Jul. 201**8**). *Compassion-based meditation influences thought content in both young and*

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Martinon, L. M. (Jun. 2018) *"Mind Wandering in Ageing."* Paper presentation to the 'Mind Wnadering & Mindfulness' conference, Newcastle-upon-Tyne, UK.

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Martinon, L. M., Smallwood, J., Hamilton, C., Riby, L. M. (Jun. 2017) *Frogs 'legs versus Roast beef: How Culture can Impact our Mind-Wandering Experiences across the Life Span.* Paper presentation at Journées de Printemps de la Société de Neuropsychologie de langue Française, Anosognosie et Etats de Conscience, Grenoble, France

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To Dyslexia, I won.

Authors’ declaration

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

Any ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by the Faculty of Health and Life Sciences ethics committee at the University of Northumbria in Newcastle.

I declare that the word count of this thesis is 48 939 words.

SIGNED:

DATE:

“*I was trying to daydream but my mind kept wandering*.”

Steven Wright

Chapter 1. General introduction

This first chapter will introduce the concept of mind-wandering experiences and provide a comprehensive review of the literature pertaining to their complex behavioural and neural nature. Mind-wandering experiences are numerous by their content, form, or outcomes but also by the neural activity supporting their occurrence. Additionally, several factors can modulate such experiences. This chapter will stress the importance of exploring older adults as a key population to inform the mind-wandering and ageing literature. The aims and objectives of this thesis project as a whole are proposed, and outlines of each of the studies are provided.

1.1. Conceptualizing mind-wandering experiences.

The investigation of an individual's stream of consciousness has long been a topic of interest for psychologists and philosophers (William James, The principles of psychology 1890). For example, in his book Psychology, Briefer Course (1984), William James states that “The states of consciousness are all that psychology needs to do her work with. Metaphysics or theology may prove the Soul to exist; but for psychology the hypothesis of such a substantial principle of unity is superfluous” (p.181). Understanding the dynamic flow of thoughts occurring in the conscious mind is a *sine qua non* condition for a comprehensive grasp of the human condition. Accordingly, in the past decade, interest in these ever changing thoughts faced an exponential growth with over 180 articles published referring to “mind-wandering”, “task-unrelated thoughts” or “daydreaming” in 2017, compared to 24 in 2007.

However, to date, limited consensus has been found regarding the definition of these introspective thoughts. While some refer to mind-wandering experiences as task-unrelated thoughts, excluding task-free thoughts (Smallwood & Schooler, 2006), others focus on the intentionality of their occurrence (Christoff, Irving, Fox, Spreng, & Andrews-Hanna, 2016; Seli, Risko, & Smilek, 2016; Seli, Risko, Smilek, & Schacter, 2016).

Alternatively, some researchers refer to self-generated thoughts to capture the intrinsic and active nature of such experiences, as well as their relative independence from immediate sensory input (Andrews-Hanna, Smallwood, & Spreng, 2014; Ruby, Smallwood, Engen, & Singer, 2013). Recently, a family-resemblance perspective was suggested to regroup all of these definitions (Seli et al., 2018). Therefore, mind-wandering is now considered as an umbrella term covering related, and often overlapping, experiences. To enhance clarity and effective comparisons, an outline of the features of mind-wandering under study should be reported at the beginning of any body of work. Here, mind-wandering is merely conceptualised as self-generated thoughts and defined by an attentional decoupling from the environment in favour of any internal thoughts or feelings. A typical example would be reading to the end of a paragraph only to realise that one’s thoughts were drifting and therefore having to start over.

Despite incongruities in definitions, the literature is unanimous regarding the central part of mind-wandering experiences in human cognition. Accordingly, research exploring their occurrence, content, benefits, consequences, variability, and neuro-correlates have been encouraged.

1.2. The characteristics of mind-wandering experiences.

A plethora of research has explored mind-wandering experiences, showing that a third to half of our waking life is spent on such mental activity (Kane et al., 2007; Killingsworth & Gilbert, 2010; Song & Wang, 2012). Neuroimaging investigations demonstrated the importance of the default mode network (Mason et al., 2007), while behavioural studies exposed the costs, benefits, and content of these experiences (for a review see Mooneyham & Schooler, 2013).

1.2.1. The default mode network and mind-wandering experiences.

Research has explored the neuro-correlates underlying mind-wandering experiences and highlighted different patterns of brain activity in different contexts. Findings from this literature are flourishing and will be further detailed in Chapter 2. Nevertheless, here, the components of the default mode network in relation to self-generated thoughts will be explored. The default mode network (DMN) is primarily engaged during rest, under conditions of relaxation, and when little to no perceptual processing is required (for review see Raichle, 2015; **Figure 1.1**). This network is particularly active during tasks involving autobiographical memory, semantic processing, planning of the personal future, imagination, theory of mind, and self-reflection, which all share features with mind-wandering experience (Andrews-Hanna, 2012; D'Argembeau et al., 2014; Spreng & Grady, 2009; Spreng, Mar, & Kim, 2008; for a review of DMN functions see Buckner, Andrews-Hanna, & Schacter, 2008). Core regions of this network, namely the posterior cingulate cortex (PCC), medial prefrontal cortex (mPFC), and angular gyrus, have been proven to support the processing of personal information (Hu et al., 2016), a central aspect of mind-wandering experiences (Baird, Smallwood, & Schooler, 2011). However, the dorsal medial subsystem, composed of the dorsomedial prefrontal cortex (dmPFC), the temporoparietal junction, the lateral temporal cortex, and the anterior temporal lobe, is associated with more social thoughts and reflections, which is in line with behavioural findings characterising mind-wandering experiences (Baird et al., 2011). Finally, the medial temporal subsystem, composed of the hippocampus, parahippocampus, retrosplenial cortex, posterior inferior parietal lobe, and the ventromedial prefrontal cortex (vmPFC), is associated with episodic past and future thinking, elements consistently associated to mind-wandering experiences (Baird et al., 2011; Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011; for more details see Andrews-Hanna et al., 2014). Therefore, although the precise features and functions of the network are still under investigation, their nature and integrity are clearly related to a number of cognitive functions including mind-wandering experiences.

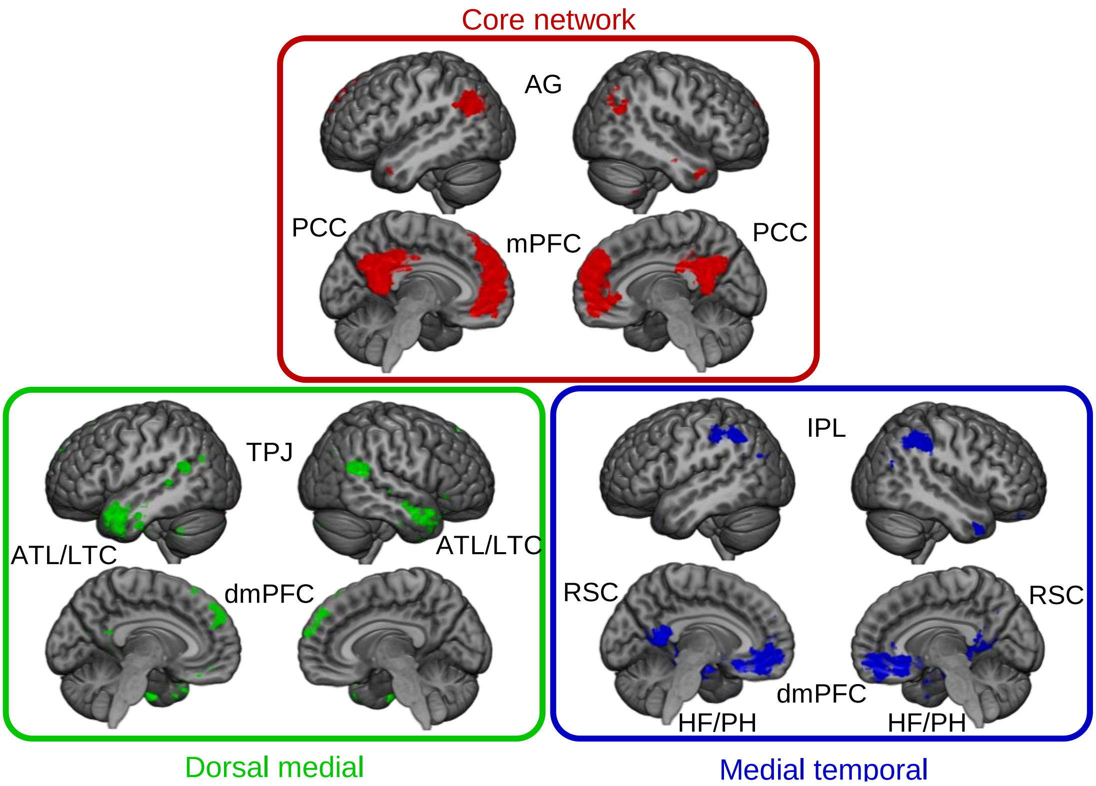


Figure 1.1. Brain regions composing the Default Mode Network.

Spatial localisation of brain areas composing the DMN generated using Neurosynth software (Yarkoni, Poldrack, Nichols, Essen, & Wager, 2011). Presentation of reverse inference statistical maps for meta-analyses corresponding to each brain areas reported. **Core network [red]**: Angular Gyrus (AG; data from 231 studies), Posterior Cingulate Cortex (PCC; data from 726 studies) and medial Prefrontal Cortex (mPFC; data from 764 studies). **Dorsal medial subsystem [green]**: Temporoparietal Junction (TPJ; data from 130 studies), Anterior Temporal Lobe (ATL; data from 154 studies), Lateral Temporal Cortex (LTC; data from 97 studies), and dorsomedial Prefrontal Cortex (dmPFC; data from 131 studies). **Medial temporal subsystem [blue]**: Inferior Parietal Lobe (IPL; data from 930 studies), Rostrosplenial Cortex (RSC; data from 101 studies), Hippocampus (H; data from 822 studies), Parahippocampus (PH; data from 63 studies) and ventromedial Prefrontal Cortex (vmPFC; data from 250 studies).

1.2.2. The costs of mind-wandering experiences

From a behavioural perspective, mind-wandering experiences come at a great cost during an array of tasks. Implications of such experiences on reading comprehension is well documented (Franklin, Smallwood, & Schooler, 2011; Reichle, Reineberg, & Schooler, 2010; Smallwood, McSpadden, & Schooler, 2008; Schooler,

2004) and has been further extended to difficulties in encoding perceptual information (Smilek, Carriere, & Cheyne, 2010). Additionally, the intrinsic relationship between mind-wandering experiences and attentional control has been shown to come at a cost during sustained attentional tasks, working memory tasks, and general measures of fluid intelligence (Mrazek et al., 2012). For example, consequences on sustained attention tasks were chiefly observed in terms of increased error rates, variability in reaction times, omissions, and anticipations (Cheyne, Solman, Carriere, & Smilek, 2009). In the same line, mind-wandering experiences seem to have a negative impact on learning and education (Pachai, Acai, LoGiudice, & Kim, 2016). For example, mind-wandering leads to poorer comprehension of university lectures and ultimately poorer performance (Lindquist & McLean, 2011; Risko, Anderson, Sarwal, Engelhardt, & Kingstone, 2012; Szpunar, Moulton, & Schacter, 2013; Wammes, Seli, Cheyne, Boucher, & Smilek, 2016). Moreover, mind-wandering experiences increase dangerous driving behaviours (Galéra et al., 2012; He, Becic, Lee, & McCarley, 2011; Martens & Brouwer, 2013; Qu et al., 2015). Costs are also found in health with short-term adverse consequences like increased heart rate, difficulty falling asleep and poorer sleep quality (Carciofo, Du, Song, & Zhang, 2014; Ottaviani & Couyoumdjian, 2013).

According to these findings, mind-wandering experiences are portrayed as a detrimental activity that should be reduced to a minimum. However, from an evolutionary perspective and given their frequency, it is somewhat unlikely that such experiences are solely negative and exempt from benefits. Critically, mind-wandering experiences are very eclectic in nature, suggesting different underlying neural systems (H.-T. Wang, Bzdok, et al., 2018; H.-T. Wang, Poerio, et al., 2018) and behavioural outcomes depending on the content or intentionality of the thoughts.

1.2.3. The content of mind-wandering experiences.

Key experiential features have been outlined while attempting to capture the functionalities of self-generated thoughts. Firstly, the central characteristic is temporality, with a large proportion of future-oriented and personal thoughts, followed by past-oriented and social thoughts (Baird et al., 2011; D'Argembeau, Renaud, & Van der Linden, 2011; Smallwood, Nind, & O'Connor, 2009; Stawarczyk, Cassol, & D'Argembeau, 2013). Future-oriented thoughts mostly take the form of inner speech and are personally relevant, realistic, concrete, and part of structured sequences of thoughts (Stawarczyk, Cassol, et al., 2013). Recent evidence suggests that future-oriented thoughts enable the refinement of goals and are supported by strong connectivity between the hippocampus and the ventromedial prefrontal cortex (Medea et al., 2016). Additionally, the medial prefrontal cortex has been shown to be key during the processing of personal goals, in both mind-wandering experiences and episodic future thinking (Stawarczyk & D'Argembeau, 2015). Critically, future-oriented thoughts tend to reduce negative mood (Engert, Smallwood, & Singer, 2014) as well as predict a more positive mood (Ruby, Smallwood, Sackur, & Singer, 2013).

On the other hand, past-related thoughts are associated with rumination (Watkins, Moulds, & Mackintosh, 2005) and negative mood (Poerio, Totterdell, & Miles, 2013). An influential study looking at mind-wandering frequency in daily-life demonstrated the negative impact of mind-wandering experiences on mood (Killingsworth & Gilbert, 2010). This finding was extended elsewhere with demonstrations of the mediating role of thoughts' temporality, with higher levels of unhappiness associated with past-oriented thoughts (Poerio et al., 2013; Ruby, Smallwood, Engen, et al., 2013; Smallwood & O'Connor, 2011; Stawarczyk, Cassol, et al., 2013). Interestingly, the negative valence of self-generated thoughts seemed to worsen the previously observed costs of mind-wandering experiences on working memory and sustained attention (Banks, Welhaf, Hood, Boals, & Tartar, 2016). Mind-wandering experiences have been reported to increase major cognitive vulnerabilities (e.g., rumination, hopelessness, low self-esteem, and cognitive reactivity) in individuals with stable trait of negative affectivity or transitorily ones like stress (Marchetti, Koster, Klinger, & Alloy, 2016). Overall, thoughts directed toward the past and the future are frequent, engage different neural networks, and have opposing effects on mood, with past thoughts being related to more negative consequences.

1.2.4. The form of mind-wandering experiences.

When considering the form of the thoughts, a bias towards verbal thoughts has been uncovered along with the influence of intention. Mind-wandering experiences seem to be merely in the form of inner speech (Delamillieure et al., 2010; Heavey & Hurlburt, 2008; Song & Wang, 2012), which may be a consequence of the prospective bias previously outlined. Indeed, future thoughts are described as largely verbal and compose a substantial amount of mind-wandering experiences (Stawarczyk, Cassol, et al., 2013). Further evidence portrays mind-wandering experiences as verbal, intrusive, and detailed (Karapanagiotidis, Bernhardt, Jefferies, & Smallwood, 2017; Medea et al., 2016; Smallwood et al., 2016).

Importantly, intentionality has been outlined as a critical feature of self-generated mind-wandering experiences. Self-generated thoughts have long been considered as mainly unintentional. In laboratory settings, it is expected that participants aim to focus on the task to the best of their ability. However, during boring and undemanding tasks, participants largely intentionally engage in mind-wandering (for a review see Seli, Risko, Smilek, et al., 2016). Conceptually, unintentional thoughts require limited conscious cognitive control and awareness compared to intentional thoughts. This has been further illustrated by a stronger integration between the DMN and the control network for intentional compared to unintentional mind-wandering experiences (Golchert et al., 2017). Experientially, intentional thoughts tend to be more future-oriented and more detailed than unintentional thoughts (Seli, Ralph, Konishi, Smilek, & Schacter, 2017). Finally, some evidence suggests more short-term consequences on academic performance for intentional mind-wandering experiences, and more long-term impacts for unintentional thoughts (Wammes et al., 2016).

However, other results showed equivalent costs on task performance for both unintentional and intentional thoughts (Seli, Cheyne, Xu, Purdon, & Smilek, 2015), highlighting the need for further investigation of this eclectic phenomenon.

1.2.5. The benefits of mind-wandering experiences.

Self-generated thoughts are heterogeneous in terms of experiences and neuro-correlates. Beyond the negative consequences of their occurrence, mind-wandering experiences promise to be highly valuable. Future-oriented thoughts have proven beneficial to alleviate negative mood, lower cortisol levels following social stress (Engert et al., 2014), and to predict a more positive mood (Ruby, Smallwood, Engen, et al., 2013). The role of prospective thoughts in the refinement of personal goals suggests that one of the main functions of self-generated thoughts lies in the planning of personally relevant future goals (Baird et al., 2011; Medea et al., 2016). Elsewhere, mind-wandering experiences enhance ones' creativity (Baird et al., 2012; Smeekens & Kane, 2016) and social problem-solving abilities (Ruby, Smallwood, Sackur, et al., 2013). Additionally, such experiences tend to alleviate loneliness (Poerio, Totterdell, Emerson, & Miles, 2015, 2016), foster psychosocial adaptation (Poerio et al., 2016), and a more patient style of making decisions (Smallwood, Ruby, & Singer, 2013). Ultimately, a functionality for such thoughts could be the relief of boredom, since mind-wandering experiences are known to assist a mechanism by which dishabituation can occur (Mooneyham & Schooler, 2013, 2016; Schooler et al., 2011). Importantly, recent work demonstrated how different patterns of content have different functional associations (H.-T. Wang, Poerio, et al., 2018).

From these investigations, mind-wandering experiences can be described as largely self-related with a tendency toward future thoughts and predominantly supported by the DMN. Importantly, while these lapses of attention can come at some cost (e.g. errors, negative mood), they also seem to present numerous benefits to life.

In response to such heterogeneity, the modelling of a theory conceptualising these experiences is ever more important.

1.3. The process account of mind-wandering experiences

One difficulty when trying to grasp the mind-wandering state is accounting for the vast array of potential experiences that can occur. This section will present details of the underlying processes that, together, explain the diversity of mind-wandering experiences. In particular, the component process account of mind-wandering (Smallwood & Schooler, 2015) assumes that different types of thoughts and feelings arise through the flexible combination of a smaller number of underlying processes. Smallwood and Schooler (2015) identify three important aspects of mind-wandering occurrences using the component process account of mind-wandering, and in Chapter 2, how neuroimaging may help to understand these features will be explored more fully. The first process involves the temporally evolving attentional state, where there is decoupling from the processing of information in the external environment in favour of internal thought. The second process refers to the generation of the thought content, while the third considers the 'executive' processing operations, enabling the coordination, monitoring, and regulation of the self-generated thoughts.

1.3.1. How does attention become internally focused?

When self-generated thoughts emerge, there is a release from the processing of task-relevant information extracted from the external environment. One of the potential roles of perceptual decoupling is its necessity for a coherent internal train of thought to emerge (Kam & Handy, 2013; Smallwood, 2013). The flexible decoupling and reorganisation of processes would be key to facilitate a conscious focus on self-generated information. Another possibility is that perceptual decoupling is related to the availability of limited cognitive resources (Franklin, Mrazek, Broadway, & Schooler, 2013). In this case, perceptual decoupling simply reflects the fact that attention resources are no longer being directed to the task at hand but have been diverted to maintain inner thoughts. However, recent evidence does not support this latter theory. Individuals with high mind-wandering rates were found to do better at memory tasks, and worse on executive tasks (Poerio et al., 2017).

1.3.2. How do people self-generate task-unrelated mental content?

Self-reports on the content of thoughts during mind-wandering episodes reveal the recurrence of past and future-oriented thoughts (Baird et al., 2011). It is proposed that the direction of this mental time travel is heavily dependent on episodic memory processes (Tulving, 2002). Evidence supports the proposal that the episodic memory system plays a role in self-generated mental content of mind-wandering experiences, emphasising the role of the DMN (Smallwood & Schooler, 2015). Accordingly, by linking connectivity measures to cognitive task performance, Poerio et al. (2017) demonstrated the implication of memory and the DMN in the generation of content of self-generated thoughts. Elsewhere, the DMN and the link between self-generated thought and episodic memory ability has been uncovered in neuropsychological populations (e.g. amnestic mild cognitive impairment; Dunn et al., 2014). In addition to the temporal make-up of mind-wandering content, affect and mood has dominated the literature. However, the relationship between the temporal orientation and valence of mind-wandering thought needs to be explored further. It is possible that a reciprocal relationship exists whereby the emotional valence of self-generated thought depends on its temporal direction, and additionally, that affective processes play a key role in determining the temporal content of self-generated thought during mind-wandering.

1.3.3. How do people coordinate and/or regulate mind-wandering experiences?

Currently, evidence suggests that executive functions play a key role in the context regulation of self-generated thoughts. Individuals with high levels of executive functioning limit their mind-wandering occurrence in demanding tasks (Kane & McVay, 2012). However, they also report more mind-wandering episodes in undemanding tasks, suggesting that cognitive control enables the maintenance of mind-wandering (Levinson, Smallwood, & Davidson, 2012). Thus, high levels of executive functioning seem to enable individuals to exert more flexibility into whether or not they allow their mind to wander or focus, and this may be modified depending on task demands (Rummel & Boywitt, 2014). This suggests that executive control not only permits the occurrence of mind-wandering episodes but also enables a more flexible adjustment of mind-wandering to situational demands. These data mirror general experimental work on dual-tasking, known as the context regulation hypothesis, where coordination of the task at hand and self-generated thoughts can be considered primary and secondary tasks (Huang & Mercer, 2001).

A related body of research also suggests that meta-cognitive processes play a role in the regulation of thought content. Meta-cognition refer to the knowledge one has about its own cognitive processes and cognitive processes in general (Flavell, 1979). Those with greater levels of meta-cognition regarding the content of their thoughts during a task tend to show greater variability in their attention between on-task and off-task states (Allen et al., 2013). Furthermore, evidence suggests that increasing awareness of mind-wandering states through meditation practice leads to reductions in these off-task thoughts (Mrazek, Franklin, Phillips, Baird, & Schooler, 2013).

1.4. Influencing factors of mind-wandering experiences.

Building upon the component process account of mind-wandering, and to further comprehend the complexity of mind-wandering experiences, it is essential to consider influencing factors. Negative mood and meditation have already been mentioned, however many other factors can be considered. Here, characteristics originating from pathologies, the environmental context, and individual differences will be reported.

1.4.1. Pathologies

Many pathologies present distinct features on functions highly related to mind-wandering. Whether it is the integrity of the DMN, attentional processes, executive function, or working memory capacity, pathologies such as Attention-Deficit/Hyperactivity Disorder, depression, Autism Spectrum Disorder or schizophrenia, all present neurocognitive characteristics indicative of different mind-wandering experiences. However, research is limited and has only focused on attention-deficit/hyperactivity disorder and depressive patients.

1.4.1.1. Attention-deficit/hyperactivity disorder

Attention-deficit/hyperactivity disorder (ADHD) is characterised by a reduced ability to exert and maintain cognitive control of behaviour. Individuals present persistent symptoms of inattention, hyperactivity, and impulsivity (DSM-V). Multiple neurocognitive deficits have been evidenced in this population, which includes aspects of executive functioning such as response inhibition (Alderson, Rapport, & Kofler, 2007; Lijffijt, Kenemans, Verbaten, & van Engeland, 2005), working memory (Martinussen, Hayden, Hogg-johnson, & Tannock, 2005; Rhodes, Coghill, & Matthews, 2005), attentional shifting, and planning (Kempton et al., 1999; Rhodes et al., 2005). Given this unusual behavioural and cognitive profile, the study of this disorder can inform the attentional component in theories of spontaneous thought processes. Shaw and Giambra, (1993) showed that individuals with ADHD are more inclined to mind-wander than healthy controls during a vigilance task. While performing a boring and undemanding cognitive task, participants diagnosed with ADHD experienced more task-unrelated-thoughts and false alarms, illustrating their higher levels of non-conscious processing and poor inhibitory control. Elsewhere, the frequency and negative consequences of mind-wandering have been positively associated with ADHD symptomology (Franklin et al., 2016). Interestingly, ADHD was positively correlated with both the frequency of mind-wandering and a lack of awareness of mind-wandering.

Meta-awareness is an essential component of the mind-wandering process, as it enables one to be aware and conscious of the wandering mind. A lack of such awareness and monitoring of one’s consciousness thus leads to the inability to control the occurrence of mind-wandering episodes. Therefore, these findings support the role of executive control in mind-wandering and further stress the importance of self-monitoring and meta-awareness in mind-wandering occurrence.

Additionally, considering the difficulties that ADHD individuals have with cognitive control and the lack of awareness of that failure, one would expect a difference in intentionality rate of mind-wandering. Critically, ADHD individuals were found to exert a different ratio of intentionality than controls, specifically with less intentional than unintentional mind-wandering (Seli, Smallwood, Cheyne, & Smilek, 2015). Exploring these potential changes in relation to the neuro-cognitive patterns of this population contribute, therefore, to the refining of theories regarding the regulation of both the disengagement from the task and the generation of mind-wandering episodes.

1.4.1.2. Depression

In a similar vein, depression is associated with cognitive deficits and a distinctive pattern of self-generated thoughts. Symptoms in depression are predominately related to mood, but also include intrusive thoughts, ruminations, and deficits in executive function and attention (Austin, Mitchell, & Goodwin, 2001). Indeed, a meta-analysis illustrated that depression severity was positively correlated with cognitive performance in the domains of episodic memory, executive function, and processing speed (McDermott & Ebmeier, 2009). Thus, cognition in depression shows similarities with mind-wandering experiences. For instance, both are implicated in shifting attention away from the here and now, and both are related to attention and executive functions. This is further supported by the success of mindful therapies for depression (Marchand, 2012). In these therapies, the focus is on maintaining attention on the here and now. Moreover, mindfulness has been shown to reduce mind-wandering frequency (Mrazek et al., 2013). A strong and positive correlation between dysphoria (i.e., sub-clinical depression) and mind-wandering occurrence has been found, emphasising their relation (Smallwood, O'Connor, & Heim, 2005). A later study also demonstrated that dysphoria is associated with more accessible mind-wandering experiences (Smallwood, O'Connor, Sudbery, & Obonsawin, 2007). As mentioned earlier, sadness tends to precede mind-wandering occurrence, especially when the experience is retrospective (Poerio et al., 2013). Overall, these examples from the literature emphasise how explorations in this population are a great asset in evaluating the role of affect in experiences of mind wandering, thus enabling a deeper understanding of what may trigger the generation of such thoughts.

The investigation of self-generated thoughts in the context of different neurocognitive profiles is highly valuable. Importantly, looking closer at specific populations will help refine theories of mind wandering, giving more strength to a rising field. Ultimately, by understanding these neurocognitive profiles and patterns of mind-wandering experiences, such investigations will be beneficial to the design of strategies and interventions improving patients' lives.

1.4.2. Context-dependent characteristics

Beyond the investigation of pathologies, more transient factors are known to influence mind-wandering experiences. Within context-dependent characteristics, the length of the activity at hand has been repeatedly reported as a factor encouraging mind-wandering experiences. Research shows that the more time spent on a task, the more frequently self-generated thoughts occur (Risko et al., 2012; Smallwood, Obonsawin, & Reid, 2002; Szpunar et al., 2013). The environment and the material used in the task can also influence mind-wandering frequency rates. One example is the number of changes presented (e.g. audiovisual features), where the fewer the changes, the higher the frequency of mind-wandering experiences (Faber, Radvansky, & D'Mello, 2018). Participants' interest in the presented material is equally important, as motivation tends to increase focus, and therefore decreases mind-wandering rates (Lindquist & McLean, 2011; Smallwood & Schooler, 2006; Unsworth & McMillan, 2013). This has been further corroborated by experimental manipulation of participants' motivation to perform a task (Seli, Schacter, Risko, & Smilek, 2017). Low motivation to perform well at an activity has been associated with more intentional than unintentional self-generated thoughts, compared to when motivation is high (Seli, Cheyne, et al., 2015). Together, these factors corroborate the proposition that one of the purposes of mind-wandering is to relieve boredom.

1.4.3. Individual differences and other factors

Extrinsic characteristics, such as the consumption of alcohol (Sayette, Reichle, & Schooler, 2009), nicotine craving (Sayette, Schooler, & Reichle, 2010), sexual arousal, and acute hunger (Rummel & Nied, 2017), have shown increases in the number of mind-wandering experiences. While only alcohol consumption and cigarette craving reduced participants' awareness, acute hunger and sexual arousal altered thoughts content with more thoughts about the near future (i.e. food-related and sex-related thoughts, respectively). These findings particularly relate to the implication of current concerns in the generation of mind-wandering experiences. For example, inducing the anticipation of a negative event (i.e. concern) showed a subsequent increase in negative affect predicting the frequency of mind-wandering experiences (Stawarczyk, Cassol, et al., 2013). Similarly, stress inductions increase negative affect and mind-wandering frequency (Vinski & Watter, 2013). More negative, past-oriented, and social thoughts are associated with biological markers of stress (e.g. cortisol and alphaamylase levels; Engert et al., 2014). In a similar vein, stereotype threats tend to increase mind-wandering rates (Schuster, Martiny, & Schmader, 2015). As for personality traits, mind-wandering experiences are predicted by neuroticism in laboratory settings and openness to experience in everyday life (Kane et al., 2017).

Working memory capacity is another influencing factor driving individual differences in mind-wandering. Indeed, working memory capacity and cognitive resources have clear implications for internal and external information flow. For instance, individuals with high working memory capacity can adjust their mind-wandering experience in relation to task demands, with low rates in demanding tasks and higher rates in easy tasks (Kane & McVay, 2012; Randall, Oswald, & Beier, 2014; Rummel & Boywitt, 2014). Conversely, mind-wandering experiences negatively affect participants' performance in working memory tasks (Mrazek et al., 2012). Overall, increasing ones' working memory capacity and ability to focus is a promising avenue to control mind-wandering experiences. Work from the mindfulness literature is informative regarding working memory capacity. This approach is the most documented in increasing cognitive resources, including working memory capacity, for example, a two-week mindfulness intervention improved participants working memory capacity and reduced mind-wandering rates (Mrazek et al., 2013). For participants with initially high mind-wandering rates, the increased working memory capacity was mediated by the reduction of mind-wandering experiences. Notably, even interventions as short as 8 minutes have proven significant in reducing the frequency of mind-wandering (Mrazek et al., 2012).

Together, the literature on working memory suggests that examining populations with reduced cognitive resources and known working memory impairments will be enlightening. Critically, a wealth of work has documented the cognitive changes of the ageing population, showing declines in episodic memory, working memory, and executive control abilities (Braver & West, 2008). Based on this work, a lack of cognitive control was suspected to increase older adults' experiences of mind wandering. Nevertheless, robust findings outline an age-related decrease in mind-wandering experiences (Giambra, 1989; Jackson & Balota, 2012; Jackson, Weinstein, & Balota, 2013; Krawietz, Tamplin, & Radvansky, 2012; McVay, Meier, Touron, & Kane, 2013;

Shake, Shulley, & Soto-Freita, 2016; Staub, Doignon-Camus, Bacon, & Bonnefond, 2014; Zavagnin, Borella, & De Beni, 2014). Investigating mind-wandering experiences in a population presenting both attentional and memory deficits will undoubtedly inform the generation and control processes of mind-wandering experiences. In the following section, an overview of the research investigating this counterintuitive finding will be provided, with an emphasis on older adults' experiential, cognitive and neural characteristics.

1.5. Mind-wandering during the ageing process

1.5.1. Older adults' experiential and cognitive features.

The age-related decrease of mind-wandering frequency has been reported using different measures, such as retrospective questionnaires (Giambra, 1989, 2000) and online experience sampling methods (Giambra, 1989; Jackson & Balota, 2012; Jackson et al., 2013; McVay et al., 2013; Zavagnin et al., 2014). Initial evidence was introduced by Giambra, using both longitudinal (Giambra, 2000) and cross-sectional comparisons (Giambra, 1973, 1993), and has been corroborated by recent research (Frank, Nara, Zavagnin, Touron, & Kane, 2015; Jackson & Balota, 2012; Jackson et al., 2013; Krawietz et al., 2012; McVay et al., 2013; Shake et al., 2016; Staub et al., 2014; Zavagnin et al., 2014). Moreover, a decrease was found for both intentional and unintentional mind-wandering experiences at a trait and state-level (Seli, Maillet, Smilek, Oakman, & Schacter, 2017). This can be informative regarding the implication of cognitive control and motivation in the ageing population. Additionally, older adults have more difficulty in recoupling their attention to the task after a mind-wandering experience, leading to heavier consequences on task performance (Jackson & Balota, 2012; Zavagnin et al., 2014). A number of avenues have been explored to explain this unexpected finding, such as older adults' lack of awareness, higher motivation, change in personal concern, or other dispositional factors like memory deficits, lower negative affect, and higher mindful abilities.

Despite older adults having relatively intact meta-cognitive skills, they tend to not always use monitoring effectively to control learning and cognition (Hertzog & Hultsch, 2000). Hence, the validity of older adults' report of mind-wandering experiences has been questioned. Research has demonstrated that older adults tend to be less able to catch themselves mind-wandering (Einstein & Mcdaniel, 1997; Jackson & Balota, 2012; McVay et al., 2013; Zavagnin et al., 2014). However, using eye tracking, Frank et al., (2015) were able to predict older adults' reports of task-unrelated thought by using eye movement patterns. Thus, support for self-report as a valid measure of mind-wandering frequency was provided for both young and older adults.

After validating older adults' reports, the implication of their increased task engagement (potentially driven by older adults' higher conscientiousness) has been explored. Indeed, motivation is known to reduce mind-wandering activities (Unsworth & McMillan, 2013), by helping the maintenance of executive control and the level of performance during an activity (Thomson, Besner, & Smilek, 2015). Critically, a mediation effect of motivation on the age-related mind-wandering decrease has been reported (Frank et al., 2015; Krawietz et al., 2012). Therefore, older adults' task engagement explained their mind-wandering rates. Yet, in each case, motivation scores were collected after participants had completed the task, leading to a potential bias toward their perceived performance at the task.

Earlier behavioural work focused on the distinction between task-related interferences (TRI) and task-unrelated thoughts (TUT) to explore older adults' mind-wandering experience. Crucially, older adults present significantly larger rates of TRI compared to young adults (Frank et al., 2015; McVay et al., 2013; Zavagnin et al., 2014). TRIs are not directly supporting task activity; instead, they are evaluative of one's performance (e.g. accuracy, time left). Interestingly, the ageing stereotype, illustrated by the belief that older adults cannot be successful at cognitive tasks, was found to increase the occurrence of TRI and negatively affected task performance (Jordano & Touron, 2017). It was hypothesised that older adults' high rates of TRI would overcome their low mind-wandering rates. Nevertheless, older adults still report more on-task thoughts than young adults (McVay et al., 2013), indicating that TRI rates did not compensate for small mind-wandering rates.

Alternatively, interpretations of the age-related decrease in mind-wandering experiences have focused on older adults' change in personal concerns. Older adults' emotional goals and regulation are known to evolve (Carstensen & Charles, 1998), meaning that they may experience fewer personal thoughts because of less anxiety regarding everyday life issues. In this context, laboratory settings may induce a bias with a lack of cues relevant to older adults' concerns to trigger self-generated thoughts (McVay et al., 2013). This brings the question of whether these findings will transfer to real life experiences. Interestingly, studies using more ecologically valid settings present conflicting results. While Giambra (2000) showed a decrease in mind-wandering experiences (i.e. retrospective questionnaire), Gardner & Ascoli, (2015) reported a surprising increase in future-oriented thoughts in older adults using experience sampling (i.e. diary study). Therefore, it might be the case that, as in the prospective memory literature, mind-wandering decreases in experimental settings, but increases, or remains unchanged in ecological settings (Bailey, Henry, Rendell, Phillips, & Kliegel, 2010; Rendell & Craik, 2000).

Nonetheless, with a laboratory approach, several elements of older adults' neurocognitive profile can inform the age-related decrease of mind-wandering frequency. Indeed, mental time travelling abilities seem to change in ageing. Mental time travel comprises the capacity to re-experience events from the personal past, and to pre-experience future anticipated events through imagination (Wheeler, Stuss, & Tulving, 1997), and is one of the most recurrent form of mind-wandering experiences. Studies have revealed poorer ability for imagining future than a-temporal experiences for older adults (Rendell et al., 2012). Additionally, the frequency of involuntary future thoughts decreases with age, whereas the frequency of involuntary memories does not (Berntsen, Rubin, & Salgado, 2015). Therefore, older adults seem to have more difficulties thinking about the future. Preliminary evidence from the mind-wandering literature suggests a reduction of future directed thoughts in favour of more a-temporal thoughts (Jackson et al., 2013). However, Gardner and Ascoli (2015) reported a paradoxical increase in future-oriented thoughts in older adults (e.g. in diary studies). By prompting participants randomly during their normal daily activities, the authors demonstrated higher probability for older adults to recall a thought somewhat related to their personal future (e.g. formation of an intention, recollection of an intention, and musings of possible future events). Together, these findings strongly suggest that spontaneous thoughts are subject to changes when age increases.

Furthermore, older adults report more positive affect, less negative affect, and greater life satisfaction as compared to young adults (Carstensen & Charles, 1998; Grühn, Kotter-Grühn, & Röcke, 2010). These characteristics may act as protective features preventing older adults from continually engaging in mind-wandering activities. In a laboratory context, positive, but not negative affects were found as a mediating factor for older adults' lower mind-wandering rates (Frank et al., 2015). Similarly, older adults' greater mindfulness abilities (Splevins, Smith, & Simpson, 2009) may reduce the occurrence of both negative affect and mind-wandering experiences. Mindfulness meditation is reported as a strong factor reducing mind-wandering activities (Mrazek et al., 2013; Mrazek, Mooneyham, & Schooler, 2014) and negative mood (Lane, Seskevich, & Pieper, 2007), while increasing life satisfaction (Kong, Wang, & Zhao, 2014). Nevertheless, one study, which briefly explored this possibility, failed at demonstrating any mediating effects (Frank et al., 2015).

In summary, multiple hypotheses have aimed to explain the unexpected finding of a decrease in mind-wandering experiences during ageing. Older adults' poor awareness, increased task engagement, change in personal concerns, memory deficits, positive bias, and mindful abilities have all been considered. From these investigations, it is evident that a combination of factors, as opposed to one, could explain older adults' self-generated thoughts. Critically, older adults' neurocognitive profile and the heterogeneity of self-generated thoughts have both been largely overlooked. In younger populations, multiple facets of mind-wandering experiences have been investigated, and are highly informative. However, studies in ageing merely focused on the frequency of thoughts, leaving aside priceless information about older adults' experiences, and how this may drive self-generated thoughts. Additionally, older adults' general cognitive experiences are not without grounding from structural and functional brain changes. Yet, to the best of my knowledge, no study has directly investigated the impact of these changes on older adults' self-generated thoughts.

1.5.2. Older adults' neural activity

Starting with an electrophysiological approach, undeniable changes in brain activity are found in ageing. Studies have documented a decrease in lower frequency bands (i.e. delta and theta) and an increase of higher frequencies (i.e. beta; Cummins & Finnigan, 2007; Duffy, Albert, McAnulty, & Garvey, 1984; Duffy, McAnulty, & Albert, 1993). Higher frequency bands are typically recruited during attentional tasks. Thus their increase most likely reflects the need for more task engagement from this population to carry out a more difficult task (Deiber et al., 2015).

Similarly, neural changes have been documented in older adults' brain structure. Older adults present an overall shrinkage of brain volume (e.g. Tisserand & Jolles, 2003) with significant consequences on brain regions overlapping with the DMN (Raichle et al., 2001). A large body of literature has outlined the frontal lobes as being particularly vulnerable in ageing (Rabbitt, 2005; Robbins et al., 1998) and this has driven the hypothesis by which frontal atrophy is responsible for the functional decline observed. Typical frontal-executive abilities are reported to show impairment in ageing include working memory, inhibition control, planning and decision making (see Greenwood, 2000; West, 2000; West, 1996 for discussion of the frontal ageing hypothesis). The vulnerability of the ageing brain also includes the temporal lobes (Fjell et al., 2009; Pfefferbaum et al., 2013; Naftali Raz, Ghisletta, Rodrigue, Kennedy, & Lindenberger, 2010), and the hippocampus (Du et al., 2006; Fjell et al., 2009). Indeed, a link between hippocampal volume and explicit memory has been found in later life (Raz, Gunning-Dixon, Head, Dupuis & Acker, 1998). Largely, research investigating the medial-temporal lobes highlights deficits in the episodic memory domain particularly when performance is measured during memory recall rather than recognition. The deterioration of these central areas of the brain will inevitably affect the integrity and functionality of the DMN, and provides important clues regarding age difference in self-generated thought.

Despite discoveries of functional reorganisation and compensation in ageing (Greenwood, 2007; Reuter-Lorenz & Cappell, 2008; Reuter-Lorenz & Lustig, 2005), research has revealed a functional impairment of the DMN in this population (Damoiseaux et al., 2008). Decreased activity was found in the middle frontal gyrus, posterior cingulate cortex, middle temporal gyrus, and the superior parietal regions. Critically, connectivity between the temporal poles and the posterior cingulate cortex is predictive of both greater mental time travelling involving social agents, and unpleasant task-unrelated-thoughts (Smallwood et al., 2016). Additionally, heightened connectivity from the hippocampus to the posterior cingulate cortex predicts greater specificity of thoughts (Smallwood et al., 2016). As such, evidence from the ageing brain implies changes in mind-wandering experiences for older adults. Research has demonstrated lower functional connectivity between regions of the DMN in ageing (Damoiseaux, 2017). This was associated with poorer performance on cognitive tasks involving memory and executive functions (Andrews-Hanna et al., 2007; Damoiseaux et al., 2008; L. Wang et al., 2010). Evidently, this confirms the hypothesis in which older adults' compromised neural activity (e.g. DMN), will interfere with their ability to self-generate thoughts (e.g. evidenced by different thoughts' content and frequency). An additional argument for this proposition is the investigation of Alzheimer's patients. Alzheimer's disease is a progressive dementia illustrated by memory difficulties, but also deficits of executive function. Recently for the first time, an article has reported a further decrease in mind-wandering frequency in this population compared to healthy older adults (Gyurkovics, Balota, & Jackson, 2018). Interestingly, a resting-state fMRI study showed decreased activity in the DMN in Alzheimer's patients compared with age-matched healthy controls (Greicius, Srivastava, Reiss, & Menon, 2004). Thus, both mind-wandering frequency and the DMN appear affected by ageing and aggravated further by Alzheimer's disease.

1.6. Project overview and rationale

Overall, mind-wandering experiences are portrayed as heterogeneous by their content, form and outcome. According to recent imaging work, these characteristics, as well as other cognitive functions, are largely supported by the DMN, with distinct patterns of activity and connectivity depending on the nature of the experience. Numerous variables can influence the frequency and the nature of self-generated thoughts. Among these variables, age seems to be a crucial avenue to examine because of the counterintuitive finding displaying reduced frequency. Older adults present impairment in multiple functions that are key to the generation and control of mind-wandering experiences, namely the functional activity and connectivity of the DMN, memory processes, and executive functions. While the decreased frequency of mind-wandering experiences in ageing is appropriately documented (in laboratory settings), limited considerations have been made regarding the nature of the experience, or the implication of the neural changes reported.

This thesis aims to examine self-generated mind-wandering experiences in ageing using convergent methods. The strategy of triangulation whereby self-reports, behavioural measures, and neurocognitive measures are used in tandem will help to explain and explore a phenomenon often difficult to grasp. Importantly, thoughts' heterogeneity and associated neural activity will be at the centre of this thesis. Hence, this project promises to be highly beneficial to the understanding of both self-generated thoughts and normal ageing. An original contribution to knowledge will be provided by, (i) investigating the implications of the ageing neurocognitive profile onto the complex experience of mind-wandering, and by (ii) exploring the impact of influencing factors such as one's sociocultural context, mindful abilities and meta-awareness on the overall mind-wandering experience in ageing.

Starting with a methodological approach, Chapter 2 will argue for the use of convergent methods (e.g. imaging) in the investigation of self-generated thoughts. Building on these recommendations, Chapter 3 will use electrophysiology to untangle the implication of older adults' neuro-cognitive profile on their limited mind-wandering experiences. The ongoing and temporal measures of mind-wandering experiences will provide supplementary information about their underlying neural activity. Investigation of older adults' neurocognitive profile and its implication on self-generated thoughts will be further pursued in Chapter 4, with the use of functional connectivity magnetic resonance imaging. Chapter 5 will explore the influence of culture on the experiences of mind-wandering across different age groups. The assumption that mind-wandering experiences are identical in different cultures is hazardous: social norms and language are strong factors that could potentially change the nature of these experiences. Finally, Chapter 6 will firstly consider the influence of meta-awareness on thoughts content and secondly will attempt to manipulate experimentally the content of mind-wandering experiences in a population of young and older adults. As such, this will document the role of both thought content and meta-awareness in the age-related decrease of mind-wandering experiences.

Chapter 2. Convergent methods

When evaluating internal states such as mind wandering, it is restricting to rely only on one measure. Instead, it is essential to use converging methods as they provide different points of view on otherwise covert states of mind. Specifically, while self-report measures disclose the heterogeneous nature of these thoughts, imaging techniques can target when and where they arise. The high temporal precision of the electroencephalogram and event-related potentials can uncover the temporal dynamics of mind wandering. Additionally, techniques such as functional magnetic resonance imaging (fMRI) enable the processes behind these experiences to be pinpointed in neural space. Furthermore, functional and structural connectivity measures (e.g. electroencephalogram - EEG coherence; diffuse tensor imaging – DTI) expose the neural communication behind the generation and maintenance of internal states. In this chapter, emphasis will be plced on the need for converging operations in studying self-generated experience, and will evaluate the strengths of each technique in addressing specific aspects of the wandering mind.

2.1. Why use converging methods to study mind-wandering?

By nature, mind-wandering is a private and continuous evolution of thought patterns across time (Smallwood, 2013). These internal and temporal aspects of the experience make the combination of self-report measures and neuroimaging techniques fundamental to the comprehension of self-generated thoughts. Although self-report and behavioural studies alone are leading to great strides in developing our understanding of how and why the mind wanders (Smallwood & Schooler, 2015), the aim here is to explore how combining these methods with neuroimaging can accelerate this understanding, and reveal the temporal patterns and neural processes that underpin these experiences. While techniques such as experience sampling

(Csikszentmihalyi & Larsen, 1987) have made it possible to estimate participants' thoughts and feelings as they occur, providing an 'online' measure of mind-wandering, this data relies on subjective self-reports, rather than objective recordings. By comparison, behavioural studies of mind-wandering may be considered less subjective as they generate measures of the observable consequences associated with performing dull, monotonous tasks. Yet, the occurrence of mind-wandering during these slips of action (i.e. errors, omissions) is nevertheless something that has to be inferred. Studies have shown that lapses in performance can have different features than self-reports of off-task thought (Konishi, Brown, Battaglini, & Smallwood, 2017). The limitations of these approaches make it a challenge to establish complete scientific accounts of internal trains of thought associated with mind-wandering. The ability to make inferences about internal states is argued to be improved through the strategy of triangulation, whereby self-reports, behavioural measures, and neurocognitive measures are used in concert (Smallwood & Schooler, 2015). In this context, neuroimaging tools are important for understanding internal states because they: (i) provide insight into the nature of the neural processes that underpin different attentional states, and (ii) they help shed light on the temporal dynamics that internal states can have. To date, tools such as the electroencephalogram and event-related potentials have already proven to be effective measures of the timely occurrence of self-generated thoughts, whereas functional magnetic resonance imaging tools reveal the contribution of key brain areas.

Contemporary accounts of the mind-wandering experience argue that ongoing thoughts are heterogeneous regarding both their content and relationship to functional outcomes (Smallwood & Andrews-Hanna, 2013). The literature illustrates a range of things that people think about when their mind wanders, reflecting variables such as temporal focus, affective state, and interest (Smallwood & Schooler, 2015; see Chapter 1). Since different patterns of thought are likely to have distinct cognitive profiles, this diversity of experiences suggests that an important element in the study of mind-wandering is the assessment of multiple experiential factors. In addition, evidence suggests that mind-wandering episodes are not only different in terms of content, but also variable in terms of patterns of associated functional outcomes. While some studies have shown that mind-wandering occurrence has a negative impact on mood (Killingsworth & Gilbert, 2010) and cognitive task performance (Mrazek, Smallwood, & Schooler, 2012; Smallwood, McSpadden, & Schooler, 2008), others have revealed the positive effects of task-unrelated thought (Baird et al., 2012, 2011; Medea et al., 2016; Ruby, Smallwood, Engen, et al., 2013; Smallwood et al., 2013).

In this context of multiple patterns of experiences reflecting distinct functional outcome, neuroimaging can help move forward our understanding of patterns of ongoing thought. For example, it could help determine which cognitive and neural processes are common to multiple different types of experience, as well as identifying those processes that are distinct to specific patterns of experience. Combined with behavioural measures of mind-wandering, neuroimaging techniques would provide a layer of more objective data related to this subjective state, which is otherwise only accessible by self-reports. Neuroimaging techniques provide covert measures of underlying cognitive processing, thus helping to determine whether variable mind-wandering frequency, content, and outcomes are associated with parallel physical differences in the brain. Moreover, advances in machine learning offer the potential to infer the heterogeneity of different experiential states directly from the combined decompositions of neural and self-reported data (Vatansever et al., 2017; H.-T. Wang, Bzdok, et al., 2018; H.-T. Wang, Poerio, et al., 2018).

This chapter will first outline self-report and behavioural methods of measuring mind-wandering. This will be followed by an analysis of how neuroimaging tools could augment our understanding when used in combination with these methods. Lastly, recent discoveries about mind-wandering, which have been achieved with neural connectivity measures, will be reviewed. Together, the process of triangulation will be highlighted through which different self-report and behavioural methods are combined with the available neuroimaging techniques.

2.1.1. Self-report methods

There are three basic forms of experience sampling that are used in studies of ongoing thought: online experience sampling, retrospective experience sampling estimation, and dispositional measurement. Online experience sampling involves gathering self-reports regarding a participant's ongoing experience 'in the moment' while they are completing other activities (Csikszentmihalyi & Larsen, 1987; Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004; Smallwood & Schooler, 2015). Typically in the literature, the *probe-caught method* is employed in which participants are intermittently interrupted and asked to describe the content of their experience (Smallwood & Schooler, 2006). This method has been used in both ecological (e.g. Killingsworth & Gilbert, 2010) and laboratory settings (e.g. Stawarczyk, Majerus, Maj, et al., 2011). In the former context, participants are prompted randomly as they go by their daily life via a text message on the phone. Using this paradigm, participants report the content of their experience and the nature of their activity at the time (e.g. Song & Wang, 2012). In laboratory settings, participants only report their internal experience while carrying out a mundane task. An important issue here is the duration between the probes. Indeed, it has been evidenced that greater reports of off-task thought come with larger gaps between probes (Seli, Cheyne, & Smilek, 2013; Smallwood et al., 2002). Additionally, the phrasing used to probe participants' thoughts should be considered. That is, the use of an 'on-task' frame (e.g. 'To what extent were your thoughts on task during the previous activity?') results in lower mind-wandering frequency compared to a 'mind-wandering' frame (e.g., 'To what extent were you mind-wandering during the previous activity?') (Weinstein, Lima, & Zee, 2017).

The second type of online experience sampling is the *self-caught method* where participants are asked to spontaneously report their mind-wandering episodes at the moment they occur (Smallwood & Schooler, 2006). Similar to the probe-caught method, the self-caught method depends on the participants' capacity to reflect upon their experience while performing another task, as well as their levels of meta-cognitive awareness (Schooler et al., 2011). In such paradigms, participants are informed to press a button when noticing that their mind has drifted away from the task. On multiple occasion, the combined use of the probe and self-caught method has enabled the distinction between mind-wandering frequency and meta-awareness of mind-wandering experiences (Sayette et al., 2009, 2010). For example, alcohol intoxication (Sayette et al., 2009) and cigarette craving (Sayette et al., 2010) tend to increase the probability of mind-wandering experiences (probe-caught) while decreasing the probability of noticing them (self-caught).

End of task estimations of ongoing thought also depend on self-reports but, unlike the experience sampling method, data is gathered retrospectively at the end of a task or after a block of trials, rather than in the moment. Smallwood and Schooler (2015) refer to this as *retrospective sampling* as it involves gathering estimations of experiences immediately after the task. The advantage of this method is that it preserves the natural time course of the mind-wandering task, as participants do not need to be interrupted to report their experience. Retrospective end of task estimations of mind-wandering may be gathered via a single question at the end of a task, via questionnaires (e.g. the Dundee Stress State Questionnaire, DSSQ; Matthews, Joyner, Gilliland, & Campbell, 1999), using the New York Cognition Questionnaire (Gorgolewski et al., 2014; H.-T. Wang, Poerio, et al., 2018), or through open-ended questions. Smallwood and Schooler (2015) refer to the latter as the *open-ended method.* Here, participants are asked to describe in their own words what they experienced during the previous task, which has the advantage of enabling a broader range of responses since participants are not constrained by the categories imposed by specific questions. Retrospective measures have the advantage that they do not interrupt the dynamics of cognition. Thus, combining retrospective experience sampling with the acquisition of online measures of neural function provides a promising way to understand the broader temporal dynamics of experience, using techniques that exploit temporal changes in neural signals such as functional connectivity (Biswal, Deyoe, & Hyde, 1996). However, a weakness of the retrospective approach is that this method relies on memory recall, making it impossible to relate self-reported data to a specific moment in time.

An innovative extension to experience sampling, which will be used throughout this thesis, is the simultaneous exploration of multiple dimensions of experience (Golchert et al., 2017; Karapanagiotidis et al., 2017; Konishi et al., 2017; Medea et al., 2016; Ruby, Smallwood, Engen, et al., 2013; Ruby, Smallwood, Sackur, et al., 2013; Smallwood et al., 2016; H.-T. Wang, Bzdok, et al., 2018; H.-T. Wang, Poerio, et al., 2018). This Multi-Dimensional Experience Sampling (MDES; Shrimpton, McGann, & Riby, 2017; Smallwood et al., 2016) allows the experimenter to simultaneously capture different aspects of experience, allowing their heterogeneity to be empirically evaluated. This may be especially useful when used alongside neuroimaging methodology, as this can identify whether the distinct patterns of experience observed at the level of self-reports is mirrored at the neural level. For example, Smallwood et al. (2016) found that multiple different aspects of experience - thoughts related to different temporal periods, off-task thoughts, and thoughts with vivid detail were associated with stronger connectivity at rest between regions of the temporal lobe and the posterior cingulate cortex.

It is also possible to measure dispositional differences in patterns of ongoing thought using questionnaires that map traits linked to different types of experience. For example, the Imaginal Processes Inventory (SIPI; Huba, Singer, Aneshensel & Antrobus, 1982), the Mind-Wandering Questionnaire (MWQ; Mrazek, Phillips, Franklin, Broadway, & Schooler, 2013), and the Mind-Wandering Deliberate and Spontaneous scale (Carriere, Seli, & Smilek, 2013; Seli, Carriere, & Smilek, 2015) are all individual difference measures, which ask participants to assess the characteristics of their daydreams or mind-wandering experiences in the context of their daily functioning. Similar to end of task estimation measures, this method relies on retrospective judgements concerning previous mind-wandering experience rather than online reporting. However, when these measures are used, participants have to think back over a longer period of time when reporting their experience, and this presents a greater risk of error due to misremembering and biases in reporting.

These different types of experience sampling enable researchers to investigate the role of individual differences in laboratory-based mind-wandering tasks and gather information regarding general tendencies to mind-wander in real-life situations, making them more ecologically valid. While each approach has weaknesses, in combination they offer the potential to refine our understanding of the nature of ongoing thought. For example, Shrimpton et al. (2017) argued strongly for the combined use of typical mind-wandering style measures and experience sampling, giving insight about the association between temporal focus and self-related thoughts. Elsewhere, this methodology enabled the verification of differences in spontaneous and deliberate mind-wandering both through associations with ADHD (Seli, Smallwood, et al., 2015) and in the brain (Golchert et al., 2017).

2.1.2. Behavioural Methods

Owing to issues of misremembering and the response bias associated with self-reports, researchers usually aim to corroborate self-reports of mind-wandering with measurements of the behavioural consequences. Often this involves examining performance on the very task that is designed to encourage the onset of mind-wandering in the first place. Examining the consequence of a particular state in this manner has a long history in psychology where direct measurement is not possible. For instance, when examining the cost of dual tasking on everyday memory, measures are not only made on the secondary task, but also on the primary task. Here, one can consider the ongoing activity of self-generated thoughts as a primary task, which will impact on secondary task performance. As such, by measuring the secondary task, one can indirectly measure the primary task, namely self-generation of thoughts. A typical computer-based paradigm for examining mind-wandering experiences in the laboratory involves engaging participants on a relatively mundane task that nevertheless requires sustained attention. Episodes of poorer performance on this secondary task, for example in terms of accuracy, false alarms, or reaction time variability are assumed to signal the occurrence of mind-wandering.

A task that has frequently been used to both encourage and measure mind-wandering is the Sustained Attention Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). This requires participants to respond as quickly as possible to frequent and relevant stimuli (e.g., ‘press the space bar when the letter X appears’), while inhibiting their responses to infrequent stimuli (e.g. ‘do nothing when the letter Y appears’). One advantage of this method is that researchers may use it to manipulate the prevalence of mind-wandering by varying the demands of the task. For example, in an investigation into the effect of glucose on mind-wandering, Birnie, Smallwood, Reay, and Riby (2015) found that probed self-reports of mind-wandering were associated with false alarms on the SART (i.e., erroneously pressing the response key to the infrequent stimuli). Furthermore, this association was stronger on easier trials of the SART, supporting the inference that mind-wandering is more prevalent when the demands of the ongoing tasks are low. The SART has been used extensively and has uncovered important mind-wandering consequences, such as increased reaction times before errors and decreased reaction time after errors, which is particularly true in ageing (Jackson & Balota, 2012). This reflects changes in attentional focus with the reengagement of attention on the task after an error. Such patterns have been replicated using a modified version of the SART which used the auditory modality (Seli, Cheyne, Barton, & Smilek, 2012). Additionally, Seli et al. (2013) developed the metronome task, which involves responding synchronously (via button presses) with a continuous rhythmic presentation of tones, and demonstrated behavioural variability in the responses as a marker of mind-wandering.

Although sustained attentional tasks such as the SART have been used extensively in the mind-wandering literature, they have received recent criticism regarding their precision in measuring both sustained attention and the likelihood of mind-wandering (Dillard et al., 2014). Problematically, the SART does not include any control condition or baseline, therefore preventing researchers from generating strong conclusions regarding the variation in mind-wandering rates (see paradigm from Konishi, McLaren, Engen, & Smallwood, 2015). Thus, a variant of the cognitive task used by Konishi et al. (2015) has received great interest and was used in this program of work to both encourage and measure mind-wandering experiences. In this n-back paradigm, participants alternate between blocks of trials in which they either make decisions about the location of shapes, which are currently available to the senses (0-back) or with respect to their location on a prior trial (1-back). Like the SART, the N-back task makes it possible to manipulate the demands of the task, with an increase in working memory load during the 1-back trials, but it also makes it possible to simultaneously investigate the role of perceptual input during mind-wandering, and thereby test separate hypotheses regarding the role of the DMN during mind-wandering.

2.2. Neuroimaging Tools

The array of subjective and behavioural indicators of mind-wandering provide important lines of insight into the psychological features of ongoing thought, however, in isolation may struggle to provide the high levels of detail needed to refine our understanding of this important psychological state. It is proposed that neuroimaging measures add a further layer of objectivity to the experimental toolkit when exploring patterns of self-generated thought. To date, studies using Event-Related Potentials (ERPs) and Electroencephalogram (EEG) have provided important support for the view that periods of ongoing thought can become perceptually decoupled from external events. Furthermore, functional Magnetic Resonance Imagery (fMRI) has enabled the identification of spatially separable cognitive processes, allowing researchers to make inferences about the neural mechanisms underlying different aspects of self-generated thought.

2.2.1. ERPs and EEG

ERPs have proven to be a particularly valuable tool for evaluating the level of perceptual engagement. Before the implementation of more complex attentional abilities, sensory information is processed relatively fast, within 150 to 200 milliseconds, and described by components known as the P1 and N1. While N1 has been found to be sensitive to auditory stimuli type and presentation predictability, P1 may reflect the "cost of attention" (Luck, Heinze, Mangun, & Hillyard, 1990). Elsewhere, P1 and N1 have been used to indicate respectively, the attentional filtering and categorisation of perceptual information before integrating semantic knowledge (Klimesch, 2011, 2012), and the discrimination process when judgements about the stimuli are needed. Interestingly, these components are found to be attenuated following reports of task-unrelated-thought (Kam et al., 2010). Therefore, the reduction of their amplitude is suggestive of a reduction of brain-evoked response to sensory input, and a shift to the processing of self-generated thoughts (Baird, Smallwood, Lutz, & Schooler, 2014). Together, the examination of early components has shown that during certain mental states, the processing of perceptual descriptions of events in the external environment is reduced.

The study of a later component, the P3 (occurrence between 250 and 500 milliseconds post-stimulus), is assumed to reflect the engagement of attentional processes. Studies have shown that this is linked to a reduction in amplitude during mind-wandering compared to being task focused (Barron, Riby, Greer, & Smallwood, 2011; Kam et al., 2010, 2012; Kam & Handy, 2013; Smallwood, Beach, Schooler, & Handy, 2007). Given the well-documented role of the P3 in attentional processes, these data suggest that periods of off-task thought are associated with changes in attentional distribution. However, studies have shown that this process reflects a switch away from the task, rather than a failure to inhibit task-irrelevant information. Barron et al. (2011) used a 3-stimulus oddball paradigm to understand whether off task thought was linked to lower processing of task events, regardless of their relevance to the task, or whether the attenuation was specific to task-relevant information. The 3-stimulus oddball task typically comprises the presentation of task-relevant infrequent targets (requiring a response) in a train of frequent stimuli that generates an ERP component called the P3b, while additional rare task-irrelevant stimuli are presented, which generates a component known as the P3a. Barron and colleagues demonstrated a reduction of both the P3a and P3b, linked to off-task reports suggesting that the processing of all stimuli in the environment is reduced, rather than just those that are important to the task.

Further evidence in favour of the decoupling hypothesis has been provided by analysis of the EEG signal. In these studies, EEG signals are captured in a 5 to 10 seconds epoch before self-reports of particular types of experience, and during a similar epoch afterwards. In this approach, the pre-period is considered representative of the neural processes relevant to the particular state, while the post-period is thought to represent the reengagement of task focus since attention has been redirected toward the task. Using this paradigm, Braboszcz and Delorme (2011) demonstrated an increased activity of lower frequencies such as theta (4-7 Hz) and delta (2-3.5 Hz), and a decrease of higher frequencies, namely alpha (9-11 Hz) and beta (15-30 Hz), during mind-wandering as compared to breath focus (mindful condition). Delta power has been associated with poor cognitive ability (Harmony, 2013), and also linked to a lower state of vigilance (Roth, 1961). Thus, the authors suggest that their findings highlight a reduction of alertness to the task during mind-wandering experience. In a similar vein, Baird et al. (2014) observed significantly more pronounced reductions in spectral power during mind-wandering, compared with task focus over frontal scalp regions in the alpha and beta band. Enhanced alpha activity is mostly found during wakeful relaxation and reflects inhibition of task-irrelevant cortical areas (Klimesch, Sauseng, & Hanslmayr, 2007). In contrast, beta band activity is related to active concentration and maintenance of current cognitive states (Engel & Fries, 2010), together enabling the efficient treatment of external input. Nevertheless, one should keep in mind that the functional significance of the frequency bands is still unclear, as it is sometimes difficult to associate cognitive functions in a unique and direct way with frequency bands. Thus, a given frequency band is unlikely to underly a single cognitive function in the brain (For an overview of the frequency bands functional significance see Britton et al., 2016).

The appeal of electrophysiological studies is that EEG and ERPs can also capitalise on both time and frequency. Braboszcz and Delorme (2011) used Mismatch Negativity (MMN) as a marker of brain response to the sensory detection of a sudden auditory change (Näätänen, Paavilainen, Rinne, & Alho, 2007). The amplitude of MMN is thought to represent the focus of one's attention (Sabri, Liebenthal, Waldron, Medler, & Binder, 2006). Thus, findings of lower amplitude of the MMN during periods of off-task thought reflect a disengagement of attention from external stimuli being processed. Braboszcz and Delorme (2011) also outlined an additional layer of analyses by considering the impact of meta-cognitive processes. The moment where participants consciously realise their mind has been wandering is central, as it allows the redirection of attention toward the task. Findings revealed that this process of refocusing was related to an increase of the alpha peak frequency and a long-lasting increase in alpha power. Considering that peaks of alpha frequency are thought to represent a state of "cognitive preparedness" (Angelakis, Lubar, Stathopoulou, & Kounios, 2004), and that alpha power has been linked to working memory (Jensen, Gelfand, Kounios, & Lisman, 2002), the authors suggest that together the peak of alpha and its general increase in power may be markers of attention, being transferred from self-generated information to information relevant to the external task. Together, these EEG and ERP findings generate strong evidence for the decoupling hypothesis and provide information regarding the contribution of meta-awareness during mind-wandering episodes.

Using ERPs and EEG alongside behavioural and self-report measures has unravelled evidence in support of the perceptual decoupling hypothesis. Off-task thought is linked to reductions in the cortical processing of the environment at a very early stage, and both task-relevant and unrelated sensory information is processed in less detail. Additionally, the processing of an external input is less stable, and this is accompanied by a decrease in the neural efficiency of task-related actions. Collectively, this suggests that when people are off-task their cortex is responding less to environmental input. The combination of self-reports with electrophysiological measures is therefore highly valuable in disentangling internal from external processes. In addition, when used alongside fMRI described below, such methods can contribute significantly to understanding the heterogeneous nature of thought content.

2.2.2. Functional Magnetic Resonance Imaging

Functional Magnetic Resonance Imaging (fMRI) is a critical tool for the identification of brain areas and neuro-cognitive networks implicated in various cognitive processes, including self-generated thoughts. A large proportion of previous fMRI research has focussed on the DMN (see Chapter 1; for review see Raichle, 2015). Studies have shown that the DMN can be more active during off-task thought. Using experience sampling, Christoff, Gordon, Smallwood, Smith, and Schooler (2009) demonstrated activation of the DMN along with executive network regions during mind-wandering. This basic observation has been replicated by two independent research groups (Allen et al., 2013; Stawarczyk, Majerus, Maquet, & D’Argembeau, 2011). In general, the executive and default networks are thought to act in opposition to each other, so that when the executive network becomes activated, the default network is deactivated or actively suppressed (Weissman, Roberts, Visscher, & Woldorff, 2006). However, there are psychological phenomena where one might predict co-activation. For example, co-activation of those networks is similar to neural recruitment observed during creative thinking (Beaty, Benedek, Kaufman, & Silvia, 2015; Beaty et al., 2018; Kounios et al., 2008, 2006), autobiographical planning (Spreng et al., 2010), during naturalistic film viewing (Golland et al., 2007), immersive simulative mental experiences (Mar & Oatley, 2008), and periods when information from memory can guide decision making (Konishi et al., 2015; Murphy et al., 2017). What is common about these examples is the requirement that goal relevant cognition must rely on information from memory.

A straightforward approach to the neural processes of mind-wandering is the comparison of the brain activity of self-generated experiences that are produced spontaneously, and as part of a task. A recent example is the use of multivariate pattern analysis (MVPA) by Tusche, Smallwood, Bernhardt, and Singer (2014) to identify similarities between spontaneous and task-related examples of positive and negative thoughts. In their research, the authors compared brain activity associated with specific emotional content, which was either self-generated or externally-generated by a task. They found similar patterns of activation (i.e. medial orbitofrontal cortex; mOFC) for both the task-generated and task-free affective experiences, which suggests commonalities in the nature of thoughts regardless of the way they have been initiated. Ultimately, the use of MVPA enables researchers to draw parallels between task-induced and naturally occurring affective experiences, and to test important features of contemporary accounts of how patterns of self-generated thought emerge.

2.2.3. Functional and Structural Connectivity

The high spatial definition of fMRI also allows the relationship between the organisation of neural function and patterns of self-generated thought to be investigated. These approaches depend on connectivity analyses that estimate the connections between different brain regions, which can be derived from both the functional (i.e. the BOLD signal) and the structural domain (i.e. white matter connections, for a comprehensive review see Rubinov & Sporns, 2010). Emerging studies are beginning to pinpoint the neural architecture underlying mind-wandering episodes. Karapanagiotidis et al. (2017) assessed whether individual variability in the content of their thoughts related to markers of structural connectivity. Structural connectivity using DTI identified a temporo-limbic white matter region, highly connected to the right hippocampus in people who spontaneously engaged in more mental time travel. Functional connectivity analyses revealed a temporal correlation of the right hippocampus with the dorsal anterior cingulate cortex, a core region of the DMN, which was modulated by inter-individual variation in mental time travel. Therefore, spontaneous thoughts experienced during mind-wandering, especially those linked to mental time travelling, seems to be particularly associated with the hippocampus and its integration with the DMN. This assumption has been highlighted by evidence that individuals with hippocampal amnesia are less likely to experience off-task episodes with rich experiential content (McCormick, Rosenthal, Miller, & Maguire, 2018).

Similarly, Smallwood et al. (2016) explored whether individual differences in the functional architecture of the cortex predicted the nature of spontaneous thoughts. Results illustrated that the functional connectivity of the temporal poles with the posterior cingulate cortex was predictive of both greater mental time travel involving social agents and unpleasant task-unrelated-thoughts. Heightened connectivity from the hippocampus to the posterior cingulate cortex predicted greater specificity to thought, thus giving further insight into the key role that the hippocampus seems to be playing when related to specific nodes of the DMN. Additionally, findings support the hypothetical role of DMN subsystems in contributing to different qualities of spontaneous thought. Furthermore, this study highlights that, to generate spontaneous thoughts, the posterior regions of the DMN are crucial elements integrating information from both the medial and anterior aspects of the temporal lobe. Another study using functional connectivity evidenced the integrity of the hippocampus to the DMN by investigating the underlying neural processes of goal concreteness during mind-wandering experience (Medea et al., 2016). These authors first demonstrated that our capacity to develop more concrete descriptions of both goals and aspects of our knowledge is supported by brain networks centred on the hippocampus. A greater coupling between the hippocampus and more dorsal medial frontal regions, including the pre-supplementary motor area, was a specific predictor of the generation of more concrete goals. The authors speculate that connectivity between each region supports a process in which goal states are evaluated, refined, and encoded for further evaluation. Thus, adding further upon the role of the hippocampus in the integration of DMN nodes. Finally, Golchert et al. (2017) looked at another potential aspect of mind-wandering experiences, namely intentionality. Analysis demonstrated that the intentionality of the mind-wandering state depends on integration between the executive and default networks, with more intentionality being associated with greater integration between these systems. Thus, suggesting that the linkage between the executive and default networks is important, and allows one to deliberately guide a self-generated train of thought, in line with specific goals. The combined use of functional and structural connectivity highlights further the heterogeneity of mind-wandering experiences, as specific characteristics are consistently associated with variations in neural recruitments.

Altogether, connectivity measures based on MRI enabled the discovery of important key brain network properties. Notably, the hippocampus has been related to the DMN, evidencing the importance of this area. Nevertheless, each study has revealed a link to different areas of the DMN (i.e. ACC, PCC, dmPFC), most certainly reflecting the diversity of mind-wandering experiences. This clearly illustrates how the high variability of mind-wandering experiences relates to disparate neural recruitment. A more recent study demonstrated that states of mind-wandering elicited positive functional connectivity between regions of both the executive and default networks (Mooneyham et al., 2016). Here the use of dynamic functional connectivity enabled the identification of different states of functional connectivity across known networks. This measure is based on the principle that functional connectivity relationships between brain regions and networks are dynamically influenced by time, and reflects changes in cognitive states (Calhoun, Miller, Pearlson, & Adalı, 2014; Hutchison et al., 2013). As such, it is not only the links binding different brain areas that are interesting, but also how this binding changes over time. Thus, beyond the co-activation of the executive and default networks, dynamic functional connectivity measures suggest that these networks are synchronised in their activity during mind-wandering experiences. This highlights how they may work in a complimentary way during periods of off-task thought, mirroring patterns of evidence from other examples of memory-driven thought.

Finally, neuroimaging methods hold promise for understanding the dynamics of experience. One important metric is phase locking of neural processes. Brabroszcz and Delorme (2011) identified impaired phase-locking of theta frequency when participants were thinking about something unrelated to the task being performed when compared to periods of task-focus. Interestingly, mental training in focused attention (meditation) tends to increase theta band phase-locking (Slagter, Lutz, Greischar, Nieuwenhuis, & Davidson, 2009), and also reduces the occurrence of mind-wandering episodes (Mrazek et al., 2012). As such, this EEG based connectivity measure gives further indications toward a decreased alertness of participants when engaged in mind-wandering experiences.

On the other hand, coherence measures have been widely used to investigate connectivity within the DMN. Coherence is a measure of "coupling" and of the functional association between two brain regions (Thatcher, 2010). EEG phase differences are used to measure the directional flow of information between two EEG electrodes sites. Using mean phase coherence, Berkovich-Ohana, Glicksohn, and Goldstein (2014) exerted that DMN deactivation during a task, compared to resting states, was illustrated by a lower gamma and increased alpha mean phase coherence. The authors suggest that this reflects a control/executive system coupling transition. A lower gamma band would reflect the decoupling of the control/executive system with the DMN, whereas the increase in the alpha band could reflect the coupling of this system with task-activated network. Therefore, this illustrates the dynamic changes in coupling/decoupling of the default and executive networks in relation to mind-wandering. Additionally, a recent study investigated the neuronal differences between thoughts triggered either internally or externally by using correlation coefficient measure, which is similar to coherence measures (Godwin, Morsella, & Geisler, 2016). Findings revealed increased functional connectivity over parietal areas within the alpha band for internal compared to external thoughts. According to the authors, this could reflect neural mechanism enabling the suppression of attention directed toward the external environment to favour internally-directed processes. As such, connectivity measures seem to confirm the decoupling process account previously outlined.

In conclusion, the use of neuroimaging tools and converging methods has proven to be informative in the study of mind-wandering. Supporting the perceptual decoupling hypothesis, ERP methodologies revealed that, when mind-wandering, ones' perceptual processing is attenuated. The use of EEG acknowledged that mind-wandering is associated with less alertness and cognitive processing, and requires more neural processing to reach task demand and re-couple attention to the task. fMRI studies have provided evidence that activity in both the default and executive networks are necessary to generate mind-wandering experiences, which was further highlighted by connectivity measures. An increasing number of researchers argue strongly for converging methods, including recent developments in the neurosciences and traditional behavioural techniques to clarify the variation in the neural recruitment underlying the occurrence of multiple mind-wandering experiences. Particularly, this thesis will use this approach to converge toward an understanding of the mind-wandering experience in ageing. This will be carried out both within studies and across this project. The joint use of self-report and brain activity (EEG) or brain connectivity (fMRI) measures will help refine the theory of mind-wandering in ageing. The EEG work will target the effect of age-related change in brain activity on self-generated thoughts. This will be extended to brain connectivity as measured by fMRI. Additionally, thought heterogeneity in ageing will be explored with the triangulation of different methodological context (i.e. culture, meta-awareness, meditation) to further endorse existing theories. Individually each methodological approach will inform the initial question of thought content in ageing. Nevertheless, the combination of the three will also bring substantial knowledge about the versatile nature of mind-wandering experiences. Ultimately, focusing on the ageing population will be beneficial to both the understanding of mind-wandering experiences and the neurocognitive profile of older adults more generally.

– Section A –
Consideration of the neurocognitive processes underlying mind-wandering experiences in ageing.

Chapter 3. Understanding mind-wandering experiences in young and older individuals using electrophysiology.

Previous chapters have outlined the heterogeneity of mind-wandering experiences, the influence of age, and the critical need for converging methods. Although age-related decreases in off-task thought are now well documented, a clear neuro-cognitive account of what underlies this change in self-generated thought is lacking. This Chapter will aim to (i) describe the link between age-related changes in brain electrophysiology and age-related changes in self-generated thought, as well as (ii) define neural patterns underlying specific self-generated thoughts. Multi-dimensional experience sampling was used to measure thought heterogeneity, in combination with online and resting state measures of electrophysiology in young and older adults. Results showed that in young adults, beta power over centro-parietal right area enabled the flexible adjustment of mental time travelling to match task demands, a pattern not found in older adults. Furthermore, general increases in alpha and beta power were indicative of the involvement of the default mode network in off-task thoughts. Delta power was found essential to mental time travelling experiences by lowering concentration and supporting memory processes. Interestingly, hemispheric differentiation in gamma power was representative of thought modality, with the left hemisphere supporting verbal rehearsing during a demanding task.

3.1. Introduction

Numerous research studies have outlined an age-related reduction in off-task thoughts (Giambra, 1989; Jackson & Balota, 2012; Jackson et al., 2013; McVay et al., 2013); yet consideration of older adults' neurocognitive profile is lacking. Cognitively older adults are known to present deficits in features essential to the generation and control of mind-wandering experiences, namely episodic memory and attentional control (Addis, Musicaro, Pan, & Schacter, 2010; Addis, Wong, & Schacter, 2008;

Schmitter-Edgecombe, Vesneski, & Jones, 2000; Smallwood & Schooler, 2015). Such behavioural changes have been linked to the age-related reorganisation of brain activity and connectivity (e.g. Fjell & Walhovd, 2010). Accordingly, neurocognitive changes in ageing should also impact mind-wandering experiences regarding content and frequency. Therefore, this study aimed to document thought content in ageing, and identify the role that age-related changes in brain activity play in self-generated thoughts. Additionally, by combining the temporal precision of the electroencephalogram to online measures of self-generated thoughts, neural patterns underlying different thoughts will be identified.

Mind-wandering experiences are eclectic and largely portray future and personally-relevant thoughts (Baird et al., 2011; D'Argembeau et al., 2011; Smallwood, Nind, et al., 2009; Smallwood et al., 2011) with a tendency toward verbal, intrusive, or detailed features (Karapanagiotidis et al., 2017; Medea et al., 2016; Smallwood et al., 2016). In the case of older adults, evidence suggests an increase of task-related interferences (i.e. thoughts about ones performance or strategy; Frank et al., 2015; McVay et al., 2013; Zavagnin et al., 2014) and a-temporal thoughts (i.e. imaginary thoughts that do not belong to either the past or the future; Jackson et al., 2013; Rendell et al., 2012). Outside of the mind-wandering literature, older adults present difficulties at imagining future experiences, with fewer occurrences (Berntsen et al., 2015), as well as fewer details (Rendell et al., 2012). Some evidence suggests that involuntary past-related thoughts remain stable across life (Berntsen et al., 2015), however laboratory-based studies have demonstrated difficulties for older adults at retrieving detailed autobiographic memories (Schacter, Gaesser, & Addis, 2013). Overall, this profile is suggestive of changes in, not only the frequency but also, the nature of mind-wandering experiences. Further support for this claim is the age-related decline of neural networks underlying mind-wandering experiences (e.g. prefrontal cortex, parietal regions and medial and lateral temporal; Andrews-Hanna et al., 2014; Biswal et al., 2010; Damoiseaux, 2017; Damoiseaux et al., 2008).

Recent advances in the neuroscience literature have been influential in documenting age-related changes in brain activity and connectivity. Particularly, fMRI work has identified vulnerabilities in the frontal lobes (Rabbitt, 2005; Robbins et al., 1998; see also details of the frontal ageing hypothesis West, 2000; Greenwood, 2000; West, 1996), as well as reduced activity and connectivity in the DMN (Biswal et al., 2010; Damoiseaux, 2017; Damoiseaux et al., 2008), which is largely active during mind-wandering experiences (Fox, Spreng, Ellamil, Andrews-Hanna, & Christoff, 2015; Mason et al., 2007). Particularly relevant to the present chapter is evidence suggesting resting state measures of brain activity influence EEG age-related decreases in activity in lower frequency bands (i.e. delta and theta), and increased activity in higher frequency bands, specifically the beta band (Cummins & Finnigan, 2007; Duffy et al., 1984, 1993). Enhanced recruitment of higher frequency bands is also found when online measures are used with increased alpha and beta activity evident during the completion of demanding attentional tasks (Deiber et al., 2015). Therefore, older adults' brain activity tends to shift toward frequency bands related to higher order processing to support performance.

Importantly, older adults' changes in spectral power are tapping into frequency bands related to off-task thoughts (i.e. theta and beta band). An influential study (Braboszcz & Delorme, 2011) assessed the neuro-correlates of mind-wandering during a breathing focus task where participants pressed a button when noticing a mind drift. Analyses of a 10 second epoch before a button press evidenced increased theta power and decreased occipital alpha and fronto-lateral beta power during mind-wandering compared to breath focus. The contribution of the alpha and beta band was later confirmed (Baird et al., 2014), suggesting a reduction of alertness to the task during mind-wandering experiences. Indeed, higher alpha and beta power are mostly associated with inhibition of task-irrelevant cortical areas (Klimesch et al., 2007) and maintenance of current cognitive states (Engel & Fries, 2010) respectively; together enabling the efficient treatment of external input. Overall, evidence to date suggests older adults' changes in brain activity (i.e. theta and beta band) may underlie age-related changes in mind-wandering experiences.

The present study will document further the neural characteristics underlying different self-generated thoughts, an approach that is yet to be taken with EEG. Recent fMRI research has demonstrated links between variability in thought content and patterns of brain activity and connectivity (Medea et al., 2016; Smallwood et al., 2016; H.-T. Wang, Bzdok, et al., 2018). For example, experiences characterised by high 'personal importance' were associated with reduced functional connectivity within the attention and control systems (H.-T. Wang, Bzdok, et al., 2018). However, such investigations are still lacking input from the temporal precision of EEG. Mind-wandering experiences can be considered as a simplistic dichotomy between on- and off-task. Off-task thoughts have shown to increase theta power and decrease alpha and beta power (Baird et al., 2014; Braboszcz & Delorme, 2011). Nevertheless, studies combining EEG and fMRI report positive correlations between increased alpha and beta power at rest and activity in the default and self-referential networks (Mantini, Perrucci, Gratta, Romani, & Corbetta, 2007). Bearing in mind the undeniable contribution of the DMN in self-generated thoughts (Fox et al., 2015; Mason et al., 2007), increases of alpha and beta band activity should be expected during off-task thoughts. Therefore, alpha and beta band are clearly involved in off-task thoughts. Yet, the direction of this effect may vary depending on the methodology used (e.g. online versus resting states measures, or simplistic off-task versus more complex off-task thoughts). Moving towards more specific types of self-generated thoughts, the research is very limited. However, an early study measuring thoughts and spectral power during rest, has reported links between visual imagery (without goal orientation or emotional load) and frequencies between 4-7 Hz (theta band), 10-13 Hz (upper alpha band), and 18-23 Hz (beta band; Lehmann, Grass, & Meier, 1995). Other findings suggest links between future-oriented thoughts and both the alpha (7-9 Hz; Lehmann et al., 1995) and the gamma band (i.e. reduced activity; Lavallee & Persinger, 2010). Further, voluntarily re-experiencing an event was linked to more theta power and less delta power (Lavallee & Persinger, 2010).

Overall, the objectives of the present study are to, (i) link general age-related changes in brain activity to changes in thought content in ageing, and to (ii) define the neural patterns underlying different self-generated thoughts. Multi-dimensional experience sampling will be used to measure thought heterogeneity, and combined with online and resting state measures of electrophysiology in young and older adults. Principal component analyses will be conducted to identify core patterns variance in self-reported data. Replication of previous work reporting on-task thoughts, mental time travelling and the modality of the thoughts is hypothesised (Karapanagiotidis et al., 2017; Medea et al., 2016; Smallwood et al., 2016). A decrease in off-task thoughts is predicted for older adults (Giambra, 1989; Jackson & Balota, 2012; Jackson et al., 2013; McVay et al., 2013). However, no clear hypotheses can be formed regarding the impact of age on the temporality or modality of the thoughts. Older adults are expected to display reduced power in lower frequency bands and increased power in higher frequency bands at rest (Cummins & Finnigan, 2007; Duffy et al., 1984). Such patterns of change, particularly in the theta and beta band, are hypothesised to underly age-related changes in self-generated thoughts (Baird et al., 2014; Braboszcz & Delorme, 2011; Mantini et al., 2007). Lastly, using linear mixed modelling, it is expected that participants' focus will be predicted by alpha and beta band activity, either showing increased (Mantini et al., 2007) or decreased activity (Baird et al., 2014; Braboszcz & Delorme, 2011; Mantini et al., 2007). As for mental time travelling and thought modality, the lack of research prevents the description of clear hypotheses; this part of the analyses will be exploratory.

3.2. Method

3.2.1. Participants

The older adult group consisted of 18 women and 7 men (*M* = 70.08 years, *range* = 61–87) recruited using opportunity sampling. The younger adult group consisted of 16 women and 9 men (*M* = 21.68 years, *range* = 19–29) who were undergraduate students in Psychology at Northumbria University. All participants received financial compensation for their time and travel. The inclusion criteria were to be a fluent English speaker and have normal or corrected vision and hearing. Exclusion criteria were the presence or history of a neurological or psychiatric disorder, or current use of antidepressants. Older participants completed the Mini-Mental State Examination (MMSE, Folstein, Folstein, & McHugh, 1975) to ensure absence of dementia or mild cognitive impairment (threshold: score ≥26/30) (see **Table 3.1**.). Participants were seen for a minimum of one hour and thirty minutes to two hours in the EEG laboratory. This study was approved by the Ethics Committee of the Faculty of Health and Life Sciences of Northumbria University. The investigation was conducted according to the principles expressed in the Declaration of Helsinki and participants provided written informed consent.

Table 3.1. Means (Standard Deviations) of participants' characteristics as well as probe count.

Measures	Young (*SD*)	Old (*SD*)
N	25	25
N Probes	387	371
M age	21.68 (3.47)	70.08 (6.38)
Woman %	64	72
NART (errors)	20.36 (5.17)	6.16 (3.27)
Years of Education	21.68 (3.47)	18.08 (2.64)
MMSE	-	29.16 (0.8)

3.2.2. Procedure

At the beginning of the session, demographic questions were asked, followed by the NART (National Adult Reading Task; Nelson, 1982) and the MMSE (older adults only). EEG was recorded during an Eyes Closed/ Eyes Open resting state procedure. Both conditions lasted 2 minutes, and the order was randomised. EEG was also recorded during a working memory task, where participants performed an N-back task previously developed by Konishi, McLaren, Engen and Smallwood (2015). Every participant completed a practice run before performing the task. After electrodes were removed, participants were given a debriefing sheet.

3.2.3. N-back working memory task

The task was developed using PsychoPy (Pierce, 2007) and featured a 0-Back and a 1-Back condition that continuously switched from one another throughout the experimental session. In both conditions, participants saw different pairs of shapes (non-targets) appearing on the screen divided by a vertical line; the pairs could be: a circle and a square, a circle and a triangle, or a square and a triangle, with a total of 6 possible pairs (two different left/right configurations for each). The pairs never had shapes of the same kind (e.g. a square and a square). In both tasks, a block of non-targets was followed by a target requiring participants to make a manual response. The target was a small stimulus presented in the centre of the line, in blue if in the 0-Back condition and in red if in the 1-Back condition. In the 0-Back condition, the target was flanked by two shapes and participants had to indicate, by pressing the left or right arrow key, on which side was the same shape as the target shape. In the 1-Back condition, the target was flanked by two question marks and participants had to respond depending on which side the target shape was on the prior trial (see **Figure 3.1**.).

Each block lasted between 40 to 120 seconds before switching to the other condition; the change of condition was signalled by a message (“SWITCH”) that

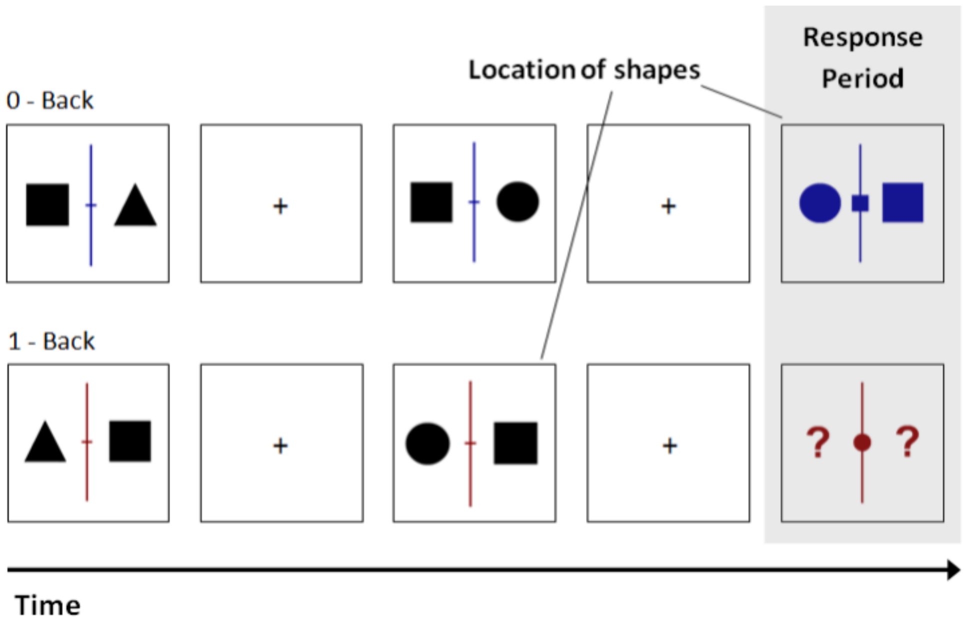


Figure 3.1. Illustration of both 0-Back and 1-Back conditions included in the working memory task used.

remained on screen for five seconds. On each trial, the number of non-targets preceding the Targets varied between two and six, the number of trials per block varied between two and five, and the total number of blocks was eight for each condition. The whole task lasted approximately 30 minutes. The total number of targets varied between 10 and 21 per condition. In order to sample the participants' ongoing experiences, a probe-caught, Multi-Dimensional Experience Sampling method was used (MDES; Smallwood et al., 2016). The task was built so that there was a 50% chance of a thought probe being presented in place of a Target in a condition block. The thought probe consisted of an on-screen prompt for the participants to rate their focus level ('*My thoughts were focused on the task I was performing*.') on a visual analogue continuous scale from 0 ('*Not at all*') to 1 ('*Completely*'), responses were given using a computer mouse. This prompt was followed by 12 questions regarding characteristics of their thoughts immediately prior to the probe (**Table 3.2**.). Every presentation of non-targets, targets, probes, and SWITCH screens were separated by a fixation cross. The fixation crosses, non-targets, and targets were respectively presented for 1.5, one, and two seconds and a response from participants did not end the target presentation.

Table 3.2. Questions and scales used in Multidimensional Experience Sampling.

Measures	Probe questions	Scale (0 → 1)
Task Focus	My thoughts were focused on the task I was performing.	Not at all → Completely
Future	My thoughts involved future events.	Not at all → Completely
Past	My thoughts involved past events.	Not at all → Completely
Self	My thoughts involved myself.	Not at all → Completely
Other	My thoughts involved other people.	Not at all → Completely
Emotion	The content of my thoughts was:	Negative → Positive
Images	My thoughts were in the form of images.	Not at all → Completely
Words	My thoughts were in the form of words.	Not at all → Completely
Vivid	My thoughts were vivid as if I was there	Not at all → Completely
Detailed	My thoughts were detailed and specific.	Not at all → Completely
Habit	This thought has recurrent themes similar to those I have had before.	Not at all → Completely
Evolving	My thoughts tended to evolve in a series of steps	Not at all → Completely
Deliberate	My thoughts were:	Spontaneous → Deliberate

3.2.4. EEG acquisition and processing

Within the resting states and the cognitive task, EEG was recorded from 32 channels using an electrode cap (Biosemi) based on the international 10–20 system (Jasper, 1958). The montage included four midline sites (FZ; CZ; PZ; OZ). Based on previous work (Riby & Orme, 2013), and to allow for the analysis of both hemisphere and region, eight distinct regions were created with the remaining electrodes. These were Frontal left (FP1; AF3; F7), Frontal right (FP2; AF4; F8), Fronto-Central left (F3; FC1; FC5), Fronto-Central right (F4; FC2; FC6), Centro-Parietal left (C3; CP1; CP5), Centro-Parietal right (C4; CP2; CP6), Parieto-Occipital left (P7; P3; PO3; O1), and Parieto-Occipital right (P8; P4; PO4; O2). T7 and T8 were not included in the analysis. To assess eye blinks, electrodes were placed above and below the right eye to record the electrooculogram. All signals were digitized at a rate of 2048 per second, with a recording epoch of four to six second epochs extending backwards from experience sampling prompts. Although it is not currently possible to determine the precise onset of spontaneous attentional shifts to unrelated thoughts (Smallwood, 2013), five to ten second time windows have been used in previous studies (Baird et al., 2014; Braboszcz & Delorme, 2011; Christoff et al., 2009; Qin, Xu, & Yao, 2010). Manual eye-blink correction, removal or replacement of bad electrodes and artefact rejection were conducted offline using NeuroScan Edit 4.3. Due to too many artefacts in the cognitive task, 24 epochs out of the 758 recorded (Young = 387, Old = 371), had to be removed from the analyses (Young = 3, Old = 21), which included all data from one participant in the older adult group (14 epochs). Data from this participant was also removed from the resting states analyses due to too many artefacts. Frequency bands extracted were Delta (0-4 Hz), Theta (5-7 Hz), Alpha (8-12 Hz), Beta (13-29 Hz) and Gamma (30-50 Hz).

3.3. Results

3.3.1. Multi-Dimensional Experience Sampling

To analyse the MDES, the set of questions was decomposed using principal component analysis (PCA), applying varimax rotation (for prior examples of this approach see Konishi et al., 2017; Poerio et al., 2017; Ruby, Smallwood, Engen, et al., 2013; Ruby, Smallwood, Sackur, et al., 2013). This allowed the core patterns of variance within the self-reported data to be characterised in a smaller set of underlying dimensions. Three factor solutions were selected with eigenvalues >1, and the loadings that describe these dimensions are presented in the form of a heat map in **Figure 3.2**: Component One - *Deliberate On-Task* – described deliberate and detailed thoughts about the task in the hand with high positive valance and accounted for 28.13% of the variance. Component Two - *Mental Time Travelling* (MTT) – described episodic thoughts (past and future) with high loadings on the self and other, and accounted for 18.23% of the variance. Component Three - *Thought Modality* (Images or words) – described thoughts that varied in their modality between representations in images or those with verbal features and accounted for 8.99% of the overall variance. These patterns of ongoing thought revealed by the current decomposition are consistent with prior studies. For example, prior PCA decompositions have emphasised the distinction between task focus and episodic mental time travel (i.e. Karapanagiotidis et al., 2017; Smallwood et al., 2016).

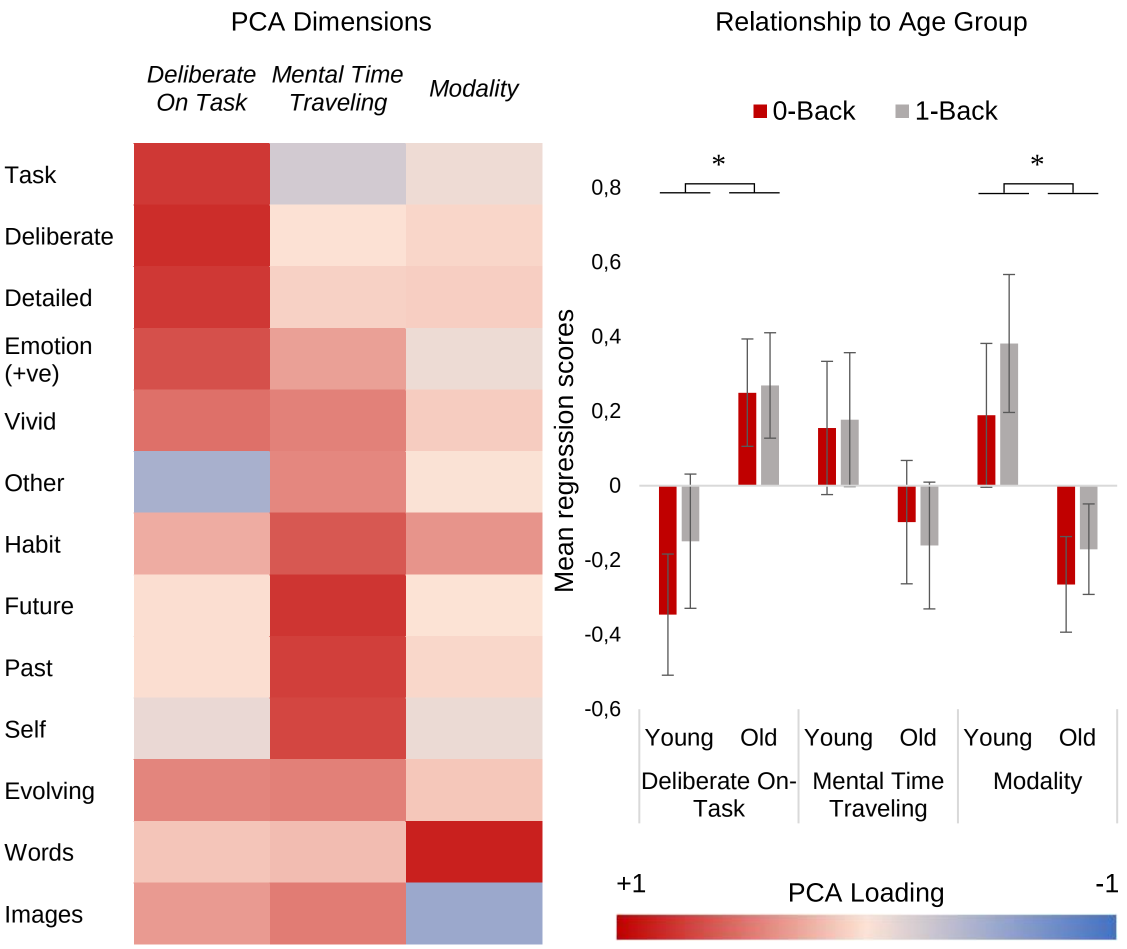


Figure 3.2. Determining patterns of self-generated thought and their relationship to ongoing task and age group.

(*Left*) Heat map illustrating the loading of the different questions on the three factors resulting from the principal component analyses (PCA). Varimax rotation was applied to the data set. (*Right*) The effects of Age (*Young*, *Old*) on mean regression scores for Deliberate On-Task, Mental Time Travelling (MTT) and Thought Modality. Scores for each task condition (*0-Back, 1 -Back*) are presented for completeness. *Note.* * p <.05; Error bars are Standard Errors.

In order to identify how these patterns of thoughts varied across the two task conditions and age groups, 2 (Age; *Young, Old*) by 2 (Task; *0-Back, 1-Back*) repeated measure Analysis of Variance (ANOVAs) were conducted on participants' mean regression scores for each factor. For the Deliberate On-Task component, a main effect of age was found, indicating that older adults were more deliberately on-task than young adults, F (1, 48) = 5.78, p = .020, η_p^2 = .11. Analyses of Thought Modality revealed a main effect of age, with older adults presenting more visual thoughts than younger adults, F (1, 48) = 5.50, p = .023, η_p^2 = .10. A main effect of task was marginally significant, suggesting that the 0-Back condition tended to foster thoughts in the form of images as opposed to words, F (1, 48) = 3.81, p = .057, η_p^2 = .07. Finally, analyses on the MTT component showed no significant effects (all *ps* > .05) (**Figure 3.2**.).

3.3.2. Brain activity in ageing and relation to the task

The first neural analysis on resting state brain activity (i.e. eyes closed) identified frequency bands over scalp areas where spectral power showed age-related changes. Multivariate Analyses of Variances (MANOVAs) were conducted on each frequency band separately. Due to multiple comparison analyses on the electrophysiological measure, alpha levels were Bonferroni corrected to .01. Results evidenced age differences on Delta power over Parieto-Occipital scalp areas [Left, F (1, 47) = 8.42, p < .01, η_p^2 = .15; Right, F (1, 47) = 12.02, p < .001, η_p^2 = .20], Theta power [Fronto-Central Left, F (1, 45) = 10.05, p < .01, η_p^2 = .18; Parieto-Occipital Left, F (1, 45) = 11.12, p < .01, η_p^2 = .20; Parieto-Occipital Right, F (1, 45) = 12.42, p < .001, η_p^2 = .22], and on Beta power over Centro-Parietal scalp areas [Left, F (1, 47) = 9.98, p < .01, η_p^2 = .18; Right, F (1, 47) = 10.97, p < .01, η_p^2 = .19]. These analyses display decreased activity in low frequency bands (delta and theta) and increased activity in higher frequency bands (beta) with age (See **Figure 3.3**.). No other results were significant (all *p*s > .05).

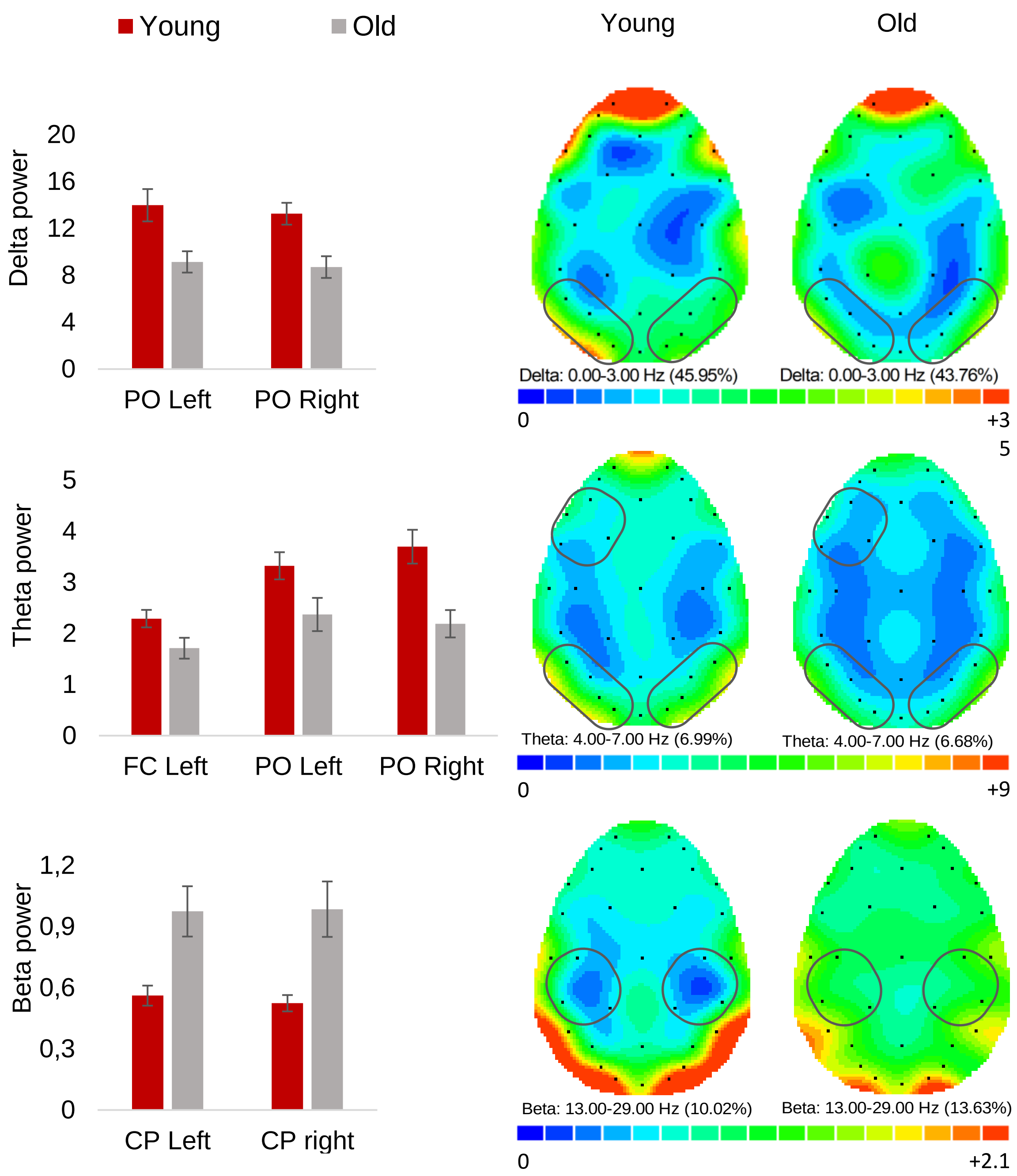


Figure 3.3. Significant effects of Age (*Young, Old*) on spectral power for delta, theta and beta bands.

(*Left*) Illustration of the effects of Age on spectral power for the relevant brain areas; (*Right*) head maps of Delta, Theta and Beta power for young and older adults. *Note*: FC = Fronto-Central; CP = Centro-Parietal; PO = Parieto-Occipital; Error bars are Standard Errors.

Next, correspondences between age-related changes in the patterns of ongoing thought and changes in the intrinsic neural function identified in prior analyses were explored. Before performing these analyses, all data were z-scored separately for old and young individuals. This step assured that gross differences in intercepts across conditions and age group were minimised, allowing relationships between the variables to be visualised more transparently. These data were analysed using a mixed ANOVA. The model had two within-participant factors: Task (*0-Back, 1-Back*), and Component (*Detailed On-Task, Mental Time Travel, Thought Modality*). Age groups (*Young, Old*) was included as between group variable. The spectral power scores for all of the significant effects (Delta PO Left and Right, Theta FC left, and PO left and right, and Beta CP left and right) were also included as covariates. The main effects of all variables (including covariates) were modelled as well as two way, three-way, and four-way interactions between task, age group, brain activity, and each PCA. Interaction terms describing the relationship between each PCA component were not included.

This analysis revealed two significant four-way interactions, Task X Age Group X Component X Beta Centro-Parietal left, F (2, 64) = 3.29, p = .044, η_p^2 = .09, and Task X Age Group X Component X Beta Centro-Parietal right, F (2, 64) = 3.17, p = .049, η_p^2 = .09. Effects were found for variation in patterns of Mental Time Travelling: Task X Age Group X Beta Centro-Parietal left, F (1, 32) = 6.62, p = .015, η_p^2 = .17, and Task X Age Group X Beta Centro-Parietal right, F (1, 32) = 8.46, p = .007, η_p^2 = .21. To understand this, the relationship between Beta Centro-Parietal activity (left and right) and how Mental Time Travelling thought changed across task was plotted separately in each age group (**Figure 3.4**). It can be seen that in younger adults, higher beta power over the Centro-parietal right scalp area is linked to more mental time travelling in the 0-Back task and less in the 1-Back, F (1, 17) = 4.66, p = .046, η_p^2 = .22, this was not found for the left hemisphere, F (1, 17) = 2.84, p = .110, η_p^2 = .14. No such patterns were found for older adults [left, F (1, 15) = 3.65, p = .075, η_p^2 = .20; right, F (1, 15) = 4.11, p = .061, η_p^2 = .22].

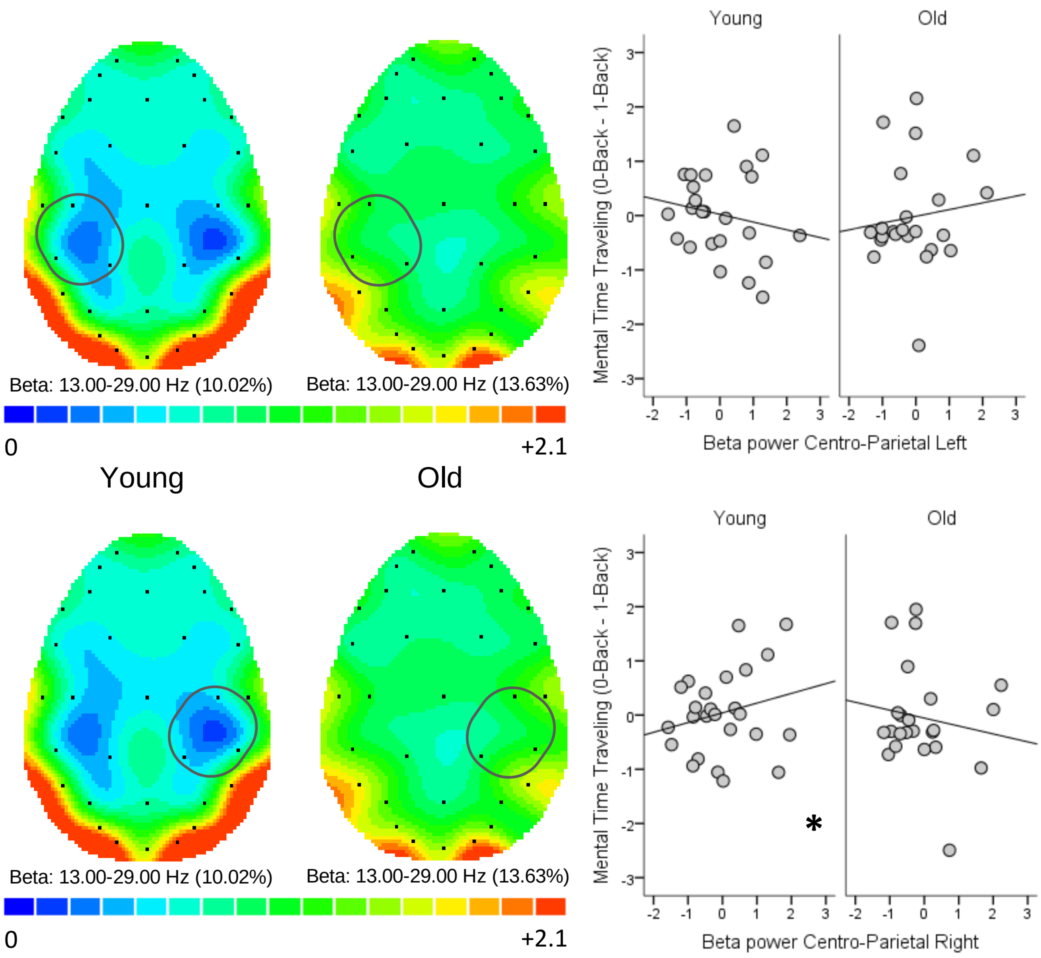


Figure 3.4. Effect of interaction between Beta power in the Centro-Parietal left and right areas of the scalp and the difference of Mental Time Travelling thoughts occurrence between the two conditions (0-Back - 1-Back).

(*left*) localisation of the age-related difference in beta power. (*right*) illustration of the relationship between beta power over the centro-parietal areas and the variation in Mental Time Travelling states across tasks in the Younger and the Older participants. *Note*. * p <.05

3.3.3. Neuronal characteristics underlying self-generated thought

The second aim of the current study was to identify the neural features underlying the occurrence of each of the three components outlined previously. Linear mixed modelling was used to account for the hierarchical structure of the data. Firstly, all variables, dependant and independent, were grand mean centred to gain clarity in the interpretation of the findings. All linear mixed models included one random effect (the intercept for each Subject) to control for the dependency arising due to repeated sampling of data within subjects. An exploratory approach was taken in this analysis as only limited research has used spectral power to investigate the neural signature of different types of self-generated thoughts. The procedure was identical for each of the three components under investigation; Deliberate On-Task, Mental Time Travelling, and Modality of thoughts.

The MIXED procedure in SPSS 24.0 (Peugh & Enders, 2005) with Maximum Likelihood Estimation was used. First, three null models were run on the dependent variables. In these null models, the intercept was allowed to vary randomly across participants. Next, the same set of predictor variables were added to each model. The predictor variables consisted of participants' age (as a continuous variable), task difficulty, and spectral power, corresponding to each of the probes from every frequency band and scalp area. The strategy applied across the analyses was to first remove predictor variables that presented a *p*-value higher than .20. After running these new models, the second step was to remove every predictor variable with a *p*-value above .10. Finally, the last step was to remove predictor variables that were not significant (*p*-value above .05), until achieving a model where each predictor variable significantly contributed to the model (see **Table 3.3**. for details of each model computed).

As recommended by Burnham and Anderson (2004), both the Akaike Information Criterion (AIC) and Schwarz's Bayesian Information Criterion (BIC) were used to guide model selection. Differences between the previous best model were calculated on both indicators. The models emerging as best fit for Deliberate On-Task, Mental Time Travelling, and Modality of thought were composed of four, three, and five predictors respectively. After the selection of these models, each parameter estimate was bootstrapped for further inspection by drawing 1991 stratified resamples. To bootstrap the confidence interval, a Bias-Corrected Accelerated method was applied. This is a non-parametric procedure - unlike the reported *p*-values, it does not require a normality assumption (Davison & Hinkley, 1997).

Table 3.3. Summary of linear mixed models computed and their BIC and AIC indicators with maximum likelihood estimation.

Model	No.	BIC	Diff.	AIC	Diff.
Deliberate On-Task					
Null		1662.094		1648.202	
OnT1	42	1788.108	-126.014	1581.545	66.657 **
OnT2	11	1620.968	41.466 **	1556.608	24.937 **
OnT3	7	1603.628	17.34	1557.643	-1.035
OnT4	4	1598.962	4.666	1566.762	-9.119
Mental Time Travelling					
Null		1391.941		1378.049	
MTT1	42	1561.301	-169.360	1354.738	23.311
MTT2	10	1372.987	18.954 *	1313.277	41.461 **
MTT3	6	1355.958	17.029 **	1314.596	-1.319
MTT4	3	1345.198	10.76 *	1317.607	-3.011
Thought Modality					
Null		1706.346		1692.454	
TM1	42	1834.297	-127.951	1627.733	64.721 *
TM2	10	1656.111	50.235 **	1596.366	31.367 **
TM3	8	1649.157	6.954	1598.589	-2.223
TM4	5	1637.957	11.200 *	1601.180	-2.591

Note: Diff. = corresponds to the difference between the indicators from the previous lowest model and the new model; No. = number of estimated parameters for model; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; * $p < .05$, ** $p < .01$.

Overall, results suggested that Deliberate On-Task thoughts are positively related to age and task difficulty, while negatively related to alpha power over Parieto-Occipital left and Beta power over Fronto-Central left areas. Mental Time Travelling was negatively related to Delta power over Frontal left areas, and Gamma power over Parieto-Occipital left areas, but positively related to Delta power over Centro-Parietal right areas. The Modality of thought was negatively related to Beta power over Frontal left areas and Gamma Centro-Parietal right, while positively related to task difficulty and Gamma power over Frontal and Centro-Parietal left areas. **Table 3.4**. provides an overview of the estimates of the final models selected after bootstrapping.

Table 3.4. Estimates of final models, after bootstrapping.

Model	Parameters	Estimates (*SE*)
OnT4	Intercept	-.2437 (.0713) ***
	Age	.0106 (.0451) ***
	Task Difficulty	.1683 (.0022) ***
	Alpha – Parieto-Occipital left	-.0206 (.0098) *
	Beta – Fronto-Central left	-.1930 (.0775) *
MTT4	Intercept	.0218 (.0187)
	Delta – Frontal left	-.0082 (.0024) ***
	Delta – Centro-Parietal right	.0110 (.0049) *
	Gamma – Parieto-Occipital left	-.3866 (.1248) **
TM4	Intercept	-.1975 (.0735) **
	Task Difficulty	.1495 (.0462) **
	Beta – Frontal left	-.3499 (.0986) ***
	Gamma – Frontal left	.2516 (.0770) ***
	Gamma – Centro-Parietal left	.2730 (.1256) *
	Gamma – Centro-Parietal right	-.3943 (.1527) **

Note: SE = Standard Error; OnT4 = Final model for Deliberate On-Task thought; MTT4 = Final model for Mental Time Travelling thought; TM4 = Final model for Thought Modality; * $p < .05$, ** $p < .01$, *** $p < .001$.

3.4. Discussion

A myriad of research has documented the behavioural consequences of age-related changes in brain functionality (Fjell & Walhovd, 2010). Additionally, not all self-generated thoughts are equal, both at a behavioural and neural level (Baird et al., 2011; D'Argembeau et al., 2011; Karapanagiotidis et al., 2017; Medea et al., 2016; Smallwood et al., 2016, 2011; Smallwood, Nind, et al., 2009; H.-T. Wang, Bzdok, et al., 2018; H.-T. Wang, Poerio, et al., 2018). The present study aimed to (i) understand how age-related differences in self-generated thoughts could be linked to age-related changes in brain activity, as well as to (ii) describe spectral power underlying different self-generated thoughts. Multi-dimensional experience sampling findings confirmed older adults' tendency to be more deliberately on-task than young adults (Giambra, 1989; Jackson & Balota, 2012; Jackson et al., 2013; McVay et al., 2013) and revealed a tendency to think more in images than words. Analyses of resting state spectral power replicated previous findings of age-related decrease activity in lower frequency bands (i.e. theta and delta) and increased activity in higher ones (i.e. beta; Cummins & Finnigan, 2007; Duffy et al., 1984, 1993). Importantly, evidence suggests that age-related change in Centro-Parietal beta power was linked to mental time travelling. Ultimately, distinct patterns of brain activity have been identified for each of the three types of thoughts evidenced at a behavioural level.

Age-related changes in brain activity have repeatedly been found to mediate cognitive deficits in older adults, such as executive functions or episodic memory (Fjell & Walhovd, 2010). Accordingly, variations in neural features are suspected to underlie age-related changes in self-generated thoughts. Results have highlighted that for young adults, beta power over Centro-Parietal right scalp area was linked to more mental time travelling in the easier condition (0-Back) and less in the harder condition (1-Back). This association was not present in older individuals. In previous research, beta band activity was thought to represent motor control, where higher beta power enables the maintenance of a steady-state contraction, while reduction of such activity was observed during voluntary movement (Baker, 2007; Klostermann et al., 2007). More recently, beta band activity was found to enable the maintenance of cognitive states (for a review see Engel & Fries, 2010). That is, beta band activity decreases when the current setting is disrupted by a novel, unexpected event. Also, increases in activity are thought to reflect the prioritisation of the status quo over new signals (Engel & Fries, 2010; Siegel, Warden, & Miller, 2009). Elsewhere, increases of beta band activity have been related to more endogenous top-down activities, while decreases of beta power accompanied by increases of gamma power are found during exogenous bottom-up activities (Engel, Fries, & Singer, 2001; Pfurtscheller, Stancák, & Neuper, 1996). Nonetheless, overactivation of the beta band induces difficulties in attentional control and cognitive flexibility, as found in Parkinson's patients (Engel & Fries, 2010; Engel, Moll, Fried, & Ojemann, 2005). Considering the present findings, the literature suggests that young adults presenting high beta band activity are prioritising endogenous top-down activities, such as mental time travelling, when task difficulty allows it. On the other hand, in the context of a demanding task, they seem able to flexibly adjust their cognitive state. This pattern was not evident in older adults. A possibility is that older adults' overall higher beta band activity jeopardises the detachment from the ongoing task when task demand permits it. Thus, they remain largely on-task and disregard any mental time travelling experiences in both conditions. While being very promising, more work is required to clarify the role of age-related changes in beta band activity in mind-wandering experiences. It is worthwhile noting that the mixed findings and difficulties in interpretation are due to general difficulties in attributing function to EEG bands.

Subsequent analyses have successfully characterised three distinct types of self-generated thoughts, using spectral power data. Deliberate on-task thoughts were related to increased age and task difficulty reproducing previous findings (Giambra, 1989; Jackson & Balota, 2012; Jackson et al., 2013; Konishi et al., 2017; Seli, Risko, Smilek, et al., 2016; Smallwood, Nind, et al., 2009), while spontaneous off-task thoughts were associated with increased alpha power over left posterior areas and beta power over fronto-central left areas. Previous work demonstrated a positive correlation between both alpha and beta power and activity in the default and self-referential networks, and a negative correlation with dorsal attention network activity (Mantini et al., 2007). Increases of alpha power are merely representative of the inhibition of task-irrelevant brain areas (Klimesch et al., 2007), while beta power reflects endogenous top-down processes (Engel & Fries, 2010). In the present study, the increase of alpha power over posterior areas suggests less processing of visual information during off-task thoughts. Such reduction of task processing may reduce exogenous bottom-up processes and give rise to endogenous top-down processes illustrated by an increase of beta power. Together, results confirm that spontaneous off-task thoughts are supported by activity in the DMN (Fox et al., 2015; Mason et al., 2007), and suggests links with less perceptual information, and the processing of endogenous top-down information. Nevertheless, research comparing spectral power between on- and off-task reported different findings, namely decreases of occipital alpha and fronto-lateral beta during off-task thoughts (Baird et al., 2014; Braboszcz & Delorme, 2011). Such striking differences may be the result of methodological differences. Firstly, the nature of the thoughts under investigation were different. The present study went beyond a simple on-task/ off-task dichotomy and instead considered the full complexity of these experiences. Secondly, in their study, Braboszcz and Delorme (2011) operationalised on-task thoughts as the period following a mind drift. Therefore, one may argue that such periods are representative of participants' re-engagement to the task and require an increase in attentional processes (reflected by increases in both alpha and beta bands). In addition, the nature of the ongoing tasks was very different (i.e. breathing focus versus working memory task), making any comparison difficult. Ultimately, as briefly stated above and in Chapter 2, it is difficult to pin down the functional significance of a frequency band as it is unlikely that one will support a single cognitive function in the brain. Therefore, although this thesis argues strongly for converging methods one also needs to be mindful of the drawbacks of the individual techniques.

Mental Time Travelling experiences were predicted by an increase of delta power over centro-parietal right and a decrease of both delta frontal left and gamma parieto-occipital left scalp regions. Previous work on voluntary mental time travelling has yielded links between pre-experiencing events and reduced gamma band activity, and between re-experiencing an event and decreased delta power (Lavallee & Persinger, 2010). While this study focused on the distance of the events (e.g. close future versus the distant future), it seems that both frequency bands are playing an important role in mental time travelling. The gamma band merely represents higher order processing of information (Fries, 2009; Jensen, Kaiser, & Lachaux, 2007). Gamma power often increases during the performance of complex tasks. Specifically, spectral power of this nature is evident when an activity requires the coordination and binding of information (Fries, 2009). Accordingly, the reported decrease in gamma power may reflect a lack of information binding due to disengagement from the task with a switch to mental time travelling. Much evidence suggests delta being implicated in attentional processes, decision-making, and signal detection (for reviews see Güntekin & Başar, 2016; Harmony, 2013; Knyazev, 2012). Furthermore, greater cognitive demands generate increases in delta activity (Güntekin & Başar, 2016), located over frontal areas during concentration (Harmony, 2013). As such, the observed decrease of frontal delta may represent a drop in concentration when participants engage in mental time travelling. This is further supported by the inhibiting role of delta in reducing interference from other thoughts and processes that may affect task performance (Harmony, 2013). Interestingly, increases in delta power were found over the centro-parietal right area. The localisation of this increased activity may be representative of a different function of delta. Previous research has found a high correlation between delta power within the DMN and the parahippocampal gyrus (Neuner et al., 2014). Importantly, the parahippocampal gyrus has repeatedly been linked to episodic memory (Strien, Cappaert, & Witter, 2009), and little evidence suggests that delta power may be associated with memory processes too (Ekstrom & Watrous, 2014). Future work should consider source localisation analyses to differentiate the role of localised delta power during mental time travelling.

Finally, thought modality was predicted by multiple factors. Verbal thoughts were predicted by increased difficulty, as well as increased gamma band activity over frontal and centro-parietal areas of the left hemisphere. As mentioned above, the gamma band is associated with the binding of information (Fries, 2009; Jensen et al., 2007). Therefore, verbal thoughts may represent strategically applied thoughts where verbalisation of the task is used and combined with perceptual information to complete a difficult working memory task. Visual thoughts were found to be more dominant in the easier task and were accompanied by increased gamma activity over the centro-parietal right area. This hemispheric differentiation between verbal and visual thoughts, although somewhat of an over-simplification, has previously been reported with verbal processing being typically related to the left hemisphere (Vigneau et al., 2006), while the right hemisphere is found more active in the processing of spatial or non-verbal information (Bryden, 2012; Durnford & Kimura, 1971). Visual thoughts were also linked to increased beta power over the frontal left scalp area. As previously stated, beta power is linked to the maintenance of a cognitive state and expecting or perceiving new signals tends to reduce such activity (Engel & Fries, 2010). Interestingly, visual thoughts were predominant in the undemanding task where the anticipation of new signals is less needed. Accordingly, beta power during visual thoughts can be interpreted as the stable treatment of perceptual information. To some extent, this is in line with earlier work on spontaneous thoughts in a task-free context. Lehmann et al. (1995) found that visual imagery without any goal orientation (or emotional load) was correlated with the beta band activity (18-23 Hz).

Having outlined the findings, it is worthwhile considering some limitations that may have influenced the results. Firstly, while the use of multi-dimensional experience sampling is now considered a very efficient means of measuring thought heterogeneity, there are drawbacks. The great number of questions may increase the difficulty of introspection, potentially leading to answers that are less representative of ones' state of mind. Also, anecdotal evidence suggested that the older adults found the probing method problematic (i.e. answers to the probes were collected via mouse click). Secondly, self-generated thoughts were measured in association with spectral power from 4 to 6 seconds prior to the probes. A number of researchers have used a similar approach based on the assumption that brain activity before a probe is representative of the self-reported thoughts' characteristics (Baird et al., 2014; Braboszcz & Delorme, 2011; Christoff et al., 2009; Qin et al., 2010; Smallwood, 2013). Although one can be fairly confident when using this assumption, caution must be taken considering the lack of evidence supporting (or dismissing) it. Two avenues should be considered in tackling this problem. Firstly, efforts should be made to identify the onset of mind-wandering experiences. A possibility is to use machine learning to identify signs of mind drift based on real-time EEG recording of brain activity. Secondly, comparing spectral power between experimentally-generated and self-generated thoughts should disentangle the role of different frequency bands during such experiences. This approach has been successfully used with fMRI (Tusche et al., 2014).

Overall, the present study replicated previous findings, both at a behavioural and neural level, while providing a deeper understanding of the repercussions of age and brain activity on the occurrence and nature of self-generated thoughts. New insight has been revealed regarding older adults' neurocognitive profile by documenting age-related changes in mind-wandering experiences. Specifically, it appears that substantially high beta power may reduce older adults' ability to flexibly adjust mental time travelling to the demand of a task. Regardless of age, it is worthwhile noting here that EEG power is often reported as having an optimal level related to efficient cognitive ability. Results showed that general increases in alpha and beta power were indicative of the involvement of the default mode network in off-task thoughts. Delta power was found essential to mental time travelling experiences, reducing concentration, and fostering memory processes. Finally, the neural activity underlying thought modality demonstrated a tendency toward the maintenance of visual processing during an undemanding task, as opposed to more complex and verbal treatment of information during the difficult task. Owing to the need for converging methods, the next chapter will use functional connectivity measures to clarify further the implication of older adults' functional architecture in self-generated thoughts.

Chapter 4. Understanding mind-wandering experiences in young and older individuals using functional connectivity magnetic resonance imaging.

Following on from the electrophysiological findings in Chapter 3, this chapter will be investigating the possibility that age-related changes in off-task thinking are correlated with changes in the intrinsic organisation of the brain, using functional connectivity measures. Given the importance of executive control and memory in coordinating and generating the content of self-generated thoughts, those regions underlying such processes are the focus. A similar approach to Chapter 3 has been applied. Laboratory measures of self-generated thought were recorded in both old and young individuals, who also participated in a resting state functional magnetic resonance imaging experiment to describe their neurocognitive architecture. In younger participants, reductions in the strength of connectivity between the left temporal pole and prefrontal DMN regions was linked to a greater shift towards off-task thoughts when task demands decreased. In older adults, this pattern was not observed. These data suggest that the reductions in off-task thought seen in older participants may be linked to age-related changes in communication between temporal and prefrontal DMN regions. In addition, they raise the possibility that the decline in off-task thought as we age may, in part, occur because of neural changes related to how self-generated thought is flexibly organised with respect to changing environmental demands.

4.1. Introduction

Although the link between ageing and reduced off-task thought is well documented in the literature, a clear neuro-cognitive account of this age-related decline is currently lacking. This chapter will therefore pursue preliminary investigations carried out in the previous chapter (Chapter 3). Component process accounts of self-generated thoughts emphasise the importance of both processes linked to memory, to produce the mental content that is not related to the external environment, and control processes, which are important for the regulation of these experiences (see Chapter 1; Smallwood, 2013; Smallwood & Schooler, 2015). Broadly, these accounts propose that the generation and representation of self-generated thoughts are subserved by memory representation processes whereas the control of self-generated thought occurrence is subserved by executive control processes (McVay & Kane, 2009; Smallwood & Andrews-Hanna, 2013). From a theoretical perspective, age-related declines in mind-wandering may emerge from declines in the integrity of neurocognitive processes either related to memory, control, or both. To investigate these possibilities, this study combines laboratory measures of self-generated thought patterns in old and young individuals, with measures of intrinsic neural organisation provided by resting state functional magnetic resonance imaging. While the literature is merely focusing on the relationship between off-task thought and ageing, studying the full spectrum of self-generated thought can aid the understanding of the age-related decrease in off-task thought. The aim here is to identify the underlying neural changes linked to age-related changes in off-task thinking and, therefore, provide valuable information with regards to age related changes in patterns of self-generated thought.

According to contemporary theory, memory processes provide representational information upon which the content of self-generated experiences are based (Baird et al., 2011; Poerio et al., 2017; Tulving, 2002) and it is well known that changes in conceptual and episodic knowledge occur with age (Addis et al., 2010, 2008; Schmitter-Edgecombe et al., 2000). Evidence from cognitive neuroscience suggests that memory processes are linked to temporal lobe structures, including both anterior regions of the lateral temporal cortex, and regions on the medial surface such as the hippocampus (Davey et al., 2016; Ellamil et al., 2016; Ralph, Jefferies, Patterson, & Rogers, 2017). At rest, these regions show increased functional connectivity with medial and lateral regions in posterior and anterior cortical regions, and collectively form what is known as the DMN (Andrews-Hanna, 2012; Buckner et al., 2008; Raichle, 2015; Spreng et al., 2008). In ageing, a clear reduction of both activity and connectivity of the DMN have been reported (Biswal et al., 2010; Damoiseaux et al., 2008; Damoiseaux, 2017). Regions closely allied to the core DMN also change with age, including both regions of the temporal cortex (Fjell et al., 2009; Raz, Rodrigue, Head, Kennedy, & Acker, 2004) and the hippocampus (Allen, Bruss, Brown, & Damasio, 2005; Du et al., 2006; Raz, Ghisletta, Rodrigue, Kennedy, & Lindenberger, 2010). In healthy young adults, connectivity of the hippocampus is related to changes in spatial, episodic, and semantic memory (Persson, Stening, Nordin, & Söderlund, 2018; Sormaz et al., 2017), along with age-related changes in this domain can mediate cognitive abilities such as episodic memory (Fjell & Walhovd, 2010).

As well as processes important for generating off-task experiences, contemporary accounts emphasise the need to understand how they are regulated (Andrews-Hanna et al., 2014; McVay & Kane, 2010). It is generally assumed that the regulation of task unrelated states depends, in part, upon executive control processes (Kane & McVay, 2012; Levinson et al., 2012; Rummel & Boywitt, 2014). Neural studies suggest that important aspects of executive control are linked to processes in regions of lateral frontal and parietal cortex that show elevated activity across a wide range of task domains (Duncan & Owen, 2000; Fedorenko, Duncan, & Kanwisher, 2013). Critically, in younger adults the connectivity between regions important for executive control predicts working memory performance and intelligence (Finn et al., 2015), whereas older adults display altered connectivity patterns between frontal and parietal areas (Meunier, Achard, Morcom, & Bullmore, 2009; Wu et al., 2012).

In younger adults, experience sampling studies in conjunction with fMRI, have shown that both the default mode and fronto-parietal networks (i.e. executive network) are active during periods of mind-wandering experiences (Allen et al., 2013; Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Stawarczyk et al., 2011). Studies have also examined individual variation in mind-wandering experience and how they relate to the organisation of neural functioning. Smallwood et al. (2016) found that variation in regions of both the temporal pole and the hippocampus were related to variations in different patterns of experience, including episodic quality, detail, and relationship to an ongoing task. Regions of the frontal parietal cortex are also important in the off-task state. Studies suggest that the connectivity of the DMN and fronto-parietal network is stronger for individuals who spend more time off-task (Mooneyham et al., 2016), especially when mind-wandering is deliberate (Golchert et al., 2017).

In the present study, a combination of experience sampling and resting state fMRI was used to explore whether age-related neural changes are associated with changes in patterns of self-generated thought. Groups of young and old participants performed a simple cognitive task, during which Multi-Dimensional Experience Sampling was used to measure patterns of thoughts and explore differences between older and younger participants. Participants also partook in a resting state functional connectivity scan that allowed the description of each individual in terms of their intrinsic architecture at rest. For the connectivity analyses, one set of seed regions was selected from the temporal lobe linked to memory - the left and right hippocampus and anterior temporal lobe (Tulving, 2002). Regions in the left and right pre-frontal cortex linked to processes of cognitive control within the memory domain were also selected – the inferior frontal gyrus (Noonan, Jefferies, Visser, & Lambon Ralph, 2013). Using these regions as seeds in a functional connectivity analysis, regions in the cortex whose connectivity varied between the older and younger individuals were identified. Next, an examination of whether any differences in neural connectivity were associated with age-related changes in self-generated thought was carried out.

4.2. Method

4.2.1. Participants

The older adult group comprised of 22 women and 17 men (*M* $_{age}$ = 66.08 years, *range* = 55–87) recruited using opportunity sampling. The younger adult group consisted of 32 women and 9 men (*M* $_{age}$ = 19.73 years, *range* = 18–23) who were undergraduate students in psychology at the University of York. All participants received financial compensation for their time and travel. The inclusion criteria were to be a native English speaker, to be right-handed, and to have normal or corrected vision and hearing. The exclusion criteria were the presence or history of a neurological or psychiatric disorder. Older participants completed the Mini-Mental State Examination, (MMSE; Folstein et al., 1975) to ensure that they did not have dementia or mild cognitive impairment (threshold: score ≥ 26/30) (see **Table 4.1**.). Participants were seen for two hours on two consecutive days. The University of York Neuroimaging Centre ethics committee approved this study. All investigation was conducted according to the principles expressed in the Declaration of Helsinki and participants provided written informed consent.

Table 4.1. Means (Standard Deviations) of participants' characteristics and probe count.

Measures	Young (*SD*)	Old (*SD*)
N	41	39
N Probes	924	981
M age	19.73 (1.34)	66.08 (6.65)
Female %	78	56.4
MMSE	-	29.03 (1.24)

4.2.2. Procedure

At the beginning of the first session, demographic questions were asked. Those over 55 years old also completed the MMSE. Participants then underwent an N-back task previously developed by Konishi et al. (2015). Every participant did a practice run before performing the task. Following this, participants carried out a number of other cognitive tasks as part of a wider ongoing project, which will not be the focus of this thesis. The next day participants were asked to perform again the N-Back task, followed by more cognitive measures, which included the NART (National Adult Reading Task; Nelson, 1982) and the DSST (Digit Symbol Substitution Test; Wechsler, 1997). Data from fMRI resting state scanning were gathered on a different day. Finally, a debriefing sheet was provided to each participant.

4.2.3. N-back working memory task

The task used in the present study was the same as the one reported in the previous chapter, for a detailed description, please refer to Chapter 3. Nonetheless, a few modifications have been applied. The task was built so that there were 12 probes per conditions. The thought probe was answered on a four-point Likert scale from 1 (‘*Not at all*’) to 4 (‘*Completely*’), using numbers on the keyboard.

4.2.4. Additional behavioural measures

Prior studies have found associations between patterns of self-generated thought and poor performance on tasks of intelligence and working memory (e.g. McVay & Kane, 2009; Mrazek et al., 2013; H.-T. Wang, Bzdok, et al., 2018), and better performance on tasks that measure creativity and problem solving (Baird et al., 2012; Smeekens & Kane, 2016; H.-T. Wang, Poerio, et al., 2018). Therefore, in this study, working memory capacity (backward digit span; Wechsler, 1997) and fluid intelligence (Raven’s Matrices; Raven, 1983) were also measured. In the backward digit span, participants had to repeat out loud numbers in the inverse order of presentation. The task started with two numbers and ended after two consecutive errors. Raven’s matrix consists of 60 multiple-choice questions, listed in order of difficulty. In each test item, participants were asked to identify the missing element that completed a pattern. Participants had 6 minutes to answer a maximum of questions. Creativity was measured using the Unusual Uses Test (UUT, Guilford, Merrifield, & Wilson, 1958). Here, participants were asked to generate within 2 minutes, as many unusual uses for an object as possible (e.g. newspaper). Then, for each of the three objects used, two independent reviewers generated a uniqueness score. Additional measures were taken to control for basic differences in psychomotor speed (Digit Symbol Substitution Task, DSST; Wechsler, 1997) and premorbid IQ (National Adult Reading Task, NART; Nelson, 1982). The DSST is a paper and pencil task were participants are presented with symbols associated with numbers. Participants were asked to write down the corresponding symbol under each digit as fast as possible. The number of correct symbols within the allowed time (90 seconds) was measured. In the NART, participants were requested to read 50 words out loud, one by one. The difficulty progressively increased, and the number of errors was measured. All participants performed these tasks in the same sessions in which patterns of self-generated thought were measured. The task measures were always performed after the assessment of self-generated thought.

4.2.5. Neuroimaging

4.2.5.1. MRI acquisition

MRI functional and structural parameters for the resting state fMRI scans were acquired using a 3T GE HDx Excite MRI scanner, utilising an eight-channel phased array head coil (GE) tuned to 127.4 MHz at the York Neuroimaging Centre, University of York. Structural MRI acquisition in all participants was based on a T1-weighted 3D fast spoiled gradient echo sequence (TR = 7.8 s, TE = minimum full, flip angle= 20°, matrix size = 256 x 256, 176 slices, voxel size = 1.13 x 1.13 x 1 mm). Resting-state functional MRI activity was recorded from the whole brain using single-shot 2D gradient-echo-planar imaging (TR = 3 s, TE = minimum full, flip angle = 90°, matrix size = 64 x 64, 60 slices, voxel size = 3 x 3 x 3 mm3, 180 volumes). A FLAIR scan with the same orientation as the functional scans was collected to improve co-registration between subject-specific structural and functional scans.

4.2.5.2. MRI pre-processing

Functional and structural data were pre-processed and analysed using FMRIB's Software Library (FSL version 4.1, http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FEAT/). Individual FLAIR and T1 weighted structural brain images were extracted using Brain Extraction Tool (BET). Structural images were linearly registered to the MNI-152 template using FMRIB's Linear Image Registration Tool (FLIRT). Functional data were pre-processed and analysed using the FMRI Expert Analysis Tool (FEAT). The individual subject analysis involved: Motion correction using MCFLIRT; slice-timing correction using Fourier space time-series phase-shifting; spatial smoothing using a Gaussian kernel of FWHM 6mm; grand-mean intensity normalisation of the entire 4D dataset by a single multiplicative factor; highpass temporal filtering (Gaussian-weighted least-squares straight line fitting, with sigma = 100s); and Gaussian lowpass temporal filtering, with sigma = 2.8s.

4.2.5.3. Region of Interest (ROI) Mask Creation

For the purpose of this study, the following regions of interests were selected. The hippocampus masks were obtained from a previously published study (Sormaz et al., 2017). The inferior frontal gyrus (IFG) were extracted from bilateral frontal regions in the 12th network from Yeo's 17 parcellations (Yeo et al., 2011). The overlaps between the extracted clusters and the anatomical frontal pole in Harvard-Oxford Cortical Structural Atlas (Desikan et al., 2006; Frazier et al., 2005; Goldstein et al., 2007; Makris et al., 2006) were excluded to create the final ROI mask. Left and right anterior temporal lobe (ATL) were assembled from visually selected clusters in Craddock (2011) parcellations (K = 12) (Craddock, James, Holtzheimer, Hu, & Mayberg, 2012). The assembled masks were upsampled from 1mm to 2mm space. The interim 2mm masks were smoothed with a gauss kernel of 1 mm and then binarised. The overlap between the hippocampus ROI masks and the anatomical temporal lobe in Harvard-Oxford Cortical Structural Atlas were excluded. The spatial distribution of these ROIs is presented in **Figure 4.1**.

4.2.5.4. MRI first level analysis

After calculating the average activity within each ROI along the time series, a functional connectivity analysis was performed for each subject separately. The resulting maps were compared at the group level using FMRIB's Local Analysis of Mixed Effects. These maps were thresholded at a Z = 3.1 to define contiguous clusters, and then significant clusters of voxels were extracted at $p < 0.05$ with family-wise error correction. The resulting connectivity maps for both age groups are presented in **Figure 4.1.**, the individual maps for both groups were used to investigate age differences in

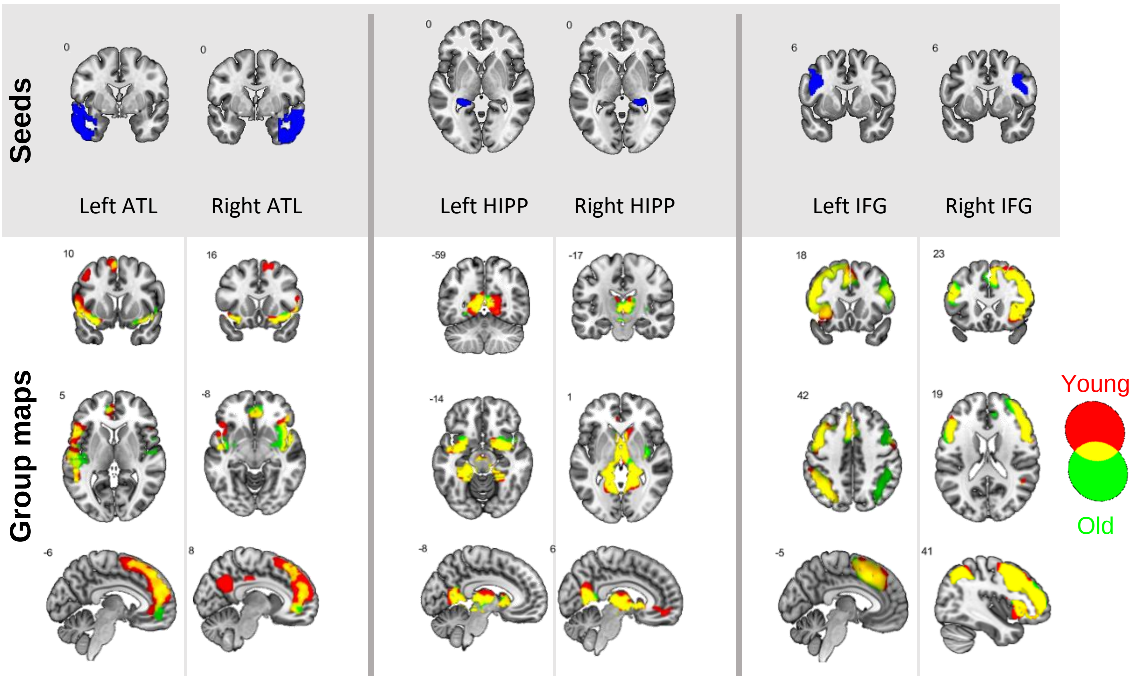


Figure 4.1. Thresholded spatial maps displaying functional connectivity of the seed region separately for younger and older participants.

The upper grey panel shows the spatial distribution of the regions used as seeds in the functional connectivity analyses. Different columns present the data for each seed region. Maps were thresholded at Z = 3.1 and were corrected for the family wise error in terms of the number of voxels in the brain, the two tailed nature of our tests and the number of seed regions. Regions of overlap across Age Groups are indicated in yellow.

connectivity and how it relates to thoughts occurrence (see 4.3.3. Brain connectivity in ageing and relation to the task, p.84).

4.3. Results

4.3.1. Behavioural performance

Simple age differences in performance for each of the measures relevant to this analysis were calculated. These comparisons used a Multivariate Analysis of Variance (MANOVA), and revealed group differences for all measures except the Unusual Uses Test (Digit symbol substitution test, F (1, 65) = 29.54, p < .001, η_p^2 = .31; National Adult Reading Task, F (1, 65) = 54.75, p < .001, η_p^2 = .46; Ravens Progressive Matrices, F (1, 65) = 35.38, p < .001, η_p^2 = .35; Unusual Uses Test, F (1, 65) = .375, p = .542, η_p^2 = .01; Backwards Digit Span, F (1, 65) = 4.07, p = .048, η_p^2 = .06. Overall, older adults were slower, had better premorbid IQ, poorer fluid intelligence and working memory capacity, than younger adults, see **Table 4.2** for descriptive data for these comparisons.

Table 4.2. Descriptive statistics, means (standard deviations), of young and older adults on cognitive measures.

	Young (*SD*) N = 35	Old (*SD*) N = 32
DSST ***	50.23 (12.45)	35.13 (10.03)
NART (errors)***	20.23 (6.38)	8.84 (6.20)
Ravens Matrices ***	10.40 (2.90)	6.56 (2.31)
UUT – Total uniqueness score	11.31 (6.22)	12.13 (4.35)
Backwards Digit Span (proportion of correct) *	.74 (.09)	.70 (.09)

Note. * p < .05, *** p < .001

4.3.2. Multi-Dimensional Experience Sampling

To analyse the MDES data, the set of questions was decomposed using principal component analysis (PCA), applying varimax rotation (for prior examples of this approach see Konishi et al., 2017; Poerio et al., 2017; Ruby, Smallwood, Engen, et al., 2013; Ruby, Smallwood, Sackur, et al., 2013). This allowed the core patterns of variance within the self-reported data to be characterised by a smaller set of underlying dimensions. Three-factor solutions were selected with eigenvalues > 1, and the loadings that describe these dimensions are presented by the heat map in **Figure 4.2**: Component One - *Deliberate On-Task* – described deliberate, detailed and positive and accounted for 27.20% of the variance. Component Two - *Mental time travelling* (MTT) – described episodic thoughts (past and future) with high loadings on the self and other, and accounted for 17.76% of the variance. Component Three - *Thought Modality* (Images or words) – described thoughts that varied in their modality between representations in images or words and accounted for 9.56% of the overall variance. These patterns of self-generated thought revealed by the current decomposition are consistent with Chapter 3 and prior studies.

In order to identify how these patterns of thoughts varied across the two task conditions and age groups, 2 (Age; *Young, Old*) by 2 (Task; *0-Back, 1-Back*) mixed ANOVAs were conducted on participants' mean regression scores for each factor. For the ***Deliberate On-Task*** component a main effect of task indicating lower scores in the *0-Back* condition than in the *1-Back* condition was found, F (1, 78) = 83.58, $p < .001$, $\eta_p^2 = .52$. The main effect of age indicated that young adults had less thoughts deliberately directed toward the task than older adults, F (1, 78) = 133.89, $p < .001$, $\eta_p^2 = .63$. The interaction between task and age was also significant, F (1, 78) = 11.62, $p < .001$, $\eta_p^2 = .13$ (see **Figure 4.2**.). Decomposition of this interaction showed less Deliberate On-Task thought for younger adults compared to older adults in both the *0-Back*, F (1, 78) = 139.77, $p < .001$, $\eta_p^2 = .64$, and the *1-Back*, F (1, 78) = 89.82, $p < .001$, $\eta_p^2 = .54$. To formally compare these discrepancies, the difference in Deliberate On-Task loadings across the *0-Back* and *1-Back* tasks were calculated, and a univariate ANOVA including age group as a single categorical variable was conducted. This revealed a significant effect of age group, F (1, 79) = 11.6, $p < .001$, $\eta_p^2 = .13$. This indicates that younger individuals tended to decrease the amount of Deliberate Task Focus in the *0-Back* relative to the *1-Back* tasks, to a greater degree than older individuals did. Analysis of the ***Mental Time Travelling*** component revealed a significant interaction between task and age, *F* (1, 78) = 16.77, $p < .000$, $\eta_p^2 = .18$ (see **Figure 4.2**.). Decomposition of this interaction showed no effect of age in the *0-Back* condition, *F* (1, 78) = .006, $p = .937$, $\eta_p^2 = .00$, but a significant main effect of age in the *1-Back* condition, *F* (1, 78) = 4.95, $p = .029$, $\eta_p^2 = .06$, indicating less MTT for younger

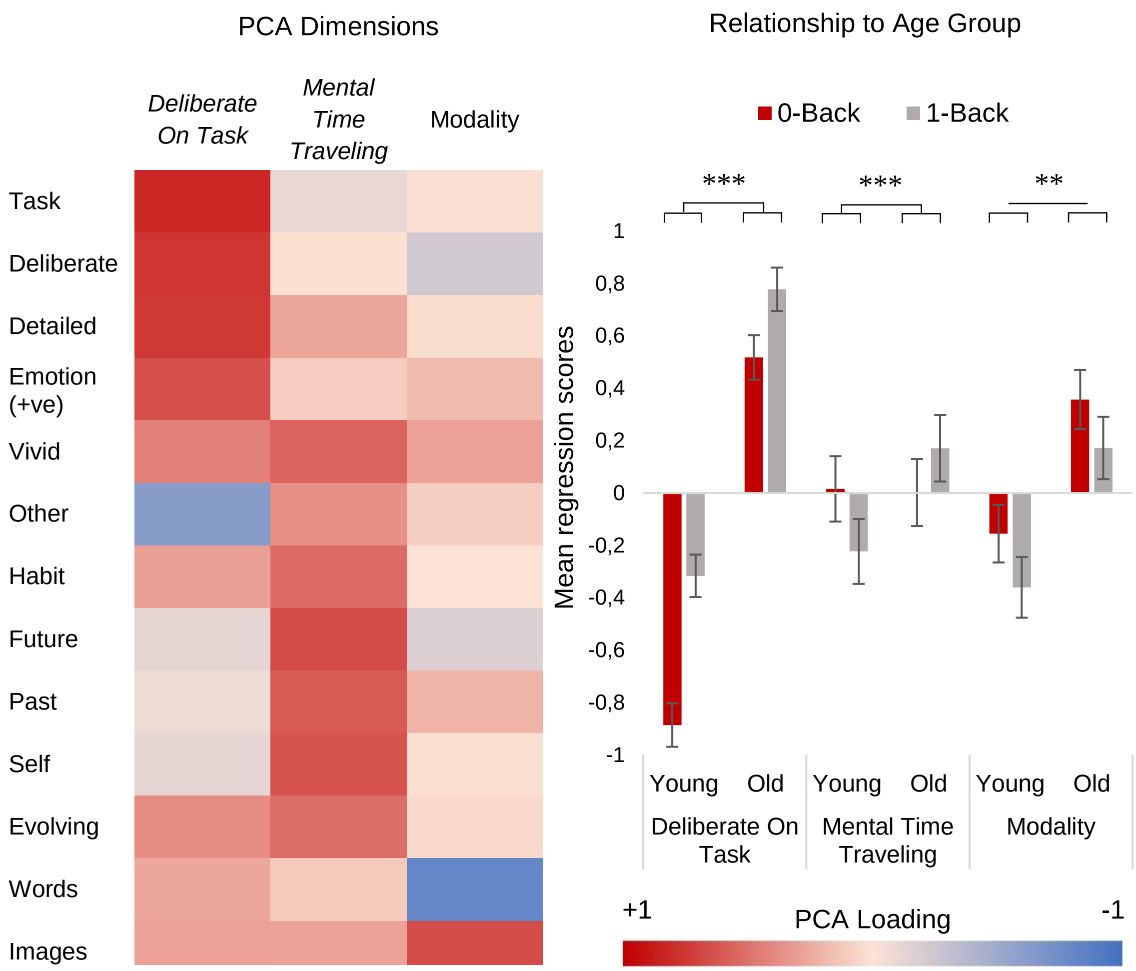


Figure 4.2. Determining patterns of self-generated thought and their relationship to ongoing task and age group.

(*Left*) Heat map illustrating the loading of the different questions on the three factors resulting from the principal component analyses (PCA). Varimax rotation was applied to the data set. (*Right*) The interaction between Age (*Young, Old*) and Task difficulty (*0-Back, 1-Back*) for the mean regression weights for On Task and MTT types of thoughts, along with the main effects of Age (*Young, Old*) and Task difficulty (*0-Back, 1-Back*) on mean regression scores for Modality type of thoughts. *Note*. *** *p* <.001; Error bars are Standard Errors.

adults compared to older adults in the more demanding task context. Finally, analysis of ***Thought Modality*** revealed a main effect of task indicating more visual experiences in the *0-Back* condition (M = .09; SD = .74), and more verbal experiences in the *1-Back* condition (M = -.10; SD = .78), F (1, 78) = 12.40, p < .001, η_p^2 = .14. The main effect of age indicated that young adults (M = -.26; SD = .59) had less thoughts in the form of images than older adults (M = .26; SD = .76), F (1, 78) = 11.84, p < .001, η_p^2 = .13.

4.3.3. Brain connectivity in ageing and relation to the task

The first neural analysis identifyed regions whose patterns of functional connectivity from the selected regions of interest showed age-related changes. Analyses consisted of a series of group level multiple regressions, in which spatial maps describing the functional connectivity of these seeds were the dependent variables and Age group was included as an explanatory variable. These analyses generally found regions of decreased functional connectivity with age (see **Figure 4.3**.). For both the left and right ATL, younger individuals had stronger connectivity with a region of dorsomedial prefrontal cortex. These patterns were generally limited to the same hemisphere as the seed region; however, a small area of overlap was apparent in the right hemisphere. The left ATL also had stronger connectivity to a cluster of Left lateral prefrontal cortex in younger individuals. Examination of both of these patterns of connectivity showed that both the seed regions and the subsequent destination regions fall within the DMN (see **Figure 4.4**.). The connectivity of the left IFG seed with a region of left anterior insula was stronger for younger relative to older individuals. This pattern of connectivity was associated with increased changes between the fronto-parietal network and the ventral attention network (see **Figure 4.4**.). Finally, no differences were found in the connectivity of the Hippocampus across age groups. Previous research has reported conflicting findings, with the posterior but not the anterior hippocampus, showing less functional connectivity in ageing (Damoiseaux, Viviano, Yuan, & Raz, 2016).

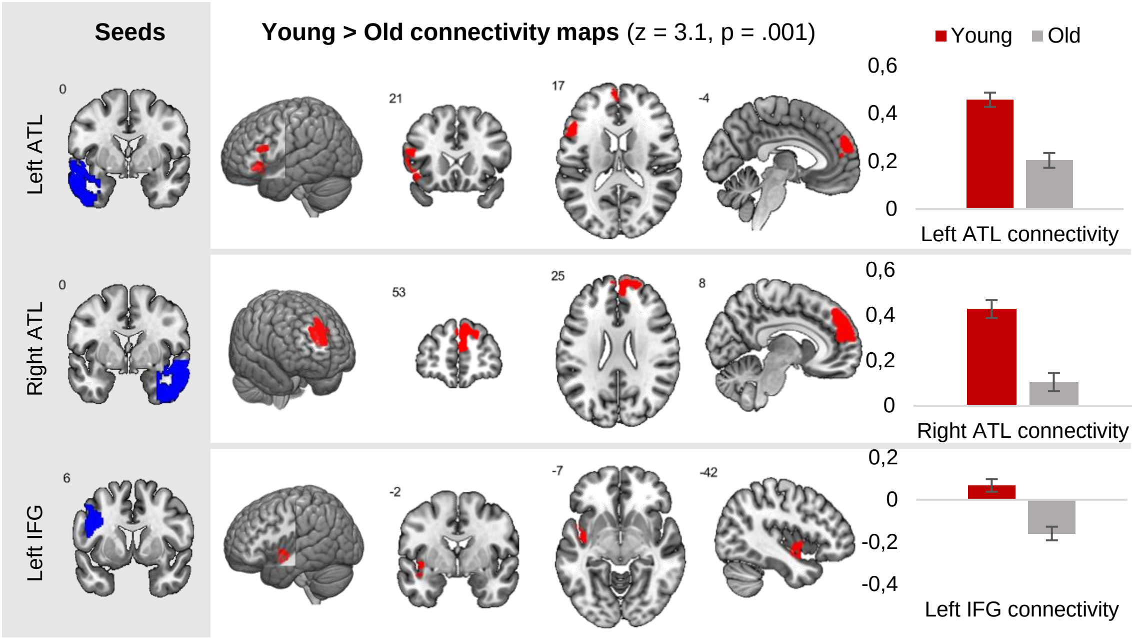


Figure 4.3. Significant effects of Age (*Young, Old*) on brain connectivity from the left ATL, the right ATL and the left IFG.

The left hand grey panel shows the regions used as seed regions in each analysis. Each row corresponds to the results of a whole brain analysis on each seed. Brain areas indicated as red in the centre panel showed greater connectivity with the seed region for Younger than Older Adults. The bar graphs in the right hand panel summarise the beta weights of the effects as generated by the model for Younger and Older participants. Abbreviations: ATL = Anterior Temporal Lobe; IFG = Inferior Frontal Gyrus. Maps were thresholded at Z = 3.1 and were corrected for the family wise error in terms of the number of voxels in the brain, the two tailed nature of our tests and the number of seed regions. *Note*. Error bars are Standard Errors.

Next, correspondences between age-related changes in the patterns of self-generated thought and changes in the intrinsic neural function identified in prior analyses were explored. Three outliers have been identified, based on the visualisation of boxplot generated in SPSS 24.0, and removed in the following analyses; two older adults (connectivity measures) and one younger adult (behavioural measures). A similar strategy to Chapter 3 was used. Accordingly, all data were z-scored separately for old and young individuals. This step assured that gross differences in intercepts across conditions and age group were minimised, allowing the relationships between the variables to be visualised more transparently. These data were analysed using a mixed ANOVA. The model had two within-participant factors: Task (*0–Back, 1-Back*), and Component (*Detailed On-Task, Mental Time Travel, Modality*). Age group (*Young, Old*) was included as between group variable. The normalised connectivity scores for all of the significant effects (Left ATL, Right ATL and Left IFG) were also included. The main effects of all variables were modelled, as well as both two-way and three-way interactions between task, age group, and each PCA component. Interaction terms describing the relationship between each PCA component were not included.

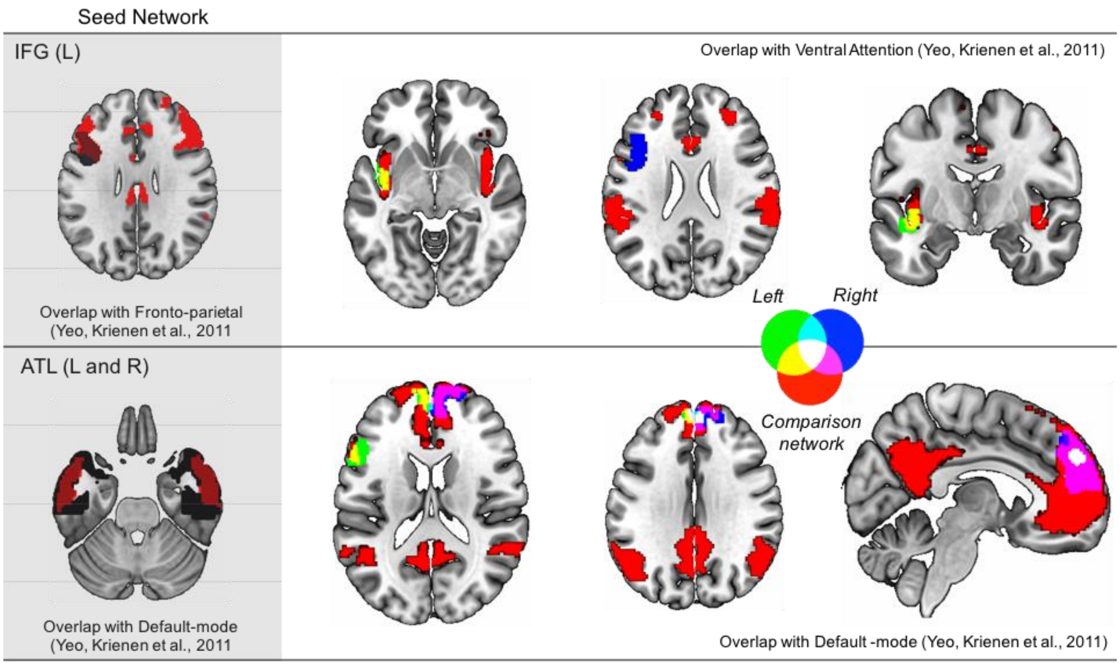


Figure 4.4. Relationship between age-related changes in functional connectivity and large scale networks.

The main panel describes the correspondence between regions showing age related changes and the relevant large scale network as described by Yeo, Krienen and colleagues (2011). The sub panel (coloured grey) shows the overlap between the seed regions (indicated in black) and the relevant network (in red).

This analysis revealed a significant four-way interaction in Task X Age Group X Component X Left ATL Connectivity, F (2, 128) = 8.41, p < .001, η_p^2 = .12. The effect was found for variation in patterns of Deliberate On-Task thought only: Task X Age Group X Left ATL Connectivity, F (1, 64) = 10.99, p = .002, η_p^2 = .15. To visualise this interaction, the relationship between left ATL connectivity and how Deliberate On-Task thought changed across task separately in each age group was plotted (see **Figure 4.5**.). In younger individuals, lower connectivity is linked to more off-task, spontaneous thought in the 0-Back task and a more deliberate on-task state in the 1-Back task. No such pattern of variation was apparent in the older individuals. There were no significant associations with any other pattern of experience, nor were there any significant Task X Age Group interactions for any task.

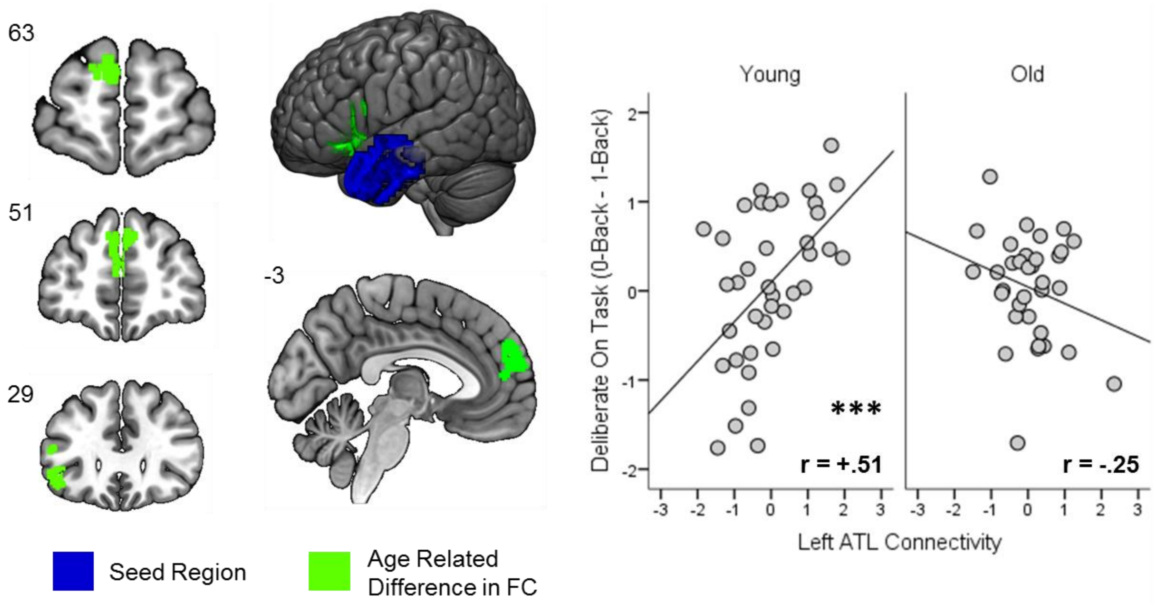


Figure 4.5. Association between patterns of age related difference in functional connectivity and patterns of self-generated thought.

The left hand panel illustrates the regions with age related differences (green) in functional connectivity from the left ATL (blue). The right hand panel illustrates the significant relationship between left ATL connectivity and the variation in Deliberate On-Task states across tasks in the younger but not the older participants. *Note*. *** p <.001

4.3.4. Relationship to control tasks

The final analysis examined the relationship between age-related changes in performance on the behavioural tasks. This will enable general understanding of the consequences underlying neurocognitive changes in ageing. A series of univariate analyses on the measures of creativity, fluid intelligence, and working memory were performed. In these, age was included as between subject variable, and the normalised connectivity from each of the significant analyses was also included. The main effects of each factor and as well as the two-way interactions between age group and each of the connectivity patterns were modelled. These revealed an age by left ATL connectivity interaction related to performance on the UUT, F (1, 64) = 4.96, p = .029, η_p^2 = .07. Comparing the association between UUT performance and connectivity with left ATL separately in each age group demonstrated a significant association in older individuals, r = -.50, p < .01, but showed no association for younger participants, r = .01, p = .996. Thus, weaker connectivity was related to more creativity in older adults only.

4.4. Discussion

The present study set out to understand whether age-related differences in patterns of self-generated thought could be linked to changes in the underlying functional architecture. Three regions were selected, each linked to different processes based on prior research: The hippocampi given their role in episodic memory, the anterior temporal lobes given their role in semantic processing, and the inferior frontal gyri given their role in the memory control. Group level analysis showed decreased connectivity between DMN regions in the anterior temporal cortex with regions of the same network in ventrolateral and dorsomedial prefrontal cortex. Additionally, the left inferior frontal gyrus had decreased connectivity with the left anterior insula, suggesting age-related changes in how regions of the fronto-parietal network communicate with the ventral attention network. The experience sampling study confirmed prior work showing more deliberate on-task thoughts in older individuals, especially in the easier 0-Back condition, and a bias toward thoughts in the form of images than words. They also reported experiences with more episodic features in the more demanding 1-Back task relative to the younger participants.

Results evidence that regions showing different patterns of ATL connectivity with the prefrontal regions of the DMN in older adults were linked to changes in the ability to increase off-task thoughts when task demands decline. In the younger individuals, lower connectivity between these sets of regions was associated with more flexible adjustment of off-task thoughts, increasing off-task thoughts in the undemanding 0-Back task relative to the harder 1-Back task. This association was absent in older individuals, who changed their focus on the task less when task demands changed, than younger participants did. Therefore, the data shows age-related changes in connectivity within the DMN occur in regions that are related to a flexible increase in off-task thought when task demands are low in younger participants. Balancing task focus in line with the demands of the task is a well-documented feature of cognition in younger individuals (Konishi et al., 2017; Seli, Risko, Smilek, et al., 2016; Smallwood, Nind, et al., 2009), and is assumed to reflect the ability to regulate the contents of self-generated thought in line with the demands of the environment (Smallwood & Andrews-Hanna, 2013). Previous work reported related findings with strong connectivity between ATL and control regions (e.g. IFG) in young adults associated with poor performance on easy semantic tasks, and more mind-wandering (Vatansever et al., 2017. This was interpreted as a failure to regulate cognition. The present study, therefore, suggests that reductions in off-task thinking as we age are linked to neural changes that may be disruptive to the ability to flexibly alter patterns of self-generated thought when external task demands change.

Importantly, results showed that older individuals with lower patterns of connectivity between the same set of temporal prefrontal regions, tended to perform better on a creativity task. Associations in older adults between performance on the Unusual Uses Task (UUT) and reduced connectivity from the left ATL, rules out simple interpretations of this age-related connectivity change as reflecting generally impaired cognitive processing. Instead, it seems that older adults who have a pattern of connectivity associated with preserved cognitive function on UUT are making more cognitive effort even when it is not needed (i.e. the undemanding 0-Back task). Prior studies in younger individuals have found correlations between better creativity and patterns of off-task experience (Baird et al., 2012; Smeekens & Kane, 2016; H.-T. Wang, Poerio, et al., 2018). If creativity and the off-task state share some underlying cognitive features, as many theorists assume, it is possible that their association with connectivity in older individuals is evidence of a certain degree of preservation of this latent factor. In support of this account, prior work showed an association between more spontaneous off-task thoughts, greater creativity, and lower within DMN connectivity (H.-T. Wang, Poerio, et al., 2018). Using independent data, but a similar experimental setup, this study used canonical correlation to identify a pattern of spontaneous off-task thought that was linked to reduced connectivity across regions of the DMN. This pattern was independently linked to better performance on tasks tapping a process of generation, such as the unusual uses task, self-reference, and measures of verbal fluency. The conceptual similarity between the current study with those H.-T Wang, Poerio, and colleagues (2018) provides independent support for the close association between creativity, spontaneous off-task thoughts and reduced connectivity within the DMN. Further corroborating evidence comes from a recent study using the same task paradigm, in which online experience sampling was combined with fMRI (Sormaz et al., 2018). Using representational similarity analysis it was demonstrated that neural signals within certain regions of the DMN are important for momentary states of detailed task focus (Sormaz et al., 2018). This result is consistent with previous (i.e. H.-T. Wang, Poerio, et al., 2018) and current data, which show that in younger individuals, stronger coupling between regions of the DMN is linked to a preference for detailed on-task thinking. Based on this emerging literature, one may speculate that understanding the intersection between creativity and off-task thought in ageing, could be an important question for future work exploring the functions that the DMN plays in cognition.

While our study implicates the DMN in age-related changes in off-task thought, many questions remain unanswered. First, the use of a cross-sectional design to examine age differences in cognition and brain function, while practical, confounds many factors that could have been addressed using a more complex longitudinal design. Studies suggest that declines in the tendency for off-task thought are consistent whether a cross-sectional or longitudinal design is used (Giambra, 1989; Shaw & Giambra, 1993), as are age-related changes in functional connectivity (Damoiseaux, 2017). Building on these findings, future studies could benefit from a longitudinal design in which individuals across a range of ages are measured on multiple occasions, a design that may help provide a more comprehensive understanding of the underlying relationships. Secondly, this study used an individual differences approach to examine patterns of self-generated thought, and thus adopted a trait level perspective on a state. While a between participant approach is efficient in helping understand variation in the neurocognitive architecture linked to patterns of self-generated thought (Golchert et al., 2017; Smallwood et al., 2016; H.-T. Wang, Bzdok, et al., 2018; H.-T. Wang, Poerio, et al., 2018), it lacks the precision that momentary experience sampling can provide (Allen et al., 2013; Christoff et al., 2009; Hasenkamp, Wilson-Mendenhall, Duncan, & Barsalou, 2012; Stawarczyk et al., 2011). Recent work has shown that MDES data can be successfully combined with measures of online neural function to identify links between experience and brain activity (Chapter 3; Sormaz et al., 2018). Building on the success of this work, it may be possible to compare measures of online neural activity across older and younger individuals. This would help determine neural patterns of activity during task performance and so could usefully constrain the interpretations that should be placed on these data.

To conclude, the present study set out to understand whether age-related changes in self-generated thought are linked to variation in the functional architecture that occur as we grow older. The focus was on brain structures supporting executive control and memory, in order to consider the coordination and generation of self-generated thoughts. It was evidenced that connectivity between the left ATL and ventrolateral / dorsomedial prefrontal cortex within the DMN was reduced in older individuals. In younger participants, this pattern of connectivity was related to the flexibility with which off-task thought is modulated. Importantly, in the older individuals, lower connectivity between the same two regions was linked to preserved performance on a creativity task, suggesting that age-related changes in this area are not linked to impairments in cognition across domains. Together these data provide converging evidence that one reason why self-generated thought becomes more focused on tasks as we age is related to changes in the connectivity of the DMN. Therefore, these results extend previous findings from Chapter 3, where spontaneous off-task thoughts were related to activity in the DMN as evidenced by alpha and beta power. This study suggests that in the future, understanding the role of the DMN in creativity and off-task thought may shed important light on an important aspect of how cognition changes as we age.

– Section B –
Consideration of other factors influencing mind-wandering experiences in ageing.

The first two empirical chapters comprising this PhD thesis disentangled the implication of older adults' brain activity in their changing experience of self-generated thoughts. Following this success, the next two empirical chapters will consider other methodological approaches to further understand mind-wandering experiences in ageing. Chapter 5 will use the perspective of cultural differences while Chapter 6 will observe the influence of both meta-awareness and meditation to unravel the heterogeneity of thought content in ageing.

Chapter 5. The implications of culture.

In this chapter, the influence of culture on the experience of mind-wandering across different age groups will be under investigation. A large-scale online questionnaire-based survey of 308 adults over 18 years of age, both in France and in the United Kingdom, examined the joint effects of culture and age. To capture a thinking style profile, self-report measures of mind-wandering frequency, mindfulness, mood, rumination, self-reflection, future thinking, depressive symptoms, and cognitive failures were gathered. Findings revealed an earlier decrease in mind-wandering frequency for French-speaking participants. Cultural effects were demonstrated on rumination and reflection rates across the lifespan, with, in general, more rumination and less reflection for English speakers. Overall, negatively toned thoughts were dominant for English compared to more expressive thoughts in general for French speakers. Confirmatory factor analyses featured different theoretical models to explain mind-wandering frequency in the French and British populations. This chapter provides clear evidence of experiential differences in mind-wandering as a function of culture and age.

5.1. Introduction

Mind-wandering has been investigated across the globe; namely, China (Deng, Li, & Tang, 2012; Song & Wang, 2012), the United States of America (Levinson et al., 2012), the United Kingdom (Smallwood, Nind, et al., 2009), Belgium (Stawarczyk, Majerus, Maj, et al., 2011), and Germany (Tusche et al., 2014). Yet, limited investigations have focused on the impact of culture on the frequency, content, and consequences of mind-wandering across the lifespan.

In 1961, one large-scale questionnaire study exploring characteristics of adults' daydreaming reported cultural differences in daydreaming frequency and content (Singer & McCraven, 1961). Afro-American and Jewish participants presented the highest daydreaming frequency compared to their British counterparts. Although the nature of the variability was not specified, the authors argued that variations in family constellations (complex bonds and family relationships) and life experiences in general, drive such differences. Indeed, Jewish cultural values, such as the encouragement of self-reflection and open communication between family members, may play an important role in mind-wandering frequency and identity creation.

Elsewhere, research has evidenced that mind-wandering scaffolds and maintains a continuous feeling of 'self' and identity (Smallwood et al., 2011; Song & Wang, 2012). Rather than explaining the pattern of findings in terms of relatively more positive aspects of daydreaming (self-reflection), for the Afro-Americans, negative life events (e.g. bullying) were suggested to give rise to a greater propensity for unpleasant thoughts and the likelihood of developing psychological problems associated with rumination (e.g. Depression, Erdur-Baker, 2009; A. West & Salmon, 2000). More recently, research showed that European-heritage students tend to mind wander more than Asian-heritage students or Japanese exchange students (Sude, 2015). Yet, others failed to demonstrate any cultural differences between Portuguese and Brazilian participants, regarding the frequency or content of mind-wandering experiences (Gonçalves et al., 2017). Nevertheless, their results suggested that Portuguese students used mind-wandering to their advantage more than Brazilian students. Together these studies point to the influence of culture on the occurrence and the characteristics of mind-wandering and provides the foundation for the chapter presented here.

Although the examination of cultural differences in mind-wandering has been neglected, data from the language domain are informative and may aid in the generation of hypotheses for future experimental work. Our thoughts and feeling during mind-wandering episodes are composed largely of inner speech rather than visual imagery (Bastian et al., 2017; Stawarczyk, Cassol, et al., 2013). Additionally, once internalised, language plays a crucial role in shaping cognitive processes and organising thoughts (Vygotsky, 1962). According to Whorf (1956), certain properties of a given language affect the way people perceive and remember, and so through language, culture may influence individual's self-generated and unconscious thought processes. For example, the differences in talking about the time between English and Mandarin speakers corresponds to discrepancies in how English and Mandarin speakers think about time (Boroditsky, 2001). Abstract thoughts involving time tend to be shaped and organised differently with vertical (Mandarin) and horizontal (English) metaphors driving how time is conceptualised. Therefore, considering that languages may impact on the nature of abstract thoughts differently, it is not unreasonable to suggest language will have a more universal impact on self-generated thoughts studied here.

The vast majority of studies investigating cultural differences on psychological phenomena often compare western and eastern populations, where differences that are more striking are expected. Comparison within European countries is rare, and due to geographic proximity, cultural similarities may be predicted. Nevertheless, some observations suggest clear cultural differences existing between French and British citizens. For example, the literature regarding the '*Déjà vu*' experience suggests that French speakers describe their experience of such thoughts as more disturbing than English speakers (Fortier & Moulin, 2015).

Additionally, a crucial element when investigating cultural discrepancies is the strong influence of the individuals' educational background on the development of moral value, and the shaping of thought processes. The education system is considered to be a product of societal norms shared by the majority of the population (Hofstede, 1984), and as such, the notable differences between the French and British educational system suggest divergent cultural values. The French educational system is mostly focused on knowledge and intellect, whereas the British system is mainly focused on the development of the individual (Mons, Duru-Bellat, & Savina, 2012). This difference can be illustrated within disparate professions. For example, in the management environment, French managers show a tendency to be more control orientated, in contrast to their British counterparts that are more prone to delegation and trust (Gröschl & Barrows, 2003). Many more examples of divergent social and psychological styles (e.g. writing methods) between French and British individuals could be highlighted here, but overall one could expect fundamental differences in the nature of self-generated thoughts.

Regardless of the culture under investigation, the scientific community agrees that the content comprising self-generated thoughts is extremely varied (Seli et al., 2018). The temporal dynamics of mind-wandering reveal a tendency for thoughts to be directed toward the future (Baird et al., 2011; D'Argembeau et al., 2011; Smallwood, Nind, et al., 2009), which are characterised by a verbal form, with a tendency to be realistic, concrete, structured, and more personally relevant (Stawarczyk, Cassol, et al., 2013). Future thinking has been related to recovery from negative responses such as stress (Engert et al., 2014), and is commonly associated with positive mood (Ruby, Smallwood, Engen, et al., 2013). Self-reflection is a core component of future thinking during mind-wandering, and self-generated thoughts are more often about the self than others (Baird et al., 2011; Smallwood et al., 2011). While the majority of spontaneous cognition is future-oriented, a smaller but significant proportion of off-task thoughts are directed to the past (Baird et al., 2011). Negative mood induction procedures have consistently been found to induce greater past-related thoughts (Smallwood & O'Connor, 2011). In the absence of mood induction, it has been evidenced that sadness tends to precede mind-wandering occurrence, and having negatively toned thoughts during mind-wandering predicts subsequent sadness (Poerio et al., 2013). Overall, thoughts directed toward the past tend to induce negative mood, while future and self-related thoughts tend to improve mood.

A further key research endeavour is the exploration of mind-wandering outcomes. If different mind-wandering styles occur across cultures, this may have some bearing on the positive and negative consequences of such episodes. For instance, mind-wandering has deleterious effects on cognitive abilities, including working memory, sustained attention, and comprehension (for a review see Mooneyham & Schooler, 2013). Mirroring work on mind-wandering, data from the mindfulness and meditation literature is informative regarding impacts on task performance. Mindfulness reduces mind-wandering frequency with subsequent improvements on everyday activities (Mrazek et al., 2013), and is often associated with well-being (Brown & Ryan, 2003) and increased cognitive abilities (Chiesa, Calati, & Serretti, 2011). However, mind-wandering also seems to benefit individuals. As mind-wandering is partly goal oriented (D'Argembeau et al., 2011) and mostly refers to the self and the future, it has been argued that one of the primary functions of mind-wandering is to enable the anticipation and planning of personally relevant future goals (Baird et al., 2011). Additional functions highlighting the adaptive value of mind-wandering have been identified, including enhanced social problem solving (Ruby, Smallwood, Sackur, et al., 2013), the fostering of a more patient style of making decisions (Smallwood et al., 2013) and more creative processing whilst problem solving (Baird et al., 2012).

Particularly relevant here is the consideration of how the ageing process modulates the frequency of mind-wandering. Given the widely reported executive function deficit in ageing (Riby, Perfect, & Stollery, 2004), past research has focused on the cognitive profile of older adults in order to comprehend the well documented age-related decrease in mind-wandering frequency (Giambra, 1989; Jackson & Balota, 2012; Jackson et al., 2013; McVay et al., 2013). It is worth noting that the complexity of the thoughts and specific content of mind-wandering episodes has in the main been neglected. Characteristics that have been associated with the ageing process can give clues to the specific components that influence the nature of mind-wandering episodes. For example, older adults are thought to be more mindful and present moment focussed (Splevins et al., 2009), and largely have more positive moods (Carstensen, Isaacowitz, & Charles, 1999). Regarding future thinking, Rendell et al. (2012) showed that older adults were worse at imagining the future than a-temporal experiences, thus, their frequency of future thoughts decreases (Berntsen et al., 2015). They also seem to experience more a-temporal than future directed mind-wandering (Jackson et al., 2013). Overall, the nature of self-generated thoughts appear to be complex during mind-wandering episodes as we age.

The purpose of this study was to identify broad discrepancies in mind-wandering by examining the differences in frequency between French (France) and English (United Kingdom) native speakers, in young, middle-aged, and older adults. To further characterise the joint effects of age and culture, a collection of seven questionnaires were used to capture key elements previously associated with the wandering mind in the literature. Namely, mindfulness abilities, mood, future thinking, self-attentiveness (rumination and reflection), cognitive failure, and depressive symptoms measures were gathered.

Unfortunately, the literature regarding the influence of culture on mind-wandering is lacking, impeding the generation of precise hypotheses, particularly when it comes to two European countries. However, variables capturing the mood and emotional content (e.g. rumination vs reflection) established whether a previously identified bias for negatively toned thoughts in English speakers and more expressive thoughts for French speakers (e.g. work examining the 'Déjà vu' experience; Fortier & Moulin, 2015) is also observed for self-generated thought. Regarding the overall effects of age, a decrease in mind-wandering frequency, future thinking, and depressive symptoms was anticipated (Berntsen et al., 2015; Giambra, 1989; Nolen-Hoeksema & Ahrens, 2002), alongside an increase in cognitive failures and mindfulness abilities

(Mecacci & Righi, 2006; Splevins et al., 2009). In addition, structural equation modelling will be used to generate an overview of the relationships linking mind-wandering experiences to the measures collected.

Conceptually, it is expected that measures of rumination, negative mood and depressive symptoms will compose a negative construct (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008; Poerio et al., 2013; Smallwood et al., 2005). Additionally, it is expected that the frequency of future-self related thoughts and self-reflection will comprise a self-related construct (Stawarczyk, Cassol, et al., 2013; Trapnell & Campbell, 1999), and that measures of mindfulness and cognitive failures will make an attentional construct (Chiesa et al., 2011; Mooneyham & Schooler, 2013). Ultimately, it is hypothesised that the theoretical model, where mind-wandering frequency is predicted by age and the previously outlined constructs (self-related, negative and attentional) will fit the present data. However, the lack of research on the impact of culture on mind-wandering experiences prevents us from formulating clear hypotheses about the variations of the model in the two populations, yet differences are suspected (Gonçalves et al., 2017; Singer & McCraven, 1961; Sude, 2015).

5.2. Method

5.2.1. Participants

A total of 471 volunteers completed an online survey, 283 in English and 188 in French. Fourteen participants were removed from the English dataset for not being native English speakers. One non-French native speaker was removed from the French dataset. Significant differences were found between the samples in terms of age [F (1, 453) = 7.56, p = .006, η_p^2 = .02] and years of education [F (1, 451) = 4.56, p = .033, η_p^2 = .01]. Therefore, the sample was matched on those two variables. The remaining data consisted of 154 native English speakers (M = 31.21, SD = 16.15, 132 female) and 154 native French speakers (M = 32.32, SD = 15.96, 130 female). To be as inclusive as possible, the inclusion criteria were to be 18 or over, and be native English or French speakers. This study was approved by the Ethics Committee of the Faculty of Health and Life Sciences of Northumbria University. The investigation was conducted according to the principles expressed in the Declaration of Helsinki, and for both populations, participants provided informed consent.

5.2.2. Measures

5.2.2.1. Mind-wandering

The Daydreaming Frequency Scale (DDFS; Giambra, 1993) is one of the 28 scales comprising the Imaginal Process Inventory (Singer & Antrobus, 1963) and consists of 12 items assessing daydreaming frequency. Participants are asked to choose on a five-point Likert scale, the nature of thoughts which are appropriate for them. For example, '*I lose myself in active daydreaming*' can be answered by either (1) *Infrequently*, (2) *Once a week*, (3) *Once a day*, (4) *A few times during the day,* or (5) *Many different times during the day*. The original 12 items of the DDFS were translated into French by Stawarczyk, Majerus, Van der Linden and D'Argembeau (2012) with a back-translation procedure. Cronbach's alphas were computed on the English (α = .92) and French version (α = .92) of the questionnaire and revealed good reliability.

5.2.2.2. Mindfulness

The Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003) is a 15-item scale introduced by the following sentences: "*Below is a collection of statements about your everyday experience. Please answer according to what really reflects your experience rather than what you think your experience should be*." Participants must rate the statements on a six-point Likert scale ranging from 1 (*almost always*) to 6 (*almost never*). For example, '*I rush through activities without being really attentive to them*' or '*I snack without being aware that I'm eating*'. A higher score indicates more mindful abilities. The French version of the MAAS was translated by Stawarczyk et al.

(2012) with a back-translation procedure. Cronbach's alphas have been computed on the English (α = .88) and French version (α = .82) of the questionnaire and revealed good reliability.

5.2.2.3. Mood

The Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) consists of two 10-items mood scales that respectively measure positive and negative affect, both as states and traits. Participants are asked to rate the extent to which they experience particular emotions *right now* concerning a five-point Likert-scale ranging from 1 (*very slightly or not at all*) to 5 (*very much*). Examples of emotions would be as such, '*distressed'* or '*excited*'. The French version of the PANAS was translated by Gaudreau, Sanchez and Blondin (2006) with a back-translation procedure. Cronbach's alphas have been computed on the English (Positive affect, α = .90; Negative affect, α = .93) and French version (Positive affect, α = .85; Negative affect, α = .91) of the positive and negative subscales of the questionnaire and revealed good reliability.

5.2.2.4. Future thinking

The Future-Self Thoughts questionnaire (FST; McElwee & Haugh, 2010) consists of 11 items designed to assess two dimensions of thoughts about one's future selves: (i) Frequency, the extent to which participants spontaneously think of themselves in the future, and (ii) Clarity, the vividness with which participants "see" themselves in the future. Participants are asked to rate the extent to which each statement describes how they think or act in their daily life, using a six-point Likert-scale ranging from 1 (*not at all true for me*) to 6 (*completely true for me*). For example, a question like '*When I daydream, I often see myself as I may be in the future*', measures Future-self thoughts frequency, and questions like '*My future seems vague and uncertain to me*' measures their clarity. The French version of the FST was translated by Stawarczyk et al. (2012) with a back-translation procedure. Cronbach's alphas have been computed on the English (Frequency, α = .91; Clarity, α = .58) and French version (Frequency, α = .82; Clarity, α = .57) of the Frequency and Clarity subscales of the questionnaire and revealed good reliability considering the number of items within each subscales (Frequency, 6 items; Clarity, 5 items).

5.2.2.5. Self-attentiveness

The Rumination and Reflection Questionnaire (RRQ; Trapnell & Campbell, 1999) consists of 24 items designed to assess reflection and rumination where participants are asked to rate the extent to which they agree or disagree to statements. Answers are given on a five-point Likert-scale ranging from 1 (*Strongly disagree*) to 5 (*Strongly agree*). According to Trapnell & Campbell (1999), rumination and reflection both involve heightened attention to self. *Rumination* is "self-attentiveness motivated by perceived threats, losses, or injustices to the self"; *reflection* is "self-attentiveness motivated by curiosity or epistemic interest in the self" (Trapnell & Campbell, 1999, p.297). For example, '*My attention is often focused on aspects of myself I wish I'd stop thinking about*' for rumination and '*I'm very self-inquisitive by nature*' for reflection. This questionnaire was translated to French by Fluckiger (2009). Cronbach's alpha were computed on the English (Reflection, α = .86; Rumination, α = .91) and French version (Reflection, α = .82; Rumination, α = .87) of the Reflection and Rumination subscales of the questionnaire and revealed good reliability.

5.2.2.6. Cognitive failures

The Cognitive Failure Questionnaire (CFQ; Broadbent, Cooper, FitzGerald, & Parkes, 1982) consists of 25 items measuring self-reported failures in perception, memory, and motor function. Participants are told that the questions will be about minor mistakes which everyone makes from time to time, but some of which happen more often than others. They must rate how often these things have happened to them in the last six months on a five-point Likert-scale from 0 (*never*) to 4 (*very often*). For example, ‘*Do you fail to notice signposts on the road?*’. The French version used in the present study was translated by Fluckiger (2009). Cronbach’s alphas have been computed on the English (α = .91) and French version (α = .87) of the questionnaire and revealed good reliability.

5.2.2.7. Depressive symptoms

The Beck Depression Inventory (BDI-II; Beck, Steer, Ball, & Ranieri, 1996) is a widely used tool for assessing the severity of depressive symptomatology. The 21 items are rated on a four-point Likert scale, from 0 to 3 points. Scores range from 0 to 63. For example, ‘*Past failure*’ can be answered by either (0) *I do not feel like a failure*, (1) *I have failed more than I should have*, (2) *As I look back, I see a lot of failures* or (3) *I feel I am a total failure as a person*. The French version used in this study was translated by Fluckiger (2009) and was validated in both clinical (depressed) and nonclinical samples. Cronbach’s alphas have been computed on the English (α = .94) and French version (α = .88) of the questionnaire and revealed good reliability.

5.2.3. Procedure

Recruitment of the participants for this study was via social media and a poster campaign both in France and the United Kingdom (UK). Participants took part in this study online using Qualtrics’ survey software (qualtrics.com). All of the questionnaires (DDFS, MAAS, PANAS, FST, RRQ, CFQ and the BDI) were presented in a randomised order. Before the end of the session, participants completed demographic information – gender, age, number of years of education, native language, and country of residence. Participants took approximately 30 minutes to complete the questionnaires. The survey was completed anonymously and no compensation was given for participation.

5.3. Results

Pearson's correlations were initially conducted between each measure for both language conditions (English, French). Analyses replicated previous findings by revealing the commonly found negative correlation linking mind-wandering to age, and positive correlations linking mind-wandering to mindfulness, cognitive failures, and depression scores (see **Table 5.1.**).

5.3.1. Effect of native language

In order to investigate the differences between French and English native speakers, Analyses of Variance (ANOVA) were conducted on participants' scores on the questionnaires (DDFS, MAAS, PA, NA, FST Clarity, FST Frequency, Rumination, Reflection, CFQ, and BDI). Regarding positive mood, an effect of native Language indicates that English speakers tended to have less positive thoughts than French speakers, F (1, 306) = 15.22, $p < .001$, $\eta_p^2 = .05$. Considering rumination, results showed an effect of native language, indicating that English speakers tended to ruminate more than French speakers, F (1, 306) = 14.70, $p < .001$, $\eta_p^2 = .05$. Finally, results on the reflection measure revealed an effect of native language, indicating that English speakers tended to reflect less than French speakers, F (1, 306) = 19.70, $p < .001$, $\eta_p^2 = .06$. Mean and standard deviation scores for each measure are presented in **Table 5.2**. In summary, results demonstrated that French native speakers reported more positive emotions, ruminated less, and experienced more reflection than English native speakers.

Table 5.1. Correlations between variables for both English and French speakers individually and jointly.

		1. Age	2.	3.	4.	5.	6.	7.	8.	9.	10.
2. DDFS	English	-.26 ***	-								
	French	-.35 ***	-								
	Total	-.31 ***	-								
3. MAAS	English	.16 *	-.49 ***	-							
	French	.10	-.45 **	-							
	Total	.13 *	-.47 ***	-							
4. PANAS Positive	English	.11	-.12	-.00	-						
	French	.02	-.13	.19 *	-						
	Total	.07	-.11	.10	-						
5. PANAS Negative	English	-.08	.24 **	-.36 ***	-.02	-					
	French	-.04	.19 *	-.37 ***	-.09	-					
	Total	-.06	.22 ***	-.35 ***	.04	-					
6. FST Clarity	English	.03	-.06	.24 **	.33 ***	-.34 ***	-				
	French	.06	-.27 ***	.27 ***	.26 ***	-.27 ***	-				
	Total	.04	-.17 **	.25 ***	.27 ***	-.31 ***	-				
7. FST Frequency	English	-.38 ***	.35 ***	-.33 ***	.08	.15	.13	-			
	French	-.31 ***	.37 ***	-.37 ***	-.05	.22 **	.09	-			
	Total	-.35 ***	.36 ***	-.35 ***	.02	.18 ***	.10	-			
8. RRQ Rumination	English	-.31 ***	.51 ***	-.47 ***	-.28 ***	.41 ***	-.18 *	.32 ***	-		
	French	-.12	.36 ***	-.40 ***	-.27 ***	.47 ***	-.23 **	.42 ***	-		
	Total	-.22 ***	.41 ***	-.44 ***	-.31 ***	.42 ***	-.19 ***	.36 ***	-		
9. RRQ Reflection	English	.11	.21 ***	-.16	.20 *	.13	.09	.09	.13	-	
	French	-.06	.27 ***	-.07	.13	-.04	.10	.24 **	.06	-	
	Total	.03	.24 ***	-.09 *	.21 ***	.06	.08	.16 ***	.04	-	
10. CFQ	English	-.07	.42 ***	-.74 ***	-.10	.39 ***	-.26 ***	.19 *	.45 ***	.06	-
	French	-.15	.51 ***	-.68 ***	-.24 **	.37 ***	-.25 **	.34 ***	.39 ***	.09	-
	Total	-.11	.46 ***	-.71 ***	-.18 **	.37 ***	-.24 ***	.26 ***	.43 ***	.05	-
11. BDI	English	-.13	.39 ***	-.53 ***	-.33 ***	.64 ***	-.39 ***	.22 **	.58 ***	.11	.58 ***
	French	-.20 *	.43 ***	-.38 ***	-.53 ***	.54 ***	-.37 ***	.28 **	.55 ***	-.08	.47 ***
	Total	-16 **	.40 ***	-.46 ***	-.40 ***	.59 ***	-.38 ***	.24 ***	.54 ***	.03	.53 ***

*Note. * p < .05, ** p < .01, and *** p < .001*

Table 5.2. Mean scores, standard deviation and number of participants of pertinent measures.

Measures	English speakers			French speakers		
	Mean	SD	N	Mean	SD	N
DDFS	3.46	.74	154	3.53	.83	154
MAAS	3.98	.87	154	4.11	.77	154
PANAS – Positive ***	2.57	.74	154	2.90	.73	154
PANAS – Negative	1.79	.79	154	1.91	.83	154
FST – Clarity	3. 610	1.11	154	3.46	1.20	154
FST – Frequency	3.65	1.31	154	3.63	1.16	154
RRQ – Rumination ***	3.73	.85	154	3.36	.87	154
RRQ – Reflection ***	3.27	.72	154	3.65	.78	154
CFQ	1.84	.60	154	1.74	.62	154
BDI	15.76	12.43	154	16.04	9.78	154

Note. *** $p < .001$

5.3.2. Effect of Age and native Language

In order to investigate individual changes across the lifespan, both samples were divided into three age groups (**Table 5.3.:** Young: 18-35, Middle-aged: 36-54 and Older adults: 55+).

Table 5.3. Age means, standard deviations, and number of participants for each defined age group for both the English and French native speaker samples.

	English			French			Total		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
Young	21.77	4.36	108	22.55	3.92	105	22.15	4.16	212
Middle-age	44.40	4.71	25	46.03	5.72	31	45.30	5.31	56
Old	64.10	5.79	21	65.72	5.72	18	64.85	5.48	39
Total	31.21	16.15	154	32.32	15.96	154	31.77	16.04	308

5.3.2.1. Mind-wandering

A 3 (Age; *Young, Middle-Aged, Old*) by 2 (Language; *English, French*) ANOVA was conducted on the DDFS daydreaming scores. A main effect of age was significant, F (2, 302) = 12.63, p < .001, η_p^2 = .08, indicating that young adults (M = 3.62, SD = .73) and middle-aged adults (M = 3.38, SD = .81) tend to mind wander more frequently than older adults (M = 2.97, SD = .82), p < .001, p = .022. Young and middle-aged adults did not differ in their mind-wandering scores, p = .159.

The interaction between language and age was significant, F (2, 302) = 3.93, p = .021, η_p^2 = .03. The decomposition of this interaction revealed that in the English-speaking group, the effect of age was significant, F (2, 151) = 8.69, p < .001, η_p^2 = .10, indicating that young (M = 3.53, SD = .73) and middle-aged adults (M = 3.62, SD = .54) were not different in their mind-wandering frequency. However, both young and middle-aged adults reported more mind-wandering than older adults (M = 2.87, SD = .76), respectively p < .001 and p = .001. In the French speaker group, the effect of age was also significant, F (2, 151) = 8.44, p < .001, η_p^2 = .10. Results showed that young adults (M = 3.70, SD = .73) had higher mind-wandering frequency than middle-aged (M = 3.18, SD = .93), p = .004 and older adults, (M = 3.09, SD = .89), p = .008. However, middle-aged adults and older adults mind-wandering frequency was equivalent, p = .999. These data presented in **Figure 5.1** demonstrate an earlier decrease in mind-wandering frequency in the French speaking group (between 36 and 54 years old).

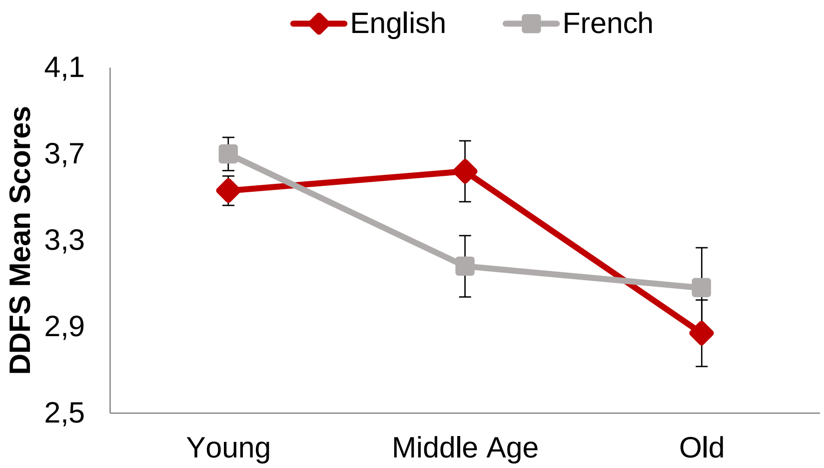


Figure 5.1. The effects of participants' native Language (*English, French*) and their age group (*Young, Middle-age, Old*) on mind-wandering frequency measured by the DDFS.

Note: Error bars represent Standard Errors.

5.3.2.2. Mindfulness

A 3 (Age; *Young, Middle-Aged, Old*) by 2 (Language; *English, French*) ANOVA was conducted on MAAS scores. A main effect of age was evidenced, F (2, 302) = 3.57, p = .029, η_p^2 = .02, indicating that young (M = 4.00, SD = .82) had a tendency to be less mindful than older adults (M = 4.37, SD = .80), p =.033. Young and older adults did not differ from middle-aged adults (M = 3.98, SD = .81) on this score, respectively p = .999 and p = .058.

Results suggested an increase of mindfulness as one grows older, in line with results regarding mind-wandering. However, mindfulness does not seem to be influenced by cultural differences between the two populations.

5.3.2.3. Mood

A 2 (Valance; *Positive*, *Negative*) by 3 (Age; *Young*, *Middle-Aged*, *Old*) by 2 (Language; *English*, *French*) ANOVA was conduct on PANAS scores. The main effect of valence was significant, indicating that participants tended to express more positive affect (M = 2.74, SD = .75) than negative (M = 1.85, SD = .81), F (1, 302) = 131.09, p

< .001, η_p^2 = .30. The main effect of native language revealed that English participants (*M* = 2.18, *SD* = .54) tend to express less affect than their French counterparts (*M* = 2.40, *SD* = .53), *F* (1, 302) = 7.21, *p* = .008, η_p^2 = .02.

Results revealed a general tendency for participants to express more positive affect than negative ones. In addition, French native speakers tended to be more expressive than English native speakers.

5.3.2.4. Future thinking

A 2 (Specificity; *Clarity, Frequency*) by 3 (Age; *Young, Middle-Aged, Old*) by 2 (Language; *English, French*) repeated measure ANOVA was conduct on FST scores. The main effect of age was significant, *F* (2, 302) = 6.63, *p* = .002, η_p^2 = .04, indicating that young adults (*M* = 3.58, *SD* = .75), scored higher on the future-self thoughts questionnaire than older adults (*M* = 2.96, *SD* = .78), *p* = .002. Young and older adults did not differ from middle-aged adults (*M* = 3.23, *SD* = 1.01) on this score, respectively, *p* = .231 and *p* = .336.

The interaction between specificity and age was significant, *F* (2, 302) = 11.01, *p* < .001, η_p^2 = .07 (**Figure 5.2.**). The decomposition of the interaction showed that future-self thoughts clarity did not change across life span, *F* (2, 305) = .163, *p* = .850, η_p^2 = .00, whereas its frequency did, *F* (2, 305) = 17.495, *p* < .001, η_p^2 = .10. Results revealed that young adults (*M* = 3.88, *SD* = 1.17) had more frequent future-self thoughts than middle-aged adults (*M* = 3.30, *SD* = 1.31), *p* = .004 and older adults (*M* = 2.77, *SD* = .98), *p* < .001. Middle-aged adults and older adults had a similar frequency of future-self thoughts, *p* = .090.

Therefore, results demonstrate that the frequency of future-self thoughts decreases with age for both French and English speakers. The clarity of the thoughts however, was not influenced by either age or culture.

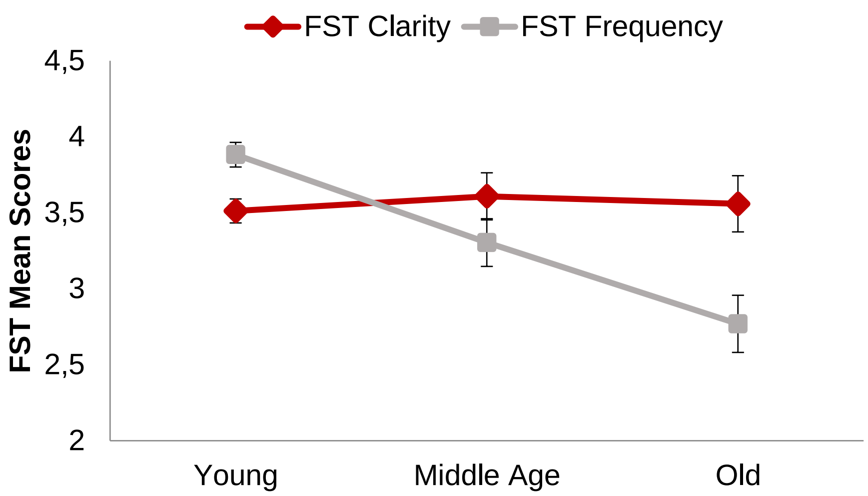


Figure 5.2. The effect of interaction between future-self thoughts (FST) specificity (*Clarity, Frequency*) and participants' age group (*Young, Middle-age, Old*).

Note: Error bars represent Standard Errors.

5.3.2.5. Self-attentiveness

A 2 (Self-Attentiveness; *Rumination, Reflection*) by 3 (Age; *Young, Middle-Aged, Old*) by 2 (Language; *English, French*) repeated measures ANOVA was conducted on RRQ scores. The main effect of age was significant [F (2, 302) = 3.35, p = .037, η_p^2 = .02], indicating that older adults (M = 3.27, SD = .59) had less self-attentive thoughts than young adults (M = 3.55, SD = .59), p = .031. Young and older adults did not differ from middle-aged adults (M = 3.49, SD = .61) on self-attentiveness, respectively p = .999 and p = .218. The three-way interaction between self-attentiveness, language and age was not significant, F (2, 302) = 1.20, p = .303, η_p^2 = .01, however, the three two-way interactions revealed interesting findings.

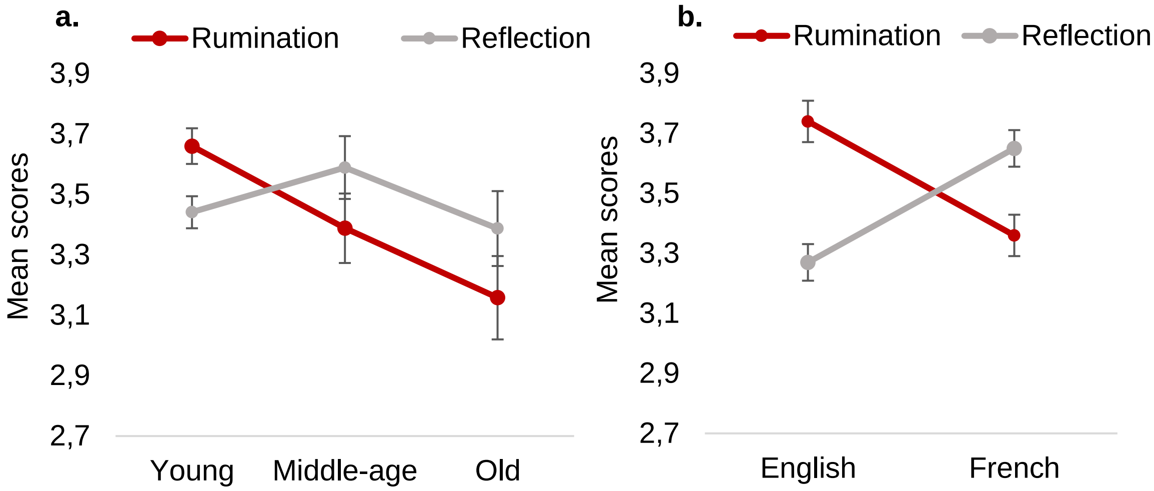
The interaction between self-attentiveness and age was significant, F (2, 302) = 4.829, p = .009, η_p^2 = .03. Further analyses revealed that reflection rates did not change across life span, F (2, 305) = 1.01, p = .365, η_p^2 = .01, whereas rumination rates did, F (2, 450) = 7.36, p = .001, ηp^2 = .03. As such, young adults (M = 3.66, SD = .06) ruminated more than older adults (M = 3.16, SD = .14), p = .003. Middle-aged (M =

3.39, *SD* = .12) adults did not differ from young or older adults on this measure, respectively $p = .112$ and $p = .607$.

The interaction between self-attentiveness and native language was significant F (1, 302) = 8.33, $p < .001$, $\eta_p^2 = .05$. Further analyses showed that both rumination and reflection rates differed as a condition of culture, respectively F (1, 306) = 14.70, $p < .001$, $\eta_p^2 = .05$ and F (1, 306) = 19.70, $p < .001$, $\eta_p^2 = .06$. However, English native speakers presented higher rates of rumination (*M* = 3.73, *SD* = .85) and lower rates of reflection (*M* = 3.27, *SD* = .72) than French native speakers (Rumination, *M* = 3.36, *SD* = .87; Reflection, *M* = 3.65, *SD* = .78).

The interaction between language and age was significant, F (2, 302) = 3.99, $p = .018$, $\eta_p^2 = .03$. Decomposition of the interaction demonstrated that in the case of French native speakers, age did not have an impact on the overall measure of self-attentiveness, F (2, 151) = 1.81, $p = .168$, $\eta_p^2 = .02$. However, age seemed to have an impact on the overall measure of self-attentiveness in the English native speaker's group, F (2, 151) = 6.06, $p = .003$, $\eta_p^2 = .07$. As such, young (*M* = 3.54, *SD* = .06) and middle-aged adults (*M* = 3.68, *SD* = .12) presented higher rates of self-attentiveness than older adults (*M* = 3.12, *SD* = .13), respectively $p = .008$ and $p = .004$. Young and middle-aged adults presented similar scores on this measure, $p = .810$.

Results demonstrated cultural and age difference regarding attention toward the self as measured by rumination and reflection. Firstly, findings showed that only rumination rates seem to be impacted by age, with a decrease of such thoughts as age increases. Secondly, French and British citizens presented an opposite pattern of self-attentiveness, with French native speakers engaging more in self-reflection and less in rumination than English native speakers. Finally, self-attentiveness revealed to be stable across time in the French population but not the British one, where a decrease occurs in later age. These data are summarised in **Figure 5.3**.



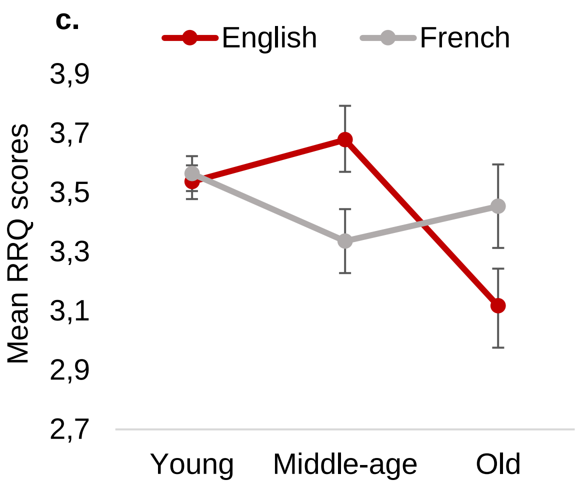


Figure 5.3. Effects of culture and age on rumination and reflection scores.

a. The effect of participants' age (*Young*, *Middle-age*, *Old*) on Rumination and Reflection rates.

b. The effect of participants' native Language (*English*, *French*) on Rumination and Reflection.

c. The effect of participants' native Language (*English, French*) and their age group (*Young, Middle-age, Old*) on their overall self-attentiveness rates.

Note: Error bars represent Standard Errors

5.3.2.6. Cognitive failures

A 3 (Age; *Young, Middle-Aged, Old*) by 2 (Language; *English, French*) ANOVA was carried out on the CFQ scores and revealed no significant effects. Surprisingly, findings did not evidence any age effect on this measure of cognitive failure.

5.3.2.7. Depressive symptoms

A 3 (Age; *Young, Middle-Aged, Old*) by 2 (Language; *English, French*) ANOVA was carried out on BDI scores. A significant main effect of age was evidenced, F (2, 302) = 4.47, p = .012, η_p^2 = .03, indicating that young adults (M = 16.83, SD = 11.58) tended to score higher on the depression inventory than older adults (M = 10.95, SD =

9.70), p = .009. Middle-aged adults (M = 15.80, SD = 9.69) scores on the depression inventory were similar to both young, p = .999 and older adults, p = .090.

Results regarding depressive symptoms did not reveal any cultural differences, but did show an effect of age, indicating that young adults tended to be more depressed than older adults.

5.3.3. Confirmatory factor analysis.

Based on the literature and the aforementioned primary analyses, it is clear that mind-wandering experiences are eclectic by nature. Specifically, three features seem to be associated with mind-wandering experiences: self-orientation, negative mood, and attentional skills. In this study, the self-related construct was measured by the reflection and future-self thoughts frequency subscales; the negative construct was measured by the depressive symptoms, negative affect and rumination scales; and the attentional construct was measured by the mindfulness and cognitive failures questionnaires. In consideration of the literature, the model will also implement age as a factor influencing mind-wandering frequency. To assess the fit of our measurement model to the data formally, confirmatory factor analysis (CFA) was used. Conclusions about structural model fits were based on commonly used fit indices with cut-offs suggested by Kline (2015): χ^2 /df < 2; CFI > .90 for reasonably good fit; RMSEA < .05 for good fit, < .08 for reasonable fit.

The fit indices of the model were as follows; χ^2 (19) = 60.80, p < .001, χ^2 /df = 3.20, CFI = .949, RMSEA = .085. All measures loaded significantly on the negative and attentional construct. Reflection marginally loaded on the self-related construct (.189). However, it seemed that only age (-.155) and the attentional construct (-.363) significantly predicted mind-wandering. Each of the four factors (self-related, negative, attentional and age) co-varied significantly with each other. Although rumination was suspected to be largely associated with the negative construct, by nature rumination has a self-related component. Therefore, with the aim of improving the model, rumination scores were added to the self-related construct. This change was based on modification indexes from this analysis, and in accordance with theory; by definition ruminative thoughts are self-related. This new model, presented in **Figure 5.4**, showed to have a reasonably good fit; $\chi^2(18) = 40.29$, $p = .002$, χ^2 /df = 2.24, CFI = .973, RMSEA = .064. The fit of the model was improved, and each measure loaded significantly on its construct of interest. In this new model, only the attentional (-.308) and self-related constructs (.314) predicted mind-wandering frequency, while the four factors co-varied significantly with each other.

Next, a group comparison was conducted to identify if the fit of the model differed between French and English native speakers. To do so, two models were compared: one allowing for variability between the two groups (H_1), and one restricting the loading of the four factors (self-related, negative, attentional and age) to an equal number in both populations (null hypothesis, H_0). Although the overall fit statistics show that both models are a good fit (H_1, $\chi^2(36) = 58.86$, $p = .009$, χ^2 /df = 1.63, CFI = .973, RMSEA = .046; H_0, $\chi^2(40) = 73.23$, $p = .001$, χ^2 /df = 1.83, CFI = .961, RMSEA = .052), the nested model comparison that assesses the worsening of overall fit due to imposing the four restrictions on the original model shows to be statistically significant $\chi^2(4) = 14.37$, $p = .006$. This finding suggests that the two models differ, and that the model with equal factor loadings (H_0) should be rejected in favour of the original model (H_1). Consequently, the model created here does not fit French and English native speakers equally and therefore separation is warranted.

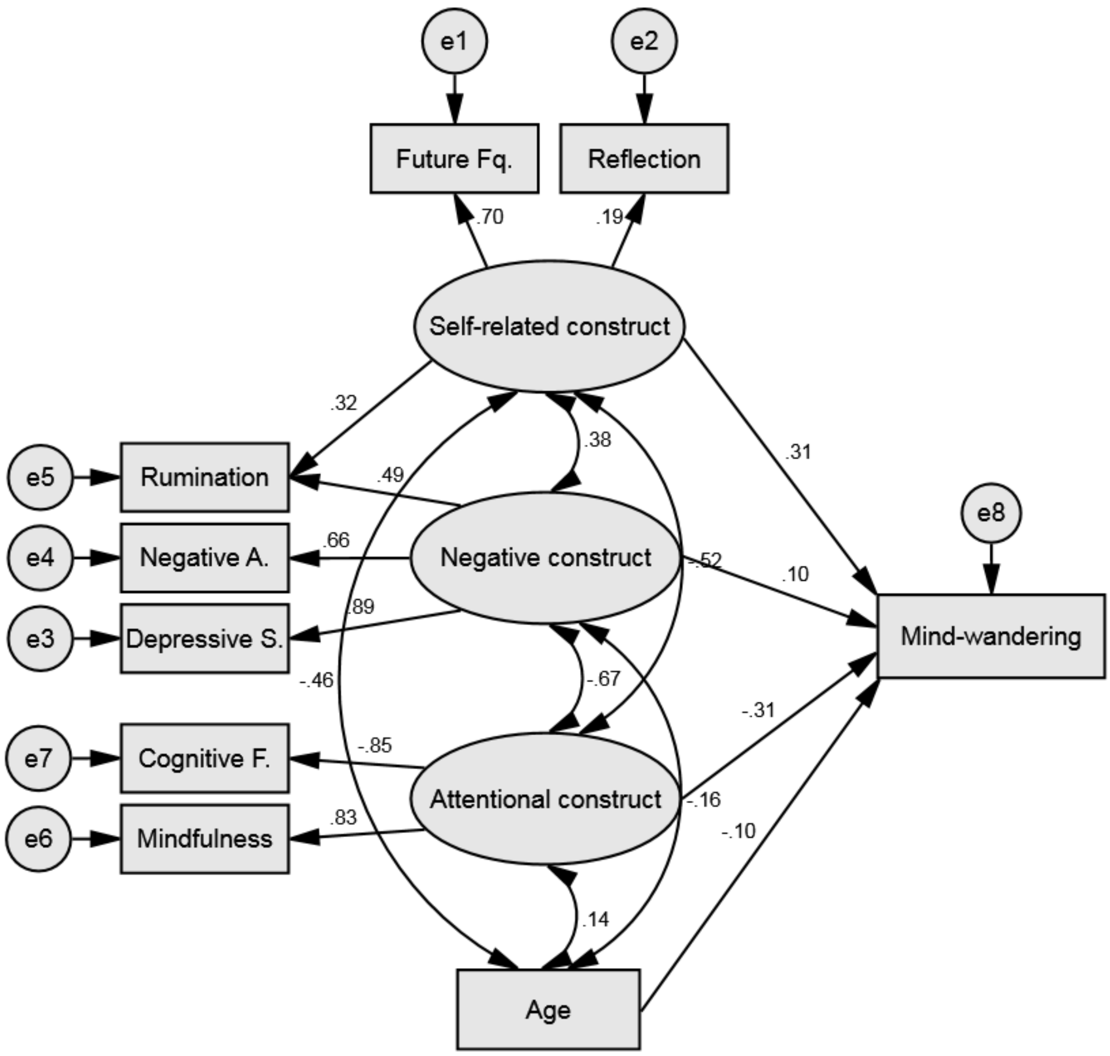


Figure 5.4. Structural equation model predicting mind-wandering frequency with self-related, negative and attentional constructs and age.

Single-headed arrows connecting latent variables (circles) and observed variable (rectangles) represent standardised path coefficients, indicating the contribution of the variables. Double-headed arrows connecting the factors represent the correlations among the factors.

Looking only at *English native speakers* the model showed to have a reasonably good fit; χ^2 (18) = 27.17, p = .076, χ^2 /df = 1.51, CFI = .980, RMSEA = .058. As shown in **Table 5.4.** the negative (.030) and attentional constructs (-.001) did not significantly contribute to mind-wandering frequency. Therefore, the model was improved by removing these two direct effects. The fit of the new model was good; χ^2 (20) = 27.19, *p* = .130, χ^2 /df = 1.36, CFI = .984, RMSEA = .048. However, the contribution of reflection was not significant (.118). Therefore, with the aim to improve further this model the measure of reflection was removed. The third model created for the English native speakers was of very good fit; $\chi^2(13) = 12.17$, $p = .514$, χ^2 /df = 0.94, CFI = 1.00, RMSEA = .000. This final model is presented in **Figure 5.5.** As can be seen, in this population only age and self-related thoughts are directly influencing mind-wandering frequency. It is worth noting that the negative (.457) and attentional constructs (-.582) significantly co-varied with the self-related construct and most likely contributed indirectly to mind-wandering frequency.

Looking only at French native speakers the model revealed to have a reasonable fit; $\chi^2(18) = 31.69$, $p = .024$, χ^2 /df = 1.76, CFI = .965, RMSEA = .071. As shown in **Table 5.4** the self-related (.068) and negative constructs (.102) did not significantly contribute to mind-wandering frequency. Therefore, the model was improved by removing these two direct effects. The fit of the new model was reasonably good; $\chi^2(20) = 33.23$, $p = .032$, χ^2 /df = 1.66, CFI = .967, RMSEA = .066. Based on modification indexes from this analysis this model was further improved by added a direct path between reflection and mind-wandering frequency. The third model created for the French native speakers was of good fit; $\chi^2(19) = 22.29$, $p = .270$, χ^2 /df = 1.17, CFI = .992, RMSEA = .034. This final model is presented in **Figure 5.5.** As can be seen, in this population it is age, attentional skills and reflection that are directly influencing mind-wandering frequency. It is worth noting that the self-related (-.352) and negative constructs (-.677) significantly co-varied with the attentional construct and most likely contributed indirectly to mind-wandering frequency. Finally, rumination scores did not significantly load onto the self-related construct (.166) yet removing it from this construct did not improve the model fit; $\chi^2(20) = 30.51$, $p = .062$, χ^2 /df = 1.53, CFI = .973, RMSEA = .059.

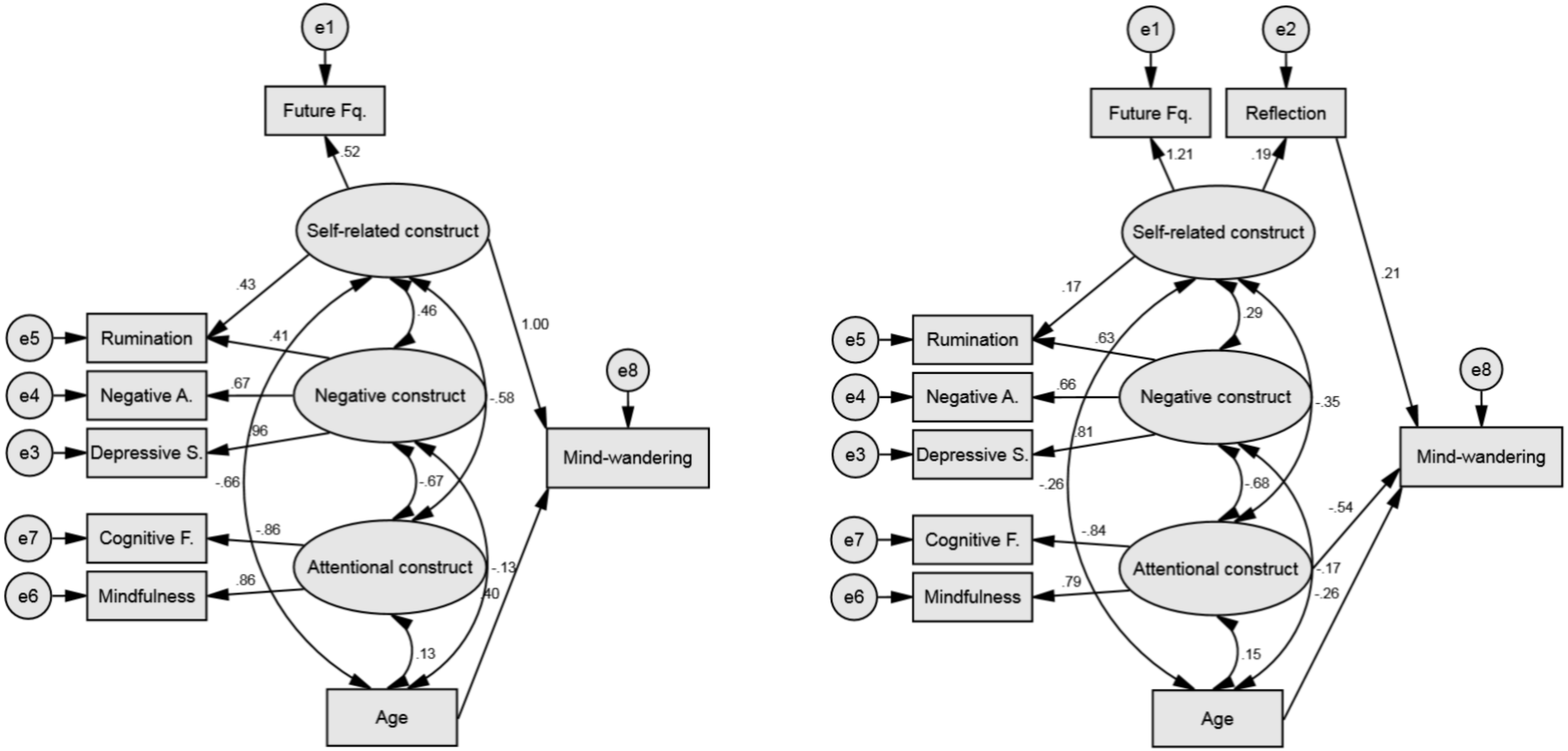


Figure 5.5. Structural equation model predicting mind-wandering frequency with different constructs in a population of native English speakers (left) and native French speakers (right).

Single-headed arrows connecting latent variables (circles) and observed variable (rectangles) represent standardised path coefficients, indicating the contribution of the variables. Double-headed arrows connecting the factors represent the correlations among the factors.

Table 5.4. Factor loading for models with data from both groups separately.

		English native speakers			French native speakers		
		Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Regression	Self-related						
	Reflection	.117	.118	-	.233	.211	.195
	Future Fq.	.528 [1]	.525 [1]	.523 [1]	1.026 [1]	1.122 [1]	1.209 [1]
	Rumination	.446 ***	.448 ***	.434 ***	.208	.184	.166
	Negative						
	Depressive S.	.959 [1]	.958 [1]	.955 [1]	.819 [1]	.810 [1]	.811 [1]
	Negative A.	.667 ***	.667 ***	.669 ***	.659 ***	.665 ***	.664 ***
	Rumination	.401 ***	.392 ***	.406 ***	.609 ***	.626 ***	.635 ***
	Attentional						
	Cognitive F.	-.860 ***	-.860 ***	-.861 ***	-.855 ***	-.845 ***	-.844 ***
	Mindfulness	.863 [1]	.862 [1]	.861 [1]	.795 [1]	.794 [1]	.794 [1]
	Mind-wandering						
	Self-related	.933 ***	.963 ***	1.00 ***	.068	-	-
	Negative	.030	-	-	.102	-	-
	Attentional	-.001	-	-	-.456 ***	-.562 ***	-.545 ***
	Age	.323	.338 *	.403 *	-.245 ***	-.267 ***	-.258 ***
	Reflection	-	-	-	-	-	.209 ***
Covariance	Self / Negative	.449 **	.467 ***	.457 ***	.330 ***	.307 ***	.288 ***
	Self / Attentional	-.592 ***	-.598 ***	-.582 ***	-.410 ***	-.385 ***	-.352 ***
	Self / Age	-.625 ***	-.626 ***	-.664 ***	-.300 ***	-.276 ***	-.257 ***
	Negative / Attentional	-.669 ***	-.670 ***	-.672 ***	-.649 ***	-.668 ***	-.677 ***
	Negative / Age	-.132	-.132	-.132	-.169 ɫ	-.170 ɫ	-.173 ɫ
	Attentional / Age	.134	.134	.134	.153	.153	.153

Note: * $p < .05$, ** $p < .01$, *** $p < .001$, ɫ $p < .07$, and [1] regression weighed at 1.

5.4. Discussion

Given the myriad of evidence demonstrating strong socio-cultural influences on cognition and behaviour, it is surprising that cultural impacts on internal trains of thought have been neglected. This study aimed to investigate the influence of culture on mind-wandering experience across different age groups, by comparing a population of English (UK) and French (France) speakers. This approach considered not only differences in the frequency of mind-wandering but critical characteristics and content that shape the occurrence of such self-generate thoughts. Overall, the data highlighted how culture drives differences in age-related declines in mind-wandering frequency. Importantly, socio-cultural experience impacted on the frequency of relatively more negative (rumination) and positive (reflection) thoughts, as well as participants' overall affective expressiveness. Finally, evidence suggests that different theoretical models, for the French and British populations, capture the complex relationships between mind-wandering and related features.

Consider first the frequently observed age-related decrease in mind-wandering frequency. Research using both self-report questionnaires (Giambra, 1989) and experience sampling in laboratory settings (Jackson & Balota, 2012) has demonstrated a reduction of mind-wandering as we age. Early explanations focussed on the cognitive capacity view of ageing to explain this counter-intuitive finding. In ageing, the capacity to direct attention and resources to the task at hand declines, resulting in a decreased ability to switch or share resources between activities and internal trains of thought. The executive failure account of mind-wandering experience (Riby, Smallwood, & Gunn, 2008; Smallwood & Schooler, 2015) suggests that one's cognitive control enables the flexible adjustment of mind-wandering events, such as reducing its occurrence in the context of a difficult task. In a similar vein, older adults' lower cognitive control may prevent them from engaging in mind-wandering experience while performing cognitive tasks. Co-ordinating multiple tasks and executive deficits of this nature have been widely reported in the ageing literature (for a meta-analysis see Riby et al., 2004). Interestingly, during ongoing tasks, if both task-related and task-unrelated thoughts are probed, older adults tend to report concerns about their performance. This task-related interference has been reported to be more dominant in older adults than young adults (e.g. McVay et al., 2013). Anxiety, worry, and monitoring of performance for older adults may demand cognitive resources to maintain performance, and further reduce the possibility of task-unrelated thoughts to emerge.

When comparing our two populations, results evidenced an earlier decrease in mind-wandering for the French speakers (36-54 years old), than for the English speakers (over 55 years old). Most research on ageing does not include this middle age group in their investigation, yet findings suggest that this period may well be subject to changes in mind-wandering rate. Early stage theories (Erikson, 1978) suggest moving from middle-age to later adulthood is a critical point in development, and many moderators of successful progression and ageing have been identified. Sociocultural context influences our roles, beliefs and values, and shapes our identity and thought processes, even when we are approaching later adulthood. Together, this suggests that individuals' sensitivity to changes at this time of life can support modifications in mind-wandering experiences. However, one must consider the nature of the items composing the DDFS. The focus is mainly made on one's general tendency to mind wander as a whole, which perhaps is not sensitive enough to capture the very nature of the different thought processes that are included under the umbrella terms of daydreaming and mind-wandering. As such, questionnaires measuring more specific type of thoughts can be highly informative.

Examination of individual differences in self-focus (rumination vs self-reflection) is particularly informative regarding the aforementioned age-related declines in mind-wandering frequency. While reflection rates seem stable across ages, rumination rates evidenced a drop in later adulthood. Rumination involves negatively oriented thought content (Nolen-Hoeksema et al., 2008), and has been associated with perceived threats, losses, or injustice to the self (Joireman, 2004), and the daydreaming style *Guilt-fear of Failure* (characterised by anguished fears, fantasies and aggression; Shrimpton et al., 2017). During early adulthood, a large number of decisions made will inevitably shape ones' future in the short and/or long term. As evidenced by the literature on the reminiscence bump, this period of life is known to be filed with key life events such as falling in love, starting a new job, and building a family (Rathbone, Moulin, & Conway, 2008). Inevitably, at the time where such important events are experienced or anticipated, one can expect greater future-related thoughts (e.g. see results on future-self thoughts; Stawarczyk et al., 2012), but also greater anguished fears, fantasies, or perceived threats to the self. Critically, these elements largely support ruminative thoughts and could explain the higher rates found in younger adults compared to older adults. This interpretation is further corroborated by younger adults' tendency to be subject to anxiety and depressive symptoms (Jorm, 2000), which are commonly associated with higher rates of rumination (Nolen-Hoeksema, 2000).

In contrast with rumination, self-reflection is defined as self-attentiveness motivated by curiosity in the self. A self-reflective thinking style enables problem-solving and promotes good mental health (Takano & Tanno, 2009; Trapnell & Campbell, 1999). Previous research has highlighted the positive nature of such thoughts with reflection associated with the *positive-constructive daydreaming* style (Shrimpton et al, 2017). Here it is suggested that the resilient features of self-reflection, such as openness to experience, self-knowledge (Trapnell & Campbell, 1999), perspective taking (Joireman, III, & Hammersla, 2002), and the ability to learn from mistakes (Joireman, 2004) are essential across all stages of life. Major self-reassessment triggered by social and personal events occur at any moment in life, whether it is choosing a career path, building a family, managing teenagers or ageing parents, or adapting to physical and cognitive changes in later adulthood (Demo, 1992; Helson & Moane, 1987; Neugarten, 1974). Therefore, it is not surprising that the therapeutic value of self-reflection is used across all ages (Appelbaum, 1973; Conte et al., 1990).

Focusing on the impact of culture, rumination rates were found to be higher for English than French native speakers, whereas the opposite pattern was evidenced for reflective rates. As previously outlined, self-reflection is of great value for openness to experience, self-knowledge, perspective taking, and the ability to learn from our mistakes. The benefits of self-reflection are in line with more general positive outcomes associated with mind-wandering including creativity, goal planning and future planning (Koestner, Lekes, Powers, & Chicoine, 2002; Smallwood et al., 2011; Verhaeghen, Joormann, & Aikman, 2014). Therefore, reflection seems particularly important in the context of positive life changes, as opposed to the relatively more negative rumination counterpart. Bearing in mind the results on mood (see discussion below), one could infer that the higher emotional expressiveness found in French speakers, may enable a larger gathering of self-knowledge throughout life; therefore, raising reflection rates. Interestingly, some features of this population illustrate this idea. For example, rates of professional reconversion elicited in France are relatively high; in 2012, a survey was conducted in France indicating that 60% of the working population declared having changed their area of work at least once (Ipsos, 2012). Among those, 55% declared that the change was by their own will and not because of dismissal, and 71% stated that this decision marked a change in their life beyond the professional aspect of things. In this context, great self-reflection skills are required, such as the ability to learn from one's mistakes, or openness to new experiences. Despite the lack of research on the impact of culture on reflection' rates, these elements suggest a concrete explanation of the French speakers' higher rates of reflection. In contrast, British citizens' propensity to be less expressive about their emotions can be interpreted as a tendency to avoid the processing of feelings. Rumination is related to more avoidance and extrinsic content of goals (Thomsen, Tønnesvang, Schnieber, & Olesen, 2011), while expressive writing interventions showed a reduction in the occurrence of ruminative thoughts in formerly depressed patients (Gortner, Rude, & Pennebaker, 2006). Together, this suggests that British citizens' tendency to overlook their feelings may foster ruminative thoughts as opposed to reflective ones.

Ultimately, the impact of culture and age on the overall rates of self-focused thoughts are in line with the previously discussed findings. Self-centred thoughts showed to be stable in the French native speakers' population, while a significant decrease occurred for English native speakers in later adulthood. Keeping in mind that French citizens self-focused thoughts are largely composed of self-reflection, and that self-reflection was evidenced as a stable feature across ages, one may consider that the unchanged rates of self-focus in this population is an expression of self-reflection foremost. Similarly, the observed decrease of self-focus thoughts for older native English speakers may be driven by the decrease of ruminative thoughts in this stage of life, and the reliance on these type of thoughts for the British population.

A further critical component influencing mind-wandering considered here is mindfulness abilities across the lifespan. This finding has been evidenced previously in the ageing literature, yet no clear interpretation of why this increase occurs has been suggested (Splevins et al., 2009). Mindfulness is defined as the ability to be focused on the present moment and often involves greater attention to detail and effective processing of stimuli in the environment. This increase in mindfulness may illustrate the age-related decrease of mind-wandering frequency and the increase of performance monitoring (i.e. Task-relevant interference; McVay et al., 2013). A somewhat simplistic view is that both concepts have been considered as opposite constructs, however numerous examples suggest that both mind-wandering and mindfulness can have benefits, as both increase creativity (Baird et al., 2012; Lebuda, Zabelina, & Karwowski, 2016). Research should further explore this apparent paradox.

Another component supporting the age-related decrease in mind-wandering frequency, is the reported reduction in the frequency of future-self thoughts with increased age. Prior research has demonstrated a decrease in future-self thought frequency as one gets older, with no age differences regarding the clarity of the thoughts (Berntsen et al., 2015; Stawarczyk et al., 2012). That is, the quality and vividness of the thoughts remain stable, merely their quantity decreases. This effect on the frequency may be due to a decrease in future perspectives as we grow old, thus inducing either fewer future-selves to think about, or a personal bias that leads to avoiding future perspectives progressively, consciously or not. From the literature the important contribution of future thinking to mind-wandering episodes is explicit (Baird et al., 2011; D'Argembeau et al., 2011; Smallwood et al., 2009). Therefore, this suggests that the reduced frequency of self-future thoughts experienced by older adults will inevitably induce a reduction of the general mind-wandering frequency.

The present study also incorporated measures of depression as well as rumination, both previously identified as important components of mind wandering. Depressive symptoms are closely associated with rumination (Austin et al., 2001; Nolen-Hoeksema, 2000), and related research has reported higher mind-wandering frequency in dysphoric patients (Smallwood et al., 2005). Results here evidenced a decrease in depressive symptoms with age, alongside the decrease of mind-wandering frequency and future thinking. This age-related decrease in depressive symptoms, which may appear counter-intuitive, has been illustrated in the literature for a "young old" population. Indeed, previous research on age differences in depression has frequently shown the "young old" (i.e. 55 to 75; Neugarten, 1974) to be less depressed than middle-aged and younger adults (Gatz & Hurwicz, 1990; Jorm, 2000). However, the "old old" adults tend to have quite high levels of depression. Here, in the older adult group, participants were above 55 years of age with an average of 64.85, therefore, fitting into the "young old" category. Altogether, findings suggest that the age-related decrease in depressive symptoms could contribute to the age-related reduction of mind-wandering episodes, along with the reduced future thinking frequency and increased mindfulness abilities. This therefore gives further insight into the relationship between depressive thoughts and mind-wandering.

Nevertheless, another element was theoretically expected to support the age-related decrease in mind-wandering frequency. Mind-wandering has long been associated with attentional deficits, thus indicating the importance to measure cognitive failures. Older adults have widely been reported to have difficulties on measures of executive control (e.g. Braver & West, 2008) but self-reported failures were not observed here. However, other studies seem to be in line with our findings. For example, a normative study did not evidence any correlations between CFQ scores (Broadbent et al., 1982) and any demographic factors, including age. An explanation is the difficulty for older adults to report their cognitive failures, or more general difficulties, in the sensitivity of the measure to capture change (especially given the data was acquired online), compared to laboratory measures of executive dysfunction. Indeed, older adults tend to claim to have remarkable worries about their cognitive abilities, but do not seem to be able to record the cognitive lapses that are known to increase in ageing (Mecacci & Righi, 2006). Additionally, data acquisition (i.e. online study) is a confounding factor that needs to be kept in mind when considering this result, as it may have induced a selective bias.

Limited work has been carried out on the individual differences in thought processes across French and English speakers. Therefore, precise predictions regarding the impact of the emotionality of thought content are difficult to generate. Overall, English speakers showed less extreme positive and negative emotions than their French counterparts. Although investigations of cultural differences in emotional expressiveness are rare, lay observations of beliefs and behaviours of French and British citizens suggest cultural differences in the expression of their emotions. British citizens have an intriguing relationship with their own and other people's emotions; they tend not to be overly demonstrative and look down on gushing public displays of emotion (Smallwood, Fitzgerald, Miles, & Phillips, 2009; Khor & March, 2007). This tendency to hide their feelings is in sharp opposition to French citizens. As an illustration, French citizens show high propensities to express their feelings toward the government, through demonstrations and strikes. A survey conducted between 2009 and 2013 revealed that France had the second highest rate of strikes, among 12 European countries, while the UK was in the 9th position (Osborne, 2016). Those drastically different approaches to self-expression are in line with work on the *Déjà vu* experience. Fortier & Moulin (2015) report French citizens' tendency to describe their experience of '*Déjà vu'* as more disturbing than English citizens. This corroborates the idea of wider self-expression from this population. Nevertheless, those elements of explanation are exploratory, and further scientific investigations should be conducted in order to clarify this finding.

Finally, confirmatory factor analyses were carried out to provide an overview of the complex relationships between the key features of mind-wandering experiences. Our theoretical model hypothesised that the combination of the negative construct (i.e. rumination, depressive symptoms and negative affect), the self-related construct (i.e. future-self thought frequency, self-reflection and rumination), the attentional construct (i.e. mindfulness abilities and cognitive failures), and age would drive the variation of mind-wandering frequency. Within this model mind-wandering frequency is portrayed as an umbrella phenomenon that integrates a multitude of features. Notably, age was found to have a limited contribution to mind-wandering frequemcy, which is surprising considering the well documented age-related decrease of mind-wandering (Giambra, 1989; Jackson & Balota, 2012; Jackson et al., 2013; McVay et al., 2013). However, the factor of age was highly connected to the self-related construct, a factor composed of two measures known to decrease with age (i.e. rumination and future-self thoughts). In addition to age, the negative construct also presented limited contribution to mind-wandering variation in frequency. Evidence has clearly outlined the relationship between mind-wandering and negative affect (Poerio et al., 2013), and depression or related symptoms like rumination (Smallwood et al., 2005). Research suggests that these negative features are largely found for past related thoughts (Smallwood & O'Connor, 2011), while future-related thoughts show positive outcomes, such as improved mood and reduction of stress (Engert et al., 2014; Ruby, Smallwood, Engen, et al., 2013). Critically, mind-wandering experiences have been described as largely future-oriented (Baird et al., 2011). Therefore, the limited contribution of the negative construct may reflect the smaller propensity of negatively oriented and past-related thoughts. Additionally, a strong relationship was evident between the negative and attentional construct, suggesting that part of the negative construct's contribution was driven by attentional lapses. Lastly, despite the reasonably good fit of the model to the data, further statistical analyses demonstrated a different fit for both English and French native speakers.

Considering both groups separately, for the English native speakers mind-wandering frequency largely relied on the self-related construct with no direct influence from the attentional construct, while the opposite pattern was demonstrated for the French native speakers. These two constructs are shown to be highly related to each other in both models. However, in the British model, the self-related construct was composed of ruminative and future-self thoughts, while it was mainly future-self thoughts in the French model. Here it is suggested that the contribution of the self-related construct in the British population is driven by their higher rates of ruminative thoughts. Despite no cultural difference outlined on the attentional measures (i.e. mindfulness and cognitive failures), the influence of this construct was significant for the French model. Research clearly states the importance of executive control to flexibly manage ones' thoughts (Smallwood & Schooler, 2015). This raises questions as to why the attentional characteristics are not central to mind-wandering frequency in the British population. One avenue to consider is the possibility of an indirect effect, where the attentional construct contributes to mind-wandering frequency via its strong relationship with the self-related construct. Subsequently, the factoring of self-reflection into the self-related construct for the British population was in agreement with the previously discussed cultural differences on self-centred thoughts. However, in the French population, where reflection rates are high, this measure contributed to the self-related construct and mind-wandering frequency directly. Ultimately, together, these findings demonstrate an influence of culture on the complex experience of mind-wandering.

Nevertheless, some limitations must be taken into account when interpreting these findings. Firstly, conducting an online survey most certainly influenced the characteristics of the population recruited. This is especially true for older adults, as not all of the ageing population have access to internet or are comfortable with the use of electronic devices. Additionally, it provoked an unbalanced distribution of participants across age groups. Secondly, it is difficult to know if the findings differentiating French from English native speakers can be attributed to a cultural difference or merely a language effect via the interpretation of the questionnaires. Indeed, even if back-translation of questionnaires is commonly used, it does not guarantee equivalence across two languages: one word in Language A may correspond to multiple words with slightly different connotations in Language B. For example, a neutral word in English, when translated into French can have a slightly negative connotation, and therefore would induce differences in participants' report. Nevertheless, correlations of similar weight are found between questionnaires for each population. For example, depressive symptoms, which were not influenced by culture, correlated positively, at the same extent for both group, with rumination rates (r = .58 and r = .55), with negative affects (r = .64 and r = .54), and mind-wandering (r = .39 and r = .43), which all varied depending on cultural affiliation. Additionally, a study controlling for the language of testing evidenced cultural differences between European American and Chinese (Ji, Zhang, & Nisbett, 2004). They stressed that the cultural effect was bigger when language was not taken into account, meaning that language of testing does modulate results, but it does not mediate them. Therefore, even though the language of testing may lead to changes in responses, such changes occurred in a limited range and did not necessarily threaten the conclusion pertaining to cultural comparisons.

In conclusion, findings from this study clearly evidence cultural differences between English and French speakers, and most importantly they seem to impact one's experience of mind-wandering significantly. Those results also gave a warning toward overgeneralization of findings. Indeed, if mind-wandering is experienced in every culture, supported by shared cognitive processes, the experience in itself may be different, as highlighted by the findings. Firstly, mind-wandering frequency decreased at an earlier age for French speakers. Then, rumination and reflection rates were different in both populations, and exerted different age-patterns. Finally, French speakers showed heightened mood as compared to English speakers. Therefore, results stress the importance of considering and measuring cultural affiliations during participants' recruitment as it can modulate the findings. Ultimately, considering these results along with the previous findings from Chapter 3 and Chapter 4, it demonstrates that the nature of mind-wandering experiences is a key element to be investigated in the ageing population. Having explored these experiences in two lab-based studies and in one large-scale questionnaire-based study, Chapter 6 considers the experimental manipulation of such thoughts using meditation training.

Chapter 6. The implications of meta-awareness and meditation.

In this final empirical chapter, the variability of self-generated thoughts in ageing will be further investigated. Having previously considered the neurocognitive profile of older adults and the implication of individual differences such as cultural affiliation, this chapter will investigate regulation processes involved in self-generated thoughts. This chapter will focus on the implication of meta-awareness and meditation practice on thought content. In the first experiment, the use of probe and self-caught methods will enable the identification of thought patterns that are more likely to reach meta-awareness in young and older adults. In a second experiment (a pilot), thought content in young and older adults will be experimentally modulated by the practice of meditation. Results demonstrated that individuals are merely aware of temporal thoughts but not task-related interferences. The time course over which thoughts are generated was suggested as a critical feature underlying this selectivity in thought control. Results also confirmed the malleability of thought content following a 4-week intervention in both young and older adults. This provides encouraging evidence for the development of interventions aimed at patients with pathological mind-wandering experiences.

6.1. Introduction

Previous investigation from this thesis, in line with the literature on spontaneous cognition and memory, clearly suggests that age-related changes in self-generated thoughts are not limited to a decreased frequency, but also include changes in thought content. While Chapter 3 and Chapter 4 outlined older adults' tendency toward deliberate on-task and visual thoughts, Chapter 5 demonstrated the importance of thought content in the age-related decrease of mind-wandering frequency. However, the influence of meta-awareness of mind-wandering experiences seemed to have been overlooked. Meta-awareness refers to one's awareness of the content and process of consciousness (Dahl, Lutz, & Davidson, 2015), which is significantly increased by the practice of meditation (Mrazek, Franklin, Phillips, Baird, & Schooler, 2013). Critically, meta-awareness of mind-wandering is the key element enabling the flexible adjustment of their occurrence and potentially content. This chapter will aim to address this gap in the literature by documenting thought content in ageing with the consideration of both meta-awareness (experiment 1) and meditation practice (experiment 2).

Typically, investigation of meta-awareness in mind-wandering consists of the combination of two experience sampling methods. Research aiming to characterise thought content largely uses the probe-caught method. This method provides an overview of the self-generated thought processes that occur during a task without relying on participants' meta-awareness (see Chapter 2 for description of the probe-caught method). Therefore, experiences of task focus, mind-wandering with awareness, or mind-wandering without awareness are collected (Smallwood & Schooler, 2006, 2015). Alternatively, the self-caught method provides sampling of only mind-wandering episodes that reached meta-awareness (see Chapter 2 for description). Thus, the combination of both methods enables the differentiation between mind-wandering experience with and without awareness. Such methodology showed that alcohol intoxication (Sayette et al., 2009) and cigarette craving (Sayette et al., 2010) tend to increase the probability of mind-wandering experiences (probe-caught), while decreasing the probability of noticing them (self-caught). Other research has found similar findings in people who wanted to reunite with a former romantic partner (Baird, Smallwood, Fishman, Mrazek, & Schooler, 2013).

However, a question that remains unanswered is whether certain types of thoughts are more likely to be noticed than others. Meta-awareness of self-generated thoughts is essential as it later leads to the suppression or perseveration of the experience (Allen et al., 2013). Identification of the differences in thought control depending on thought content could inform further the regulation process account of mind-wandering (Smallwood & Schooler, 2015). Importantly, older adults tend to not always use their monitoring skills efficiently (Hertzog & Hultsch, 2000). Therefore, investigating mind-wandering meta-awareness in this population should be informative. To address this gap in the literature, the first experiment will measure thought patterns in young and older adult groups, using a multi-dimensional experience sampling method (MDES; Karapanagiotidis et al., 2017; Smallwood et al., 2016), with a probe and self-caught method to differentiate self-generated thoughts with and without awareness.

Evidence suggests that mindfulness meditation increases awareness of mind-wandering states and leads to reductions of such experiences (Mrazek, Franklin, Phillips, Baird, & Schooler, 2013). Mindfulness-based meditation consists of being attentive to the present moment and to self-regulate attention in a non-judgmental way (Lutz, Slagter, Dunne, & Davidson, 2008; Kabat-Zinn, 1990). Its practice increases one's ability to be aware of the external environment, the bodily sensations, and the ongoing train of thoughts; resulting in an increase of self-knowledge and the power to transform one's behaviour (Vago & Silbersweig, 2012). Accordingly, interventions as short as 8 minutes have proven effective at reducing mind-wandering experiences (Mrazek, Smallwood, & Schooler, 2012). However, research on the effect of mindfulness meditation on thought content is limited. One study found a reduction of unpleasant thoughts and an increase of pleasant thoughts after a 9-weeks compassion mindfulness-based mediation (Jazaieri et al., 2016). Nevertheless, this promising finding comes with limitations as no control group was used. Additionally, to the best of my knowledge, this is the only study investigating the influence of meditation on thought content. Therefore, a second experiment, framed as a pilot study, will further document the effects of compassion mindfulness-based meditation on mind-wandering experiences and extend it to the ageing population.

Overall, the aim of this chapter is to further study thought content in ageing, while considering the implication of meta-awareness and meditation practice. The first experiment will target the identification of thought patterns that are more likely to reach meta-awareness in young and older adults. The second experiment (a pilot) will investigate the impact of compassion mindfulness-based meditation on thought frequency and content in young and older adults. In both cases, it is essential that a wide and representative sample of mind-wandering episodes be collected for older adults; however achieving this can be difficult because of the age-related decreases of mind-wandering experiences. Therefore, methodological adjustments are required to encourage self-generated thoughts. Research often reports the strong influence that a task has on mind-wandering rates (see Chapter 1). For example, tasks' difficulty or variability tend to increase participants' focus and reduce mind-wandering experience (Faber et al., 2018; McVay & Kane, 2012). The task previously used in this thesis alternates between an easy 0-back condition, where thoughts can proliferate, and a hard 1-back condition, where more focus is required (Konishi et al., 2015). Therefore, in order to promote mind-wandering experiences, only the easy 0-back condition will be used, which will reduce both task difficulty and variability (i.e. no switching between two conditions). Then, multi-dimensional experience sampling (MDES) will be used to capture the complexity of self-generated thoughts (Karapanagiotidis et al., 2017; Smallwood et al., 2016).

6.2. Experiment 1

6.2.1. Aims and objectives

The objectives of the first experiment are to document thought content in the context of meta-awareness and ageing. An undemanding task will be used to foster mind-wandering experiences, particularly in the older adult group. Multidimensional experience sampling will be carried out with probe-caught and self-caught methods separately. Previous research using MDES in probe-caught methods found that older adults experience more focused and visual thoughts than young adults did, with no difference on mental time travelling (Chapter 3 and Chapter 4). Similar findings are expected in this study. Nevertheless, considering the significant change applied to the task (i.e. suppression of the hard condition), different types of thoughts could emerge. For example, a distinction between future-self and past-social thoughts may occur (this dichotomy is often found in young adults; Baird et al., 2011; D'Argembeau et al., 2011; Smallwood, Nind, et al., 2009; Stawarczyk, Cassol, et al., 2013). Some research suggests that older adults experience fewer future-oriented thoughts and past-oriented thoughts compared to young adults. However a consensus has not been reached (Berntsen & Rubin, 2002; Berntsen et al., 2015; Jackson et al., 2013; Rendell et al., 2012; Schlagman, Schulz, & Kvavilashvili, 2006). Additionally, task simplification may uncover a-temporal thoughts and task-related interference. A-temporal thoughts relate to imaginative thoughts that cannot be specifically attributed to either the past or the future (e.g. "I need groceries"). A-temporal thoughts tend to increase in ageing, particularly when compared to future-related thoughts (Jackson et al., 2013; Rendell et al., 2012). Task-related interference (TRI) (McVay et al., 2013; Smallwood et al., 2004) on the other hand, refers to thoughts related to task performance, strategies, or time duration (e.g. "This task is boring", "I am good at this", "When is this going to end?"). Older adults experience significantly more TRI than young adults (McVay et al., 2013). No research has directly compared thought content as measured using a probe-caught and self-caught method on the effect of meta-awareness. Therefore, this part of the investigation will be exploratory. Nevertheless, it is suspected that typically occurring thoughts, such as future and past-related thoughts, will come to awareness more often than abstract thoughts.

6.2.2. Method

6.2.2.1. Participants

A sample of 36 young adults (*M* = 21.94, *SD* = 4.49) and 38 older adults (*M* = 69.42, *SD* = 7.42) were recruited for this study. The young adults' mean years of education was 15.71 (*SD* = 2.63) and the group was 80.55% composed of females. Older adults on average had 16.20 (*SD* = 4.13) years of education and 63.16% were female. Participants received either course credits or gift vouchers in compensation for their time and travel. Inclusion criteria were to be native English speaker and to have normal or corrected vision and hearing. Exclusion criteria were the presence or history of a neurological or psychiatric disorder, currently taking antidepressants, and regular practice of meditation, Tai-chi, or Yoga in the past 3 years. Older participants completed the Mini-Mental State Examination (MMSE, Folstein et al., 1975) to ensure that they did not have dementia or mild cognitive impairment (threshold: score ≥ 26/30; *M* = 28.63, *SD* = 1.28). This study was approved by the Ethics Committee of the Faculty of Health and Life Sciences of Northumbria University. The investigation was conducted according to the principles expressed in the Declaration of Helsinki and participants provided written informed consent.

6.2.2.2. Procedure

Participants were seen for a minimum of one hour and thirty minutes to two hours in the laboratory. At the beginning of the session, all participants gave informed consent, which was followed by a set of demographic questions. Older adults also completed the MMSE (Folstein et al., 1975). Participants were then asked to complete a 0-Back task adapted from Konishi et al. (2015), lasting approximately 30 minutes. The task was completed once with a probe-caught sampling method and once with a self-caught sampling method, the order of the presentation of the tasks was randomised. All participants completed a practice of the task beforehand. Finally, participants completed a set of 10 questionnaires (these will be described in the second experiment below).

6.2.2.3. The n-back working memory task

The task used in the present study followed the same procedure as the one used in Chapter 3 and Chapter 4, however, only the 0-back condition was used (see **Figure 6.1**). For further details please refer to the method section of Chapter 3 and Chapter 4. The same task was used in the probe-caught and the self-caught method.

To sample participants' ongoing experience, a Multi-Dimensional Experience Sampling method was used (Smallwood et al., 2016). Participants repeatedly answered 13 questions using a four-point Likert scale from 1 (*Not at all*) to 4 (*Completely*). Please refer to Chapter 3 for more details about the questions. In the probe-caught method, an average of 19.39 (*SD* = 1.60) probes were presented. In the self-caught method, participants were asked to carefully monitor their thoughts during the task and to press the 'p' key every time they realised that their mind was wandering. When pressing the 'p' key the same 13 questions were automatically presented on the screen. On average participants pressed the 'p' key 8.91 times (*SD* = 8.12). In both conditions, the task was set to last 15 minutes, excluding the time taken to answer the questions. The full completion of each task varied between 20 and 30 minutes. Importantly, a number of participants, namely one young adult and 10 older adults, have not reported any mind-wandering experiences in the self-caught condition. Therefore, these participants were not included in the following analyses.

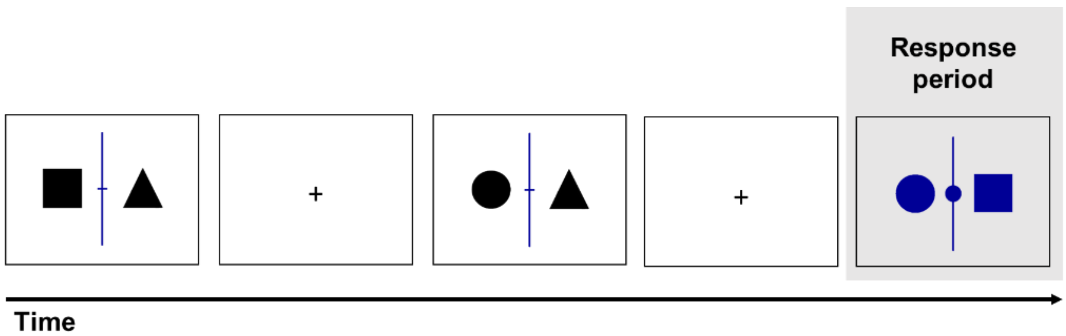


Figure 6.1. Illustration of the 0-Back task used.

6.2.3. Results

To analyse the MDES, the set of questions was decomposed using principal component analysis (PCA), applying varimax rotation. This allowed the core patterns of variance within the self-reported data to be characterized in a smaller set of underlying dimensions. Three factor solutions were selected with eigenvalues > 1 and the loadings that describe these dimensions are presented in the form of a heat map in **Figure 6.2**: Component One – *Task-Related Interference* - with high weighting indicating thoughts that were deliberate, detailed, evolving, habitual, vivid, and in the form of images, accounting for 22.59% of the variance. Component Two – *Past-Oriented Thoughts* - with high weighting indicating negatively toned thoughts relating to other people, the past, and presenting low task focus, accounting for 15.10% of the variance. Component Three – *Future-Oriented Thoughts* - with high weighting reflecting thoughts that were in the form of words and about the self and the future, accounting for 10.26% of the overall variance.

In order to identify the influence of age and method of experience sampling on these three PCA components, 2 (Age; *Young, Old*) by 2 (Measure; *Probe-caught, Self-caught*) mixed ANOVAs were conducted on participants' mean regression scores for each factor. Results on **Task-Related Interferences** revealed a main effect of age, showing that older adults (M = .23, SD = .84) experienced more TRIs than young adults (M = -.19, SD = .56), F (1, 61) = 13.41, p < .001, η_p^2 = .18. Results demonstrated a main effect of the type of measure, showing that thoughts captured using the probe-caught method (M = .17, SD = .82) were more often TRI than the ones captured using the self-caught method (M = -.01, SD = .53), F (1, 61) = 10.16, p = .002, η_p^2 = .14. Additionally, an interaction effect, illustrated in **Figure 6.2**, was found between age and the type of measure [F (1, 61) = 26.41, p < .001, η_p^2 = .30]. Further analyses showed that older adults (M = .33, SD = .93) experienced more TRI than young adults did (M = -.24, SD = .62) when measured by a probe-caught method [F (1, 72) = 9.73, p = .003, η_p^2 = .12], but not when measured by a self-caught method [F (1, 61) = 1.57, p = .215, η_p^2 = .03]. Additionally, the type of measure only had an effect in the older adult group, with more TRI when captured by the probe-caught method (M = .65, SD = .81) than by the self-caught method (M = .08, SD = .54), F (1, 27) = 21.96, p < .001, η_p^2 = .45.

Results on the **Past** oriented thoughts revealed a main effect of age, showing that older adults (M = -.53, SD = .47) experienced less past related thoughts than young adults (M = .35, SD = .53), F (1, 61) = 34.81, p < .001, η_p^2 = .36. Additionally, results demonstrated a main effect of measures, showing that thoughts captured via the probe-caught method (M = -.17, SD = .68) were less past related than the ones captured via the self-caught method (M = .42, SD = .60), F (1, 61) = 68.22, p < .001, η_p^2 = .53. However, the interaction effect between age and the type of measure was only marginally significant [F (1, 61) = 3.73, p = .058, η_p^2 = .06].

Results for the **Future** oriented thoughts revealed no effects of age on this type of thoughts, F (1, 61) = .033, p = .856, η_p^2 = .00. A main effect of measures showed that thoughts captured via the probe-caught method (M = -.09, SD = .63) were less future related than the ones captured via the self-caught method (M = .24, SD = .77), F (1, 61) = 15.44, p < .001, η_p^2 = .20. Results evidenced an interaction effect, illustrated in **Figure 6.2**, between age and the type of measure, F (1, 61) = 8.80, p = .004, η_p^2 = .13. Further analyses showed that, in the case of older adults, thoughts collected via the probe-caught method (M = -.25, SD = .70) were less future related than thoughts collected via the self-caught method (M = .37, SD = .86), F (1, 27) = 17.16, p < .001, η_p^2 = .39. However, this difference was not evident in the group of young adults, F (1, 34) = .650, p = .426, η_p^2 = .02.

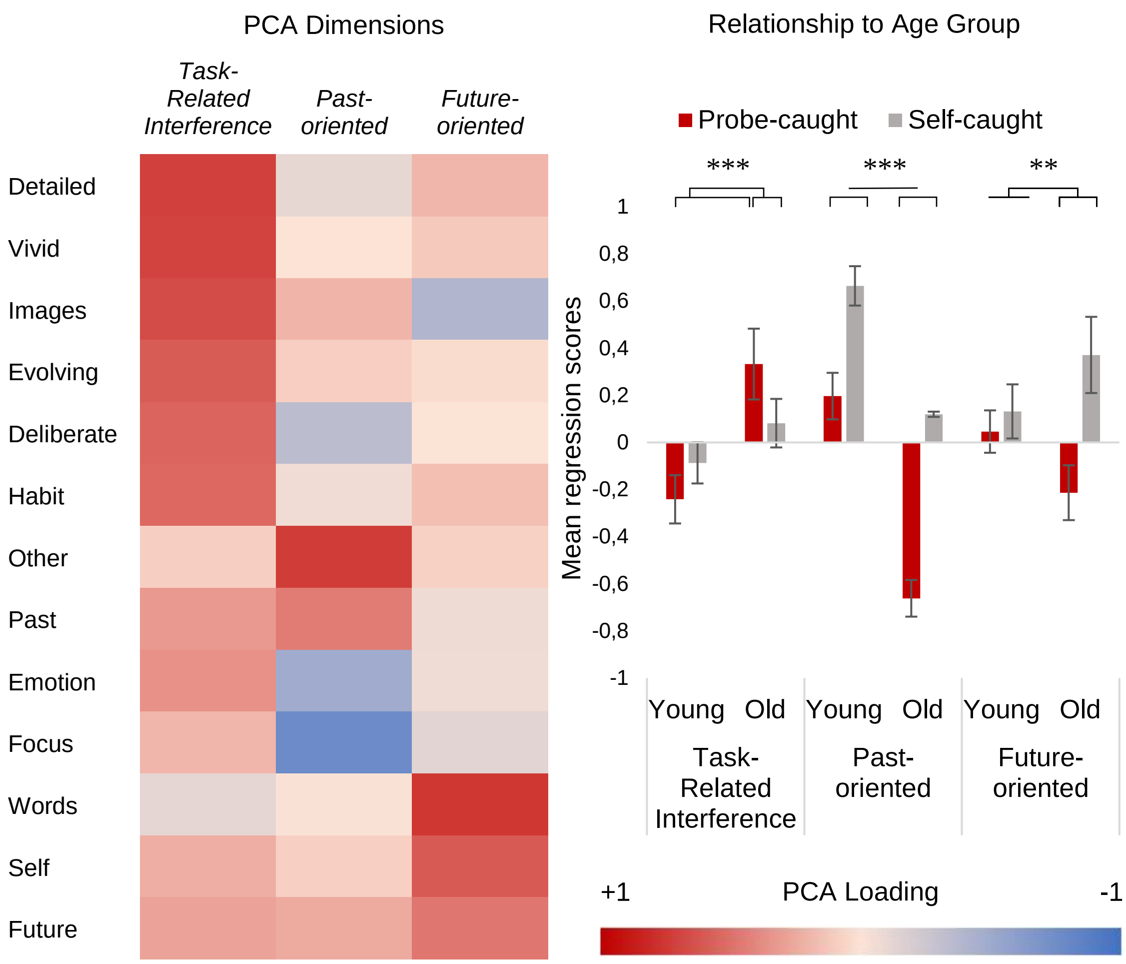


Figure 6.2. Determining different type of self-generated thoughts and their occurrence depending of the task condition and the age group.

(*Left*) Heat map illustrating the loading of the different questions on the three factors resulting from the principal component analyses (PCA). Varimax rotation was applied to the data set. (*Right*) The effects of interaction between Age (*Young, Old*) and Task measures (*Probe-caught, Self-caught*) on mean regression scores for Task-Related Interferences and Social Past thoughts. *Note*. *** p <.001 and ** p <.01; Error bars are Standard Errors.

6.2.4. Discussion

Meta-awareness is essential to the regulation of self-generated thoughts, as one needs to notice mind drift before inhibiting it. However, limited work has documented the effects of meta-awareness on thought content in young and older adults. This experiment specifically aimed to address this gap in the literature by collecting a wide sample of self-generated thoughts among young and older adults with a self and probe-caught method. Three types of self-generated thoughts were reported, namely task-related interference, past-oriented, and future-oriented thoughts. These three type of thoughts have been previously described within younger adults (Baird et al., 2011; D'Argembeau et al., 2011; McVay et al., 2013; Mooneyham & Schooler, 2013; Smallwood, Nind, et al., 2009; Stawarczyk, Cassol, et al., 2013). In the present experiment, effects of age were reported with a decrease of past-oriented thoughts and an increase of task-related interferences (TRIs). Effects of methodology outlined fewer TRIs, and more future and past-oriented thoughts in the self-caught than the probe-caught method. The effect of measure for TRI and future-oriented thoughts was particularly evident for older adults.

The use of a simplistic task enabled the distinction between past and future-oriented thoughts, which was not found in Chapter 3 and Chapter 4. A large body of research has documented these two types of thoughts separately (Baird et al., 2011; D'Argembeau et al., 2011; Smallwood, Nind, et al., 2009; Stawarczyk, Cassol, et al., 2013). Past-oriented thoughts are mainly described as being social and negative (Baird et al., 2011; Poerio et al., 2013; Ruby, Smallwood, Engen, et al., 2013; Smallwood & O'Connor, 2011; Stawarczyk, Majerus, & D'Argembeau, 2013). This was replicated in the present study, and extended by demonstrating their off-task nature, which is in line with the literature showing increased task-disengagement and errors following negative thoughts (Banks et al., 2016). Characteristics of the future-oriented thoughts outlined in the present study are also in line with previous literature with strong self-referential and verbal features (Baird et al., 2011; Stawarczyk, Cassol, et al., 2013). This is thought to reflect the autobiographical planning function of future thoughts (Baird et al., 2011; Stawarczyk, Majerus, Maj, et al., 2011).

Considering now the effect of age on these thoughts, results demonstrated a decrease of past-related, but not future-related thoughts with age. Both the mind-wandering and the voluntary autobiographical memory literature report a reduction in past-related thoughts in ageing (Berntsen & Rubin, 2002; Jackson et al., 2013; Schlagman et al., 2006). An argument for this is that older adults have a bias toward task focus and positive thoughts (Charles & Carstensen, 2010; Charles & Luong, 2013), preventing them from experiencing past-oriented thoughts which tend to be negative and off-task (Jackson et al., 2013). There is however some disagreement with this view since one study found no age-related difference in involuntary autobiographical memory using dispositional measures (Berntsen et al., 2015).

Regarding future-related thoughts, the present findings seem to contradict previous work. While retrospective reports and laboratory studies present an age-related decrease of future thinking (Berntsen et al., 2015; Stawarczyk et al., 2012), a diary study reported an increase of such thoughts in this population (Gardner & Ascoli, 2015). However, in the present study no age effect was reported on these thoughts. Rates of future-oriented thoughts were also influenced by methodological settings. Specifically, older adults reported more future-related thoughts when they had to monitor their thoughts, than when they had to recall their experience from few seconds before. Older adults have relatively well preserved metacognitive and monitoring abilities (Hertzog & Hultsch, 2000), but their recollection skills are impaired (Brewer, Marsh, Meeks, Clark-Foos, & Hicks, 2010; Sacher, Taconnat, Souchay, & Isingrini, 2009; Souchay, Moulin, Clarys, Taconnat, & Isingrini, 2007). The nature of the self-caught method (i.e. participants are asked to monitor their thoughts throughout the task) may foster this meta-cognitive skill and increase older adults' awareness of ongoing thought.

On the other hand, the probe-caught method relies on the recollection of previously experienced thoughts, and older adults may fail to adequately recall their experiences. Thus, their known difficulties in episodic remembering in the laboratory and real world settings impacts thoughts explored using this paradigm. Another interpretation involves taking into account the time needed and allocated to the generation of mind-wandering experiences. Older adults present a reduced processing speed (Salthouse, 1996) and previous chapters have documented how older adults' brain structure may jeopardise their ability to self-generate thoughts. As such, the construction of complex mind-wandering episodes may be more difficult and time consuming for this population. That is, results may be explained by the interrupting nature of the probe-caught method which compromises the construction of complex mind-wandering experiences (i.e. prompts tend to redirect attention to the task). In contrast, the self-caught methods leave older adults with sufficient time to fully create a mind-wandering experience. This implies that meta-awareness only occurs once a mind-wandering episode is entirely generated. Future work could use the temporal precision of the electroencephalogram to distinguish between these interpretations.

Task-related interferences have been identified as a third type of thought occurring during an undemanding task. In accordance with previous work (McVay et al., 2013), the present study demonstrated an age-related increase in TRIs. More specifically, older adults presented more TRIs than young adults in the probe-caught condition. Additionally, the effect of measure was only evident for older adults, with more TRIs in the probe compared to self-caught condition. Before going into the interpretation of these findings, arguments for the categorisation of this component as TRIs and not a-temporal thoughts should be made. TRIs are preoccupations about one's performance or strategies (e.g. "When is this going to end?", "I am good at this", Counting or naming the shapes), they are described as task-related while not being task-focused (McVay et al., 2013; Smallwood et al., 2004). Therefore, it is likely that TRIs will be more vivid, detailed, and habitual than future or past-related thoughts. Such phenomenological concordances were not found with a-temporal thoughts. A-temporal thoughts are imaginative but without any temporal direction (e.g. "I need groceries"; Jackson et al., 2013; Rendell et al., 2012). Therefore, similarities regarding evolving and deliberate features are expected between a-temporal and mental time travelling thoughts. It is expected that a-temporal thoughts will be less vivid and visual than past-oriented thoughts (Jackson et al., 2013; Rendell et al., 2012), and less habitual and detailed than future-oriented thoughts (Stawarczyk, Cassol, et al., 2013), which was not found here. Together, these findings support the categorisation of this component as TRIs. However, the possibility of external distractions (EDs) such as sensory perceptions/sensations irrelevant to the current task cannot be excluded (e.g. “I am cold”, “The kids outside are noisy”; Stawarczyk, Majerus, Maj, et al., 2011). Unfortunately, no study has yet investigated the phenomenal characteristics of either TRIs, EDs, or a-temporal thoughts to support this inference. Therefore, interpretation about this type of thought should be considered with caution.

Previous work has demonstrated an increase of TRIs in ageing (McVay et al., 2013). The present study reported this effect only within the probe-caught method. Previously in this discussion, it was suggested that time may be essential to the generation of complex mind-wandering experiences (i.e. future-oriented thoughts). Hence, as attentional decoupling occurs, early mind drifts could transform and produce more complex and typical mind-wandering experiences (i.e. future-oriented thoughts). Older adults present slowed cognitive processes, meaning that, for them, more time is necessary to construct complex mind-wandering experiences. As a result, they may spend more time in a state of initial mind drifts where attention is partially related to the task while not really focused on the processing of information. If TRIs are representative of such early mind drifts, it is therefore evident that the interrupting nature of the probe-caught method will increase their frequency in a population with slower cognitive processes, namely older adults. Hence, it would appear that one is more aware of fully constructed thoughts than earlier mind drifts. Another interpretation is that TRIs are not considered as mind drifts by participants, and therefore not reported in the self-caught condition. Elsewhere, older adults’ higher rates of TRI in probe-caught methods have been interpreted as the result of changes in personal concerns. Older adults may be concerned about their performance (e.g. stereotype threat; Jordano & Touron, 2017) and young adults about their daily life (e.g. McVay & Kane, 2009, 2010). Thus, resulting in a switch of self-generated thoughts from future-oriented thoughts for young adults and TRIs for older adults.

Overall, this first experiment has replicated previous findings in ageing and has evidenced the influence of methodology. This study reported that thoughts gaining consciousness are merely temporal as opposed to task-related interferences. Critically, the time course of thought generation has been outlined as an important feature to understand the regulation process of self-generated thoughts. Following these results, a second experiment will experimentally modulate thought content using meditation practice, and therefore further explore the regulation processes.

6.3. Experiment 2

6.3.1. Aims and objectives

This second experiment aims to experimentally modulate the occurrence of specific self-generated thoughts. According to the literature, the use of a compassion mindfulness-based meditation training appears to be a promising avenue (Jazaieri et al., 2013, 2016). However, mindfulness-meditation intervention studies have raised some methodological issues (Davidson & Kaszniak, 2015). Firstly, the nature of the intervention used is often insufficiently described. Mindfulness-based meditation comprises a panel of practices (e.g. breath focus, body scan), and sometimes includes compassionate features. Critically, it was found that different approaches of mindfulness meditation induce different effects on various measures (Chiesa et al., 2011; Goyal et al., 2014). In the present study, a body scan mindfulness-based meditation will be used. Additionally, considering previous findings from compassion-based meditation on thought content, compassion features will be added to the body scan to emphasise the importance of approaching mind drifts with love and kindness.

The intervention will last 4 weeks. While previous research showed effects on thought content after 9 weeks (Jazaieri et al., 2016), others found effects on mind-wandering rates after only 8 minutes of mindfulness meditation (Mrazek et al., 2012). A compromise of 4-weeks was chosen to minimise the number of dropouts and maximise the effect of the intervention.

Another common methodological issue is the lack of active control conditions. While some studies use waiting lists, others only use baseline measures to identify intervention effects (Davidson & Kaszniak, 2015). The lack of active controls prevents researchers from differentiating effects attributable to the mindfulness intervention and the ones attributable to the regular practice of any activity. Therefore, this study will use an active control condition, where participants will listen to audio-recorded books. Finally, a central issue to mindfulness intervention studies is the impossibility of achieving double blindness, as participants are inevitably aware of the mindful nature of the intervention. In an attempt to minimise this issue, both conditions were advertised as valid interventions, one targeting attention (i.e. meditation condition) and the other targeting memory (i.e. control condition). Thus, participants in the control condition should display expectations for the intervention comparable to participants in the meditation condition. This, and the credibility and appreciation of the intervention, will be assessed at the end to provide a subjective measure of participants' overall experience.

It is hypothesised that following the meditation intervention participants will be more task focused (Mrazek et al., 2012). This effect may not be found in older adults considering their already high attentive state to task performance. Regarding thought content, a reduction of negative and therefore past-related thoughts is expected in both age groups (Jazaieri et al., 2016). However, at present there is a dearth of literature regarding other types of self-generated thoughts, thus this part of the analyses will be exploratory in nature.

6.3.2. Method

6.3.2.1. Participants

A subset of the participants from Experiment 1 have taken part in this second experiment. One of the major difficulties with intervention studies is to ensure double blindness. Therefore, the study was advertised as investigating the implication of two interventions, one being a memory training (control group) and the other a meditation training (experimental group). To prevent bias during group attribution, participants were alternatively allocated to one of the groups. Additionally, groups, recordings and booklets were renamed by a researcher outside of this project to ensure double-blindness. A total of 19 young and 29 older adults completed the full experiment. Eight young adults were in the control condition (*M* = 22.50, *SD* = 4.07; 87.5% Female), while 11 were in the meditation condition (*M* = 23.64, *SD* = 5.33; 72.7% Female). Fourteen older adults were in the control condition (*M* = 69.50, *SD* = 6.95; 64.3% Female), while 15 were in the meditation condition (*M* = 67.87, *SD* = 6.37; 60% Female). Participants were seen twice in the laboratory and were asked to complete the intervention for 28 days in between. This study was approved by the Ethics Committee of the Faculty of Health and Life Sciences of Northumbria University. The investigation was conducted according to the principles expressed in the Declaration of Helsinki and participants provided written informed consent.

6.3.2.2. Procedure

After completing the first session (see method section of Experiment 1), participants were given instructions for the completion of the intervention. A booklet and access to a set of 28 recordings was provided to all participants, which were either accessed via an MP3 player or shared via an online folder. Participants in the control group were told to listen to a different story every day and to report the key elements of the story straight afterwards (see Appendix A for instructions). Participants in the experimental group were asked to listen to a guided meditation every day and to report any thoughts, feelings, or emotions experienced during the practice straight afterwards (see Appendix A for instructions). All participants were encouraged to be honest regarding the completion of the training, and three evaluative questions were asked at the end of the booklets, targeting the efficiency, benefits, and agreeableness of the intervention. After 28 days, all participants came to the laboratory for a second meeting. During this session, participants underwent the exact same procedure as the first session (please refer to the above method section p. 139). At the end, participants were fully debriefed about the aim of this study, revealing the existence of a control group. Participants were given the opportunity to access the recordings of the other condition if required.

6.3.2.3. Materials

6.3.2.3.1. Recordings

The recordings used in the control condition were taken from Librivox audiobooks (https://librivox.org/). All recordings referred to books in the public domain such as "The Necklace" by Guy de Maupassant. Book recordings lasted on average 21.05 minutes (*SD* = 2.29). In the meditation condition, four recordings were used (See Appendix B for an example). Recordings were created by a trained meditation teacher and were all based on body scan meditation while incorporating compassion features to it (e.g. "*During the meditation each time your mind wanders, just noticing that, and bringing a feeling of loving kindness and compassion for yourself, then gently coming back to the meditation practice*"). The first week was a "head to toe" body scan, the second was "toe to head", week three was only focusing on the hands, and the fourth week focused on the face. Recordings lasted 19.63 minutes in average (*SD* = 0.50).

6.3.2.3.2. Questionnaires

The **Mindful Attention Awareness Scale** (MAAS, Brown & Ryan, 2003) is a 15-item scale introduced by the following sentences: "*Below is a collection of* *statements about your everyday experience. Please answer according to what really reflects your experience rather than what you think your experience should be*." Participants must rate the statements on a six-point Likert scale ranging from 1 (*almost always*) to 6 (*almost never*). For example, '*I rush through activities without being really attentive to them*' or '*I snack without being aware that I'm eating*'. A higher score indicates more mindful abilities. Cronbach's alphas revealed good reliability (α = .89).

The **Meta-Cognitive Questionnaire** (MCQ30, Wells & Cartwright-Hatton, 2004) was used to assess participants' metacognitive beliefs, judgments, and monitoring tendencies. This questionnaire consists of 30 items capturing five aspects of metacognition, namely cognitive confidence (i.e. "*I do not trust my memory*"), positive beliefs (i.e. "*Worrying helps me cope*"), cognitive self-consciousness (i.e. "*I monitor my thoughts*"), uncontrollability and danger (i.e. "*When I start worrying I cannot stop*"), and need to control thoughts (i.e. "*It is bad to think certain thoughts*"). For each question, participants used a four-point Likert scale ranging from 1 (*Do not agree*) to 4 (*Agree very much*). Cronbach's alphas revealed good reliability for the cognitive confidence (α = .89), positive beliefs (α = .90), cognitive self-consciousness (α = .91), uncontrollability and danger (α = .90), and need to control thoughts subscales (α = .72).

The **Involuntary Autobiographical Memory Inventory** (IAMI; Berntsen et al., 2015) consists of 20 items designed to measure the frequency with which participants spontaneously think about a past or future event. Within the instructions, participants are informed that "*The following questions address how frequently memories and imagined future events come to your mind by themselves (without trying) during daily life.*" For each question, participants have to use a five-point Likert scale ranging from 1 (*Never*) to 5 (*Once an hour or more*). Examples would be, '*Memories of personal events pop into my mind by themselves—without me consciously trying to remember them.*' for past memories and '*When I am bored, imaginary future events come to my mind by themselves —without me consciously trying to evoke them.*' for future events.

Cronbach’s alphas revealed good reliability for the future (α = .91) and past subscale (α = .88).

The **Daydreaming Frequency Scale** (DDFS, Giambra, 1993) is one of the 28 scales composing the Imaginal Process Inventory (Singer & Antrobus, 1963) and consists of 12 items assessing daydreaming frequency. Participants are asked to choose on a five-point Likert scale the nature of thoughts appropriate for them. For example, ‘*I lose myself in active daydreaming*’ can be answered by either (1) *Infrequently*, (2) *Once a week*, (3) *Once a day*, (4) *A few times during the day* or (5) *Many different times during the day*. Cronbach’s alphas revealed good reliability (α = .94).

The **Short Imaginal Processes Inventory** (SIPI, Huba, Singer, Aneshensel & Antrobus, 1982) was used in order to measure three specific types of daydreaming. Fifteen items composed each one of the three types of daydreaming, namely Positive-Constructive Daydreaming (i.e. “*My daydreams are often stimulating and rewarding*.”), Guilt and Fear of Failure (i.e. “*In my fantasies, I show my anger towards my enemies.*”), and Poor Attentional Control (i.e. “*I find that I easily lose interest in things that I have to do.*”). Participants used a five-point Likert scale ranging from 1 (*Definitely not true for me*) to 5 (*Very true for me*) to answer each question. Cronbach’s alphas revealed good reliability for the Positive and Constructive (α = .84), the Guilt-Fear of Failure (α = .79), and Poor Attentional Control subscale (α = .84).

The **Rumination and Reflection Questionnaire** (RRQ; Trapnell & Campbell, 1999) consists of 24 items designed to assess reflection and rumination where participants are asked to rate the extent to which they agree or disagree to statements. Answers are given on a five-point Likert-scale ranging from 1 (*Strongly disagree*) to 5 (*Strongly agree*). According to Trapnell & Campbell (1999), rumination and reflection both involve heightened attention to self. *Rumination* is "self-attentiveness motivated by perceived threats, losses, or injustices to the self"; *reflection* is "self-attentiveness motivated by curiosity or epistemic interest in the self" (Trapnell & Campbell, 1999, p.297). Examples would be, '*My attention is often focused on aspects of myself I wish I'd stop thinking about*' for rumination, and '*I'm very self-inquisitive by nature*' for reflection. Cronbach's alphas revealed good reliability for the Rumination (α = .92) and Reflection subscale (α = .91).

The **Positive and Negative Affect Schedule** (PANAS; Watson et al., 1988) consists of two 10-item mood scales that measure positive and negative affect respectively, both as states and traits. Participants are asked to rate the extent to which they experience particular emotions *right now* with reference to a five-point Likert-scale ranging from 1 (*very slightly or not at all*) to 5 (*very much*). Examples of emotions would be, '*distressed'* or '*excited*'. Cronbach's alphas revealed good reliability for the Positive Affect (α = .89) and Negative Affect subscale (α = .86).

The **Cognitive and Emotional Regulation Questionnaire** (CERQ-short, Garnefski & Kraaij, 2006) was used to evaluate the specificity of the regulation strategies used in response to the experience of threatening or stressful life events. The questionnaire is composed of 18 items which participants answered using a five-point Likert-scale ranging from 1 (*almost never*) to 5 (*almost always*). An example of a question would be "*I think I have to accept the situation*". Cronbach's alphas revealed good reliability (α = .76).

The **World Organisation Health** (WHO; Breek, Hamming, Vries, Aquarius, & Henegouwen, 2001) questionnaire measures individuals' quality of life overall and in specific domains. It consists of 26 questions, which are answered on a five-point Likert-scale with different labels depending on the question. For example, for the question "*How would you rate your quality of life?*" participants could answer (1) *very poor*, (2) *poor*, (3) *neither poor nor good*, (4) *good* or (5) *very good*. Cronbach's alphas revealed good reliability (α = .90).

The **Beck Depression Inventory** (BDI-II; Beck et al., 1996) is a widely used tool for assessing the severity of depressive symptomatology. The 21 items are rated on a four-point Likert scale, from 0 to 3 points. Scores range from 0 to 63. For example, '*Past failure*' can be answered by either (0) *I do not feel like a failure*, (1) *I have failed more than I should have*, (2) *As I look back, I see a lot of failures* or (3) *I feel I am a total failure as a person*. Cronbach's alphas revealed good reliability (α = .90).

6.3.3. Results

6.3.3.1. Descriptive characteristics

Firstly, 2 (Age; *Young, Old*) by 2 (Condition; *Control, Meditation*) ANOVAs have been conducted on participants' year of education, days practiced, and rating to the perceived effectiveness, benefits, and enjoyment of the practice, to ensure the equivalence of the participants across conditions. Differences were found on the effectiveness [F (1, 44) = 5.43, p = .024, η_p^2 = .11] and benefits rating [F (1, 44) = 5.60, p = .022, η_p^2 = .11], showing that participants in the meditation condition perceived the intervention as more effective and more beneficial than the participants in the control condition (see **Table 6.1**).

Table 6.1. Mean (Standard Deviation) of participants' years of education, number of days practiced, and participants' rating of the intervention, all for each group under study.

	Young			Old			Overall	
	Contr.	Medi.	Total	Contr.	Medi.	Total	Contr.	Medi.
N = 48	8	11	19	14	15	29	22	26
Education	15.75 (2.25)	16.73 (3.26)	16.32 (2.85)	16.62 (3.01)	15.21 (5.16)	15.89 (4.25)	16.29 (2.72)	15.88 (4.41)
Days practiced	23.63 (2.77)	23.45 (5.24)	23.53 (4.27)	26.86 (3.46)	24.53 (6.07)	25.66 (5.04)	25.68 (3.54)	24.08 (5.65)
Effective	2.25 (.89)	3.55 (1.13)	3.00 (1.20)	2.21 (1.05)	2.40 (1.12)	2.31 (1.07)	2.23 (.97)*	2.88 (1.24)*
Benefits	2.38 (1.06)	3.55 (1.21)	3.05 (1.27)	2.14 (1.10)	2.53 (1.06)	2.34 (1.08)	2.22 (1.07)*	2.96 (1.22)*
Enjoy	2.37 (.74)	2.81 (.75)	2.63 (.76)	2.50 (1.22)	2.67 (1.23)	2.59 (1.21)	2.45 (1.06)	2.73 (1.04)

Note. * $p < .05$

6.3.3.2. Intervention effects on thoughts

To analyse the MDES, the set of questions was decomposed using principal component analysis (PCA), applying varimax rotation. This allowed the core patterns of variance within the self-reported data to be characterized in a smaller set of underlying dimensions. Ratings from both age groups, condition, time of testing (pre, post), and type of measure were assessed together. Four factors were outlined with eigenvalues > 1. However, observation of the scree plot suggested the occurrence of five factors, therefore, five factors have been selected and the loadings that describe these dimensions are presented in the form of a heat map in **Figure 6.3**: Component One – *Task-Related Interference* - with high weighting indicating deliberate, detailed, positive emotion, evolving, habitual, and vivid thoughts, accounting for 21.71% of the variance. Component Two – *On-Task Thoughts* - with high weighting indicating highly focused thoughts that are not related to other people, accounting for 16.50% of the variance. Component Three – *Future-Oriented Thoughts* - with high weighting reflecting thoughts that were about the self and the future, accounting for 9.51% of the overall variance. Component Four – *Thought Modality* - with high weighting reflecting thoughts that were in the form of words rather than images, accounting for 7.85% of the overall variance. Component Five – *Past-Oriented Thoughts* - with high weighting reflecting thoughts that were about the past and negative, accounting for 7.42% of the overall variance.

In order to identify the influence of age and method of experience sampling on these five PCA components 2 (Age; *Young, Old*) by 2 (Condition; *Control, Meditation*) by 2 (Time; *Pre-test, Post-test*) repeated measure ANOVAs were conducted on participants' mean regression scores for each factor. Unfortunately, due to many participants not having reported mind-wandering experiences during the self-caught task, including the measure (*Probe-caught, Self-caught*) as an independent variable would result in the exclusion of 5 older adults in the meditation condition and 7 in the control condition. Considering the already small sample of participants in this pilot study, the decision to exclude this variable from the analyses was made.

Results on **On-task** thoughts displayed an effect of age indicating that older adults (M = .32, SD = .45) experienced more focused thoughts than young adults (M = -.31, SD = .48), F (1, 44) = 19.33, p < .001, η_p^2 = .31. An effect of interaction between time and age was found, F (1, 44) = 4.60, p = .037, η_p^2 = .10. The interaction between time, age, and condition was also significant, F (1, 44) = 4.84, p = .033, η_p^2 = .10. Further analyses showed that an effect of time was only evident for young adults in the meditation condition [F (1, 10) = 15.73, p = .003, η_p^2 = .61] and showed increased task focus after the intervention (see **Figure 6.3**.). Results on **Future** thoughts showed a significant interaction between time and condition, F (1, 44) = 4.41, p = .041, η_p^2 = .09. Further analyses revealed an effect of time only in the control condition with a reduction of future thoughts after the intervention (pre-test, M = .11, SD = .45; post-test, M = -.09, SD = .63), F (1, 21) = 4.78, p = .040, η_p^2 = .19. Results on **Thought Modality** showed

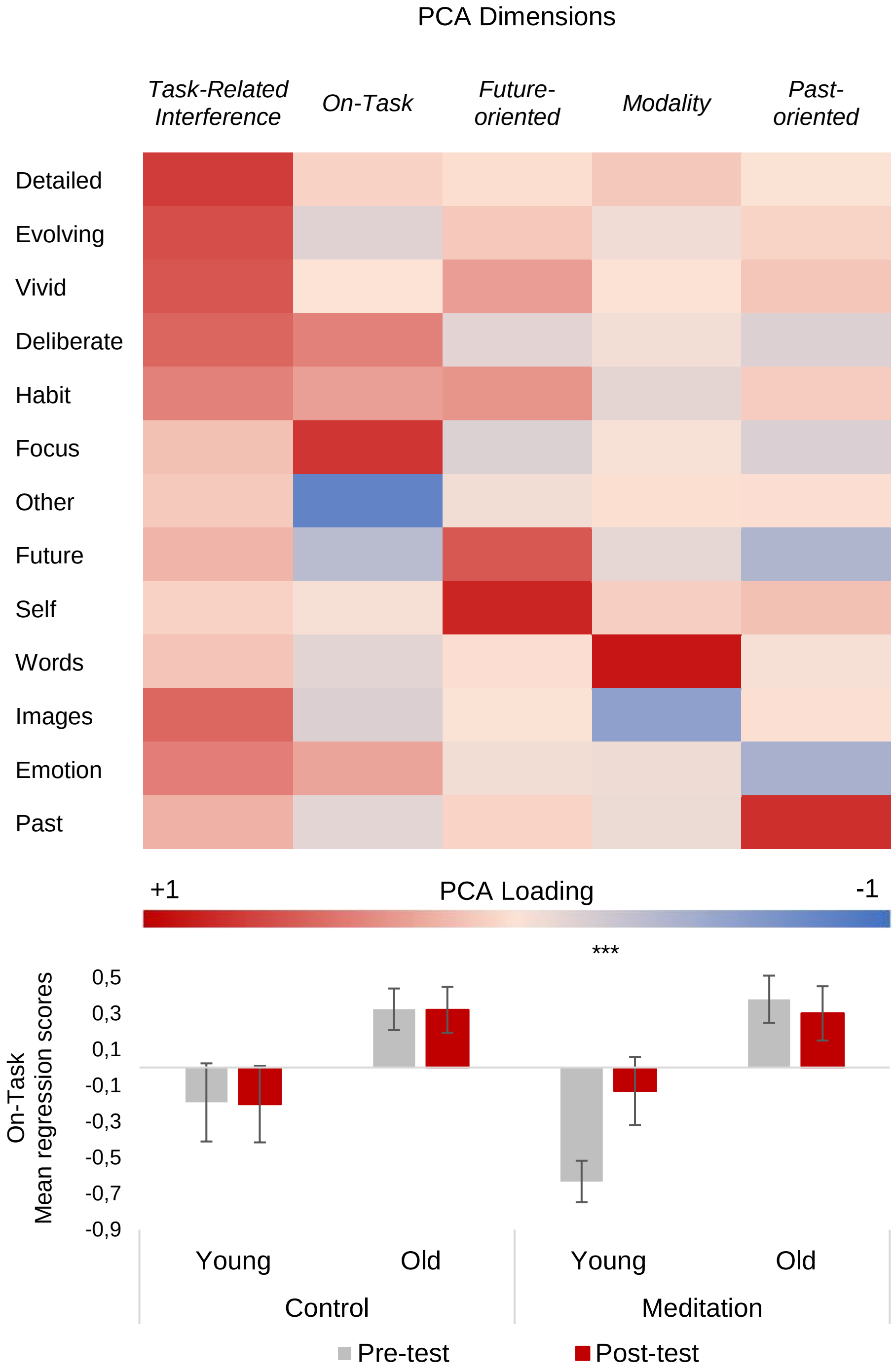


Figure 6.3. Determining different type of self-generated thoughts and their evolution depending on intervention condition and the age group.

(*Top*) Heat map illustrating the loading of the different questions on the five factors resulting from the principal component analyses (PCA). Varimax rotation was applied to the data set. (*Bottom*) The effects of interaction between Age (*Young, Old*), Condition (*Control, Meditation*) and Time (*Pre-test, Post-test*) on mean regression scores for On-task thoughts. *Note*. *** *p* <.001; Error bars are Standard Errors.

a significant interaction between time and condition, *F* (1, 44) = 4.34, *p* = .043, η_p^2 = .90. Further analyses revealed that the meditation condition marginally increased visual thoughts, *F* (1, 44) = 3.13, *p* = .089, η_p^2 = .11 (pre-test, *M* = -.01, *SD* = .67; post-test, *M* = -.17, *SD* = .68). Results on **Past** thoughts presented a main effect of time with a general reduction of past-related thought after both interventions (pre-test, *M* = .04, *SD* = .46; post-test, *M* = -.09, *SD* = .47), *F* (1, 44) = 5.21, *p* = .027, η_p^2 = .11. Results on **TRI** revealed no significant effects.

6.3.3.3. Explaining the dropout rates

Dropout rates from this intervention were revealed to be important: 47.2% of young adults and 23.7% of older adults. This section will attempt to pin down the personal characteristics differentiating participants that completed the study from the ones that did not. For this purpose, analyses will only be conducted on dispositional characteristics (measured using questionnaires) collected upon the first session.

Repeated measures ANOVAs were conducted on the questionnaires displaying a number of subscales (i.e. MCQ30, the SIPI, the RRQ, the IAMI, and the PANAS) with Dropout (*Yes, No*) and Age (*Young, Old*) as between factors. Additionally, one-way ANOVAs with the same between factors were conducted on the remaining questionnaires (i.e. DDFS, BDI, CERQ, MAAS, WHO). An interaction between SIPI and dropout was found significant, *F* (2, 140) = 7.97, *p* < .001, η_p^2 = .10. Participants who completed the study reported more positive-constructive thoughts (*M* = 3.16, *SD* = .54) and less guilt-fear of failure thoughts (*M* = 2.02, *SD* = .55) than participants who did not (Positive-constructive, *M* = 2.79, *SD* = .53; Guilt-fear of failure, *M* = 2.29, *SD* = .54), *F* (1, 72) = 8.09, *p* = .006, η_p^2 = .10 and *F* (1, 72) = 4.25, *p* = .043, η_p^2 = .06 respectively. Additionally, an interaction was found to be significant between PANAS and dropout, *F* (1, 70) = 7.18, *p* = .009, η_p^2 = .09. Participants who completed the study reported more positive affect (*M* = 34.88, *SD* = 6.95) and less negative affect (*M* = 21.77, *SD* = 8.37) than participants who did not complete it (Positive, M = 30.50, SD = .6.30; Negative, M = 17.15, SD = 5.20), F (1, 72) = 7.12, p = .009, η_p^2 = .09 and F (1, 72) = 8.58, p = .005, η_p^2 = .11 respectively.

6.3.4. Discussion

Despite previous work showing a reduction of mind-wandering frequency following the practice of meditation (Mrazek et al., 2013; Mrazek et al., 2012), limited work has considered the implication of heterogeneity of self-generated thoughts. The aim of this study was to measure the impact of meditation practice on different types of thoughts in young and older adults. In this perspective, participants either practiced meditation or listened to book recordings for 4 weeks. Multidimensional experience sampling was conducted before and after the intervention. As expected, the practice of meditation increased young adults' ability to focus on a mundane task. This effect was not found for older adults, who displayed higher focus rates than young adults at baseline. A reduction of negative thoughts initially reported by Jazaieri et al. (2016) was also replicated here for both young and older adults. Preliminary findings suggest an increase of visual thoughts after the practice of meditation. Participants in the active control group reported a decrease of both past and future-oriented thoughts. Lastly, a self-selection bias was found, with participants completing the study showing high positivity and low negativity.

A growing body of literature has explored the benefits of mindfulness-based meditation on health, wellbeing and cognition (Carmody & Baer, 2008; Chiesa et al., 2011; Evans et al., 2008; Pagnoni & Cekic, 2007). Practicing meditation increases performance on attentional control and sustained attention (Anderson, Lau, Segal, & Bishop, 2007; Chambers, Lo, & Allen, 2008; Moore, Gruber, Derose, & Malinowski, 2012) and reduces mind-wandering experiences (Mrazek et al., 2013). This was replicated in the present study where young adults reported to be more on-task after the meditation training. However, it was not the case for older adults, who were more on-task at baseline. Meditation practice also demonstrated a tendency to increase visual thoughts in both young and older adults (marginal finding). This can be explained either by the nature of the body-scan meditation which encourages the visualisation of different body parts, or by an increase in present moment awareness leading to better processing of the visual task.

One study looking into the impact of meditation on thought content has outlined a reduction of negative thoughts (Jazaieri et al., 2016). Similarly, the present study found a decrease of negative/past-oriented thoughts after the practice of meditation for both young and older adults. By nature, mindfulness-based meditation encourages individuals to notice bodily sensations as well as incoming thoughts. Individuals are guided to let go of these thoughts and to bring focus back to the present moment, often characterised by an object (e.g. body, breathing). Compassion features incorporated into mindfulness meditation are designed to nurture the acceptance of mind drift by reinforcing kindness toward oneself. This aspect is suspected to reduce negative thoughts. Nevertheless, the present study is not differentiating between the contribution of mindfulness and compassion features. Critically, the benefits of the present intervention may be explained by the combination of both mindfulness and compassion features. Future research should aim to disentangle the mechanisms by which meditation practice reduces negative and past thoughts. Furthermore, an avenue to ponder is the mediating role of thought content in the benefits of meditation-based interventions. Meditation practice reduces both negative thoughts, as well as behaviours related to their occurrence such as negative mood, depression and poor performance (Banks et al., 2016; Marchand, 2012; Poerio et al., 2013; Ramel, Goldin, Carmona, & McQuaid, 2004; Ruby, Smallwood, Engen, et al., 2013; Smallwood & O'Connor, 2011; Smallwood et al., 2005; Smallwood, O'Connor, et al., 2007). Therefore, the behavioural benefits of meditation practice could be driven by changes in thought content, particularly the reduction of negative/past thoughts.

A strength of this study was the use of an active control condition to distinguish the contribution of meditation practice from the simple practice of an activity. In the control condition, participants listened to book recordings instead of guided meditations. Young and older adults reported fewer future and past-oriented thoughts after this intervention. Similar findings were previously reported, with both meditation and listening to book recordings reducing negative mood and depressive symptoms (Zeidan, Johnson, Diamond, David, & Goolkasian, 2010). Stories used in this intervention were not personally relevant to participants. One interpretation is that this feature encouraged personal detachment from one's current concerns. Thus, the reduction of current concerns may have led to fewer thoughts intrinsically linked to the self, namely future and past-oriented thoughts. Comparing this to the effect of meditation practice, it seems that the benefits of meditation lies in the selectivity of the changes. While past-oriented thoughts are merely detrimental, future-oriented thoughts are more beneficial for everyday functioning (Banks et al., 2016; Engert et al., 2014; Poerio et al., 2013; Ruby, Smallwood, Engen, et al., 2013). Hence, the practice of meditation seems to target disadvantageous thoughts, while preserving more advantageous ones.

Finally, an exploratory approach was taken to uncover individual characteristics underlying participants' engagement in the study. Participants who completed the full study showed high positive affect and positive-constructive thoughts, as well as low negative affect and guilt-fear of failure thoughts at baseline. Positive and constructive thoughts imply a positive approach, where self-generated thoughts are seen as worthwhile and stimulating. On the other hand, guilt and fear of failure refer to a negative approach where they are seen as negative and frightening (Huba et al., 1982). The self-selective bias observed here suggests that self-efficacy is indispensable to the fulfilment of a time-consuming experiment. Participants' optimistic and pessimistic take on life may be an underlying factor encouraging study completion. Importantly, this brings a new perspective to the previously discussed findings. Firstly, the generalisation of the intervention effects described beforehand is limited. Secondly, failure to replicate a reduction of past-oriented thoughts and an increase of visual thoughts in ageing may be bound to this selectivity bias. Indeed, despite all participants in the second experiment taking part in the first one, age-effects found in experiment one (i.e. fewer past-oriented thoughts). While the lack of statistical power should be kept in mind, future studies may want to consider individual differences as factors influencing intervention outcomes.

6.4. Conclusion

Overall, limitations should be kept in mind when considering these findings. Firstly, the use of the multidimensional experience sampling method, however useful, can cause difficulties in the categorisation of the thoughts. Indeed, the lack of studies describing the phenomenological characteristics of the task-related interferences, a-temporal thoughts, or external distractions made the labelling of the component more difficult. Using a categorical approach could be used in parallel with the MDES to shed light onto the phenomenology of certain self-generated thoughts. Secondly, the difference between self and probe-caught thoughts were not analysed in the second experiment despite manifest differences in the first experiment. This decision, despite preserving statistical power, has weakened and limited the understanding of intervention effects. The literature suggests that meditation practice increases meta-awareness of one’s state of mind (Mrazek et al., 2013). Therefore, in the meditation condition, different patterns of thoughts could have been found in the probe versus self-caught method. To resolve this problem, a larger sample of participants should be recruited. As such, and in the face of recruitment difficulty with substantial dropout rates, future work should consider the use of a shorter intervention. For example, one-week interventions would enable the recruitment of more participants completing the full experiment and reduce the incidence of the self-selected bias observed here.

To conclude, understanding self-generated thoughts in the context of ageing is essential and should go beyond frequency measures. Critically, research has shown a lack of consideration of the broad complexity of these experiences, with little evaluation of how thought content adapts to different context. The present chapter focused on the influence of meta-awareness and meditation practice on thought content in ageing. In the first experiment the use of different experience sampling methods demonstrated that one is merely aware of temporal thoughts but not task-related interferences. The time course with which thoughts are generated is thought to be a critical feature to explain this selectivity. Evidence should be considered when investigating the regulation process of self-generated thoughts. A second experiment demonstrated the malleability of thought content in both young and older adults. Importantly, both interventions displayed significant results, with different patterns. Nonetheless, caution must be taken when exploring these findings as a self-selective bias was reported.

Chapter 7. General discussion of project findings.

This chapter aims to summarise the findings of the four empirical studies outlining the benefits of convergent methods in the investigation of the wandering mind. The original contribution to knowledge made by this project will be explained and discussed in relation to: the implication of the DMN in age-related changes of self-generated thoughts, the age-related changes of thought content, the sensitivity of self-generated thoughts to intrinsic and extrinsic factors, and the possibility of experimentally modifying thought content. Methodological considerations, as well as methodological limitations, that have arisen during the development of this programme of work will also be reported. Importantly, suggestions for the direction of future research are outlined, and conclusions are drawn regarding the conceptualisation of mind-wandering experiences and the implication of ageing.

7.1. Overview

A large variety of experiences fall under the name of mind-wandering. Self-generated thoughts are very heterogeneous regarding their content, form, outcomes, and underlying neural patterns (Mooneyham & Schooler, 2013; Smallwood & Schooler, 2006, 2015). This variability is particularly influenced by the environment, methodological setting, and individual differences (e.g. Faber et al., 2018; Rummel & Boywitt, 2014; Seli, Cheyne, et al., 2015; Smallwood et al., 2002). The core aim of this thesis was to investigate one of these individual differences, namely ageing.

Older adults present a diverse neurocognitive profile, with poor attentional control and episodic memory (Addis et al., 2010, 2008; Braver & West, 2008; Schmitter-Edgecombe et al., 2000), as well as a cerebral reorganisation of the DMN and atrophy of the frontal lobes (Damoiseaux, 2017; Damoiseaux et al., 2008; Rabbitt, 2005; Robbins et al., 1998). More recently, research has documented a decrease of mind-wandering experiences in ageing and a number of interpretations have been suggested (for a review see Maillet & Schacter, 2016). However, changes in thought content and how this is linked to the cerebral organisation of the brain has been overlooked. In order to address this gap in the literature, both the heterogeneity of thought processes and the underlying neural patterns were central to this project. Understanding the complexity of self-generated thoughts in this population is the key to fully understanding the component process account of mind-wandering previously outlined (see Chapter 1). Particularly, older adults' deficits in attentional control, memory, or decreased activity and connectivity within the DMN could refine the understanding of the regulation and generation processes of mind-wandering.

Self-generated thoughts are transient, covert, and sometimes occur without awareness. For these reasons studies have merely relied on participants' self-reports, making the objective measurement of mind-wandering experiences difficult. To overcome these complications, this PhD programme used convergent methods within and between studies to further characterise self-generated thoughts in ageing. With convergent methods the strength of a measure can compensate for the limitation of another. Thus, combining self-report measures with more objective measures, such as neuroimaging data, strengthened our understanding of the processes at play. The systematic investigation of this phenomenon from different perspectives has provided a more complete picture of an otherwise covert state. Specifically, the first section of this program of work, which combined self-report and neuroimaging measures, revealed the implication of the DMN. In the second section, mind-wandering experiences in ageing were studied from a behavioural perspective, outlining the flexibility of these experiences. Overall, an original contribution to knowledge was provided by (i) investigating older adults' neurocognitive profile and its relation to the complexities of mind-wandering experiences, and by (ii) exploring the impact of one's cultural affiliation, mindful abilities and meta-awareness on thought content in ageing.

7.2. Summary of the findings

First, an overview of the findings from the four empirical chapters will be presented. Summarising the data here will set the scene for subsequent theoretical discussions and consideration of the unique contribution of this thesis. Although the age-related decrease in off-task thought is now well documented, a clear neuro-cognitive account of what underlies this change in self-generated thought has been lacking. Both Chapters 3 and 4 aimed to address this gap in the literature by combining electrophysiological (Chapter 3) and functional connectivity magnetic resonance imaging (Chapter 4) with self-report measures of self-generated thoughts in young and older adults.

Chapter 3 aimed to (i) describe the link between age-related changes in brain electrophysiology and age-related changes in self-generated thought, and to (ii) define neural patterns underlying specific self-generated thoughts. In young adults, beta power over centro-parietal right area enabled the flexible adjustment of mental time travelling to match task demands; a pattern not found in older adults. General increases in alpha and beta power were indicative of the involvement of the default mode network in off-task thoughts. Delta power was found to be essential in mental time travelling experiences, most likely by lowering concentration and supporting memory processes. Interestingly, hemispheric differences in gamma power were representative of thought modality, with more left lateralised activity being associated with verbal rehearsing during a demanding task.

Following on from the electrophysiological findings, Chapter 4 investigated the possibility that age-related changes in off-task thinking were correlated with changes in the intrinsic organisation of the brain using functional connectivity measures. Given the importance of executive control and memory in coordinating and generating the content of self-generated thoughts, regions underlying these processes were the focus (i.e.

anterior temporal lobe, hippocampus, and inferior frontal gyrus Noonan et al., 2013; Tulving, 2002).

In younger participants, the reduction in the strength of connectivity between the left anterior temporal lobe and prefrontal DMN regions was correlated to a greater shift toward spontaneous off-task thought when task demands were low. Importantly, in the older individuals, lower connectivity between the same two regions was associated with preserved performance on a creativity task, suggesting that age-related changes in this area are not linked to impairments in cognition across domains. Together, these data provide converging evidence that one reason why ongoing thought becomes more focused on tasks as we age is related to changes in the connectivity of the default mode network. Therefore, these results extended findings from Chapter 3, where spontaneous off-task thoughts were related to activity in the default mode network as evidenced by alpha and beta power.

Continuing with the convergent approach of this thesis, Chapter 5 studied the implication of cultural affiliation on mind-wandering experiences across the lifespan. Dispositional measures of mind-wandering, mindfulness, mood, rumination, self-reflection, future thinking, depressive symptoms, and cognitive failures were gathered in a population of French and English native speakers. Findings revealed a decrease in mind-wandering frequency at an earlier age in French-speaking participants. Cultural effects were demonstrated on rumination and reflection rates across the lifespan, in general with more rumination and less reflection in English speakers. Overall, negatively oriented thoughts were dominant in English speakers compared to the generally more expressive thoughts in French speakers. Confirmatory factor analyses explored different theoretical models to explain mind-wandering frequency in the French and British populations. This chapter clearly evidenced experiential differences in mind-wandering as a function of culture and age.

Finally, the last empirical chapter of this thesis added to our understanding of self-generated thoughts by experimentally manipulating thought content. Particularly, this chapter aimed to further inform the regulation processes involved in mind-wandering, by considering the influence of meta-awareness and meditation on thought content. The first experiment used probe and self-caught methods to identify thought patterns more likely to reach meta-awareness in young and older adults. A second study experimentally modulated thought content in young and older adults using a meditation-based intervention. Results demonstrated that one is merely aware of temporal thoughts, but not task-related interferences. The time course with which thoughts are generated was suggested as a critical feature underlying this selectivity. Results also confirmed the malleability of thought content following a 4-week intervention in both younger and older adults. This provides the groundwork to design interventions targeting patients with pathological mind-wandering experiences.

Overall, this body of work confirmed older adults' bias toward deliberate on-task thoughts, which was particularly evident during mundane, less cognitively demanding tasks. The findings also extended our knowledge by demonstrating an age-related decrease of negatively oriented thoughts, namely ruminative thoughts and past-oriented thoughts. Older adults also experienced more visual thoughts and task-related interferences, while presenting no changes in self-reflection or future-oriented thoughts. Brain imaging data outlined the importance of the DMN in the generation of spontaneous off-task thoughts and mental time travelling. Building upon previous fMRI work (H.-T. Wang, Bzdok, et al., 2018), variability in thought content was found to reflect variability in spectral power. Finally, the use of converging methods evidenced that thought content significantly changed as a function of intrinsic and extrinsic factors. Therefore, the French culture tends to favour self-reflection, difficult tasks encourage verbal rehearsal, and meta-awareness mainly targets temporal thoughts, while meditation specifically reduces negative and past-oriented thoughts.

7.3. Original contribution to knowledge

This project has extended our knowledge on the age-related decrease in mind-wandering, age-related changes in thought content, the sensitivity of self-generated thoughts, and their malleability. Two studies specifically considered the impact of older adults' distinct neurocognitive profile on self-generated thoughts for the first time. In fact, it can be concluded that age-related changes in self-generated thoughts are underlined by age-related changes in brain activity; specifically, within the DMN. Firstly, spectral power reflecting DMN activity and endogenous top-down processes (i.e. beta band), enabled the flexible adjustment of mental time travelling in young adults. However, the older adults' beta band activity was suspected to underlie the absence of such flexibility in this population. Secondly, lower connectivity between the left temporal lobe and prefrontal regions of the DMN fostered spontaneous off-task thoughts and creative thinking in young and older adults respectively. Together, these findings indicated how mind-wandering experiences are influenced by the neurocognitive profile of older adults. While further work is needed to fully understand the role of the DMN network in mind-wandering in ageing, these studies suggest that the problem lays in the generation of these experiences.

Beyond neuroimaging, this thesis described in detail age-related changes in thought content. The behavioural findings of this project replicate the age-related decrease in off-task thoughts and extended our knowledge to the heterogeneity of self-generated thoughts in ageing. When compared to young adults, older individuals reported similar rates of positively biased thoughts (i.e. future-oriented thought, self-reflection), a smaller rate of negatively oriented thoughts (i.e. past-oriented thoughts, rumination), and more visual thoughts, as well as task-related interferences. These differences are informative due to the influence of thought content upon behavioural outcomes. Past-oriented thoughts often increase negative outcomes (e.g. task errors, negative mood; Banks et al., 2016; Poerio et al., 2013), while future-oriented thoughts enable more positive outcomes (e.g. efficient planning of personal goals, alleviate negative mood, fosters positive mood Baird et al., 2011; Engert et al., 2014; Ruby, Smallwood, Sackur, et al., 2013). Therefore, the mind-wandering profile of older adults adds to previous research describing older adults as positive and mindful individuals (Carstensen et al., 1999; Grühn et al., 2010; Splevins et al., 2009). Behavioural consequences of these changes in thought content should be investigated to clarify our understanding of ageing. Altogether, these findings addressed an important gap in the literature by further characterising the cognitive profile of older adults as well as refining our theories of the wandering mind. Moreover, this converging methods approach demonstrated the utility in combining new advances in both the neurosciences and traditional behavioural techniques.

With regards to the general population, this project also extended our knowledge about the influences of intrinsic and extrinsic factors on thought content. Intrinsic factors comprise individual differences, such as pathologies, culture or working memory capacity to name a few. As an example, research has outlined how working memory capacity positively impacts the flexible adjustment of self-generated thoughts (Rummel & Boywitt, 2014). In a similar vein, extrinsic factors, such as task difficulty, duration or variability, also modify participants' experiences. Thus, difficult tasks significantly decrease the proportion of mind-wandering experiences (McVay & Kane, 2009). A contribution from the present project was to extend our knowledge regarding both intrinsic and extrinsic factors, and their impact on thought content. The impact of task difficulty on frequency was replicated and extended to thought content with task difficulty increasing verbal thoughts. Verbal thoughts were predicted by an increase of gamma power illustrating the binding of information and higher order processing (Fries, 2009; Jensen et al., 2007). Binding enables the integration and in-depth processing of information coming from different modalities. Indeed, the functional significance regarding binding processes has been outlined with evidence of complex mental tasks increasing gamma power (Fitzgibbon, Pope, Mackenzie, Clark, & Willoughby, 2004). Thus, imaging data provided evidence that thoughts in the form of words merely reflected verbal rehearsal, a strategy particularly useful during a demanding task and an important element in working memory function. Regarding intrinsic factors, individual differences such as one's cultural affiliation and language were previously found to have notable impacts on cognition. For instance, time is conceptualised differently in Mandarin and English populations (Boroditsky, 2001), and French citizens tend to be more expressive than British citizens (Fortier & Moulin, 2015). This thesis outlined cultural difference between French and British native speakers in terms of frequency and content of self-generated thoughts. Together, describing the influence of different factors has informed us of the variability and sensitivity of thought content as well as the functionality of certain self-generated thoughts.

Finally, this project comprised one of the first intervention study aiming to change thought content in a population of young and older adults. Although self-generated thoughts are highly sensitive to various factors, limited prior work has directly aimed to modify thought content through experimentation. The successful transformation of self-generated thoughts has set the scene for a better understanding of the regulation and generation processes of mind-wandering. For example, minimising participants' personal concerns should, and has, reduced the occurrence of self-referential thoughts and informed the generation process of mind-wandering. On the other hand, improving purely attentional control skills should bring greater insight about the management of different self-generated thoughts. Last, but not least, the contribution of this study also includes the future design of interventions aimed at patients facing difficulties with mind-wandering experiences. Several clinical conditions, for instance depression and anxiety disorder, would greatly benefit from interventions targeting detrimental self-generated thoughts, while preserving beneficial ones. Particularly, meditation practice, which has been successfully used with depressive and anxious patients (Goyal et al., 2014; Hofmann, Sawyer, Witt, & Oh, 2010), was found to significantly reduce negatively oriented thoughts while protecting positive ones (Chapter 6). Future work should maximise the benefits of such interventions by studying the relationship between changes in thought content and behavioural outcomes.

7.4. Methodological considerations and limitations

Undeniable progress has been made by converging the use of behavioural measures, neuroscience, individual differences, and intervention work. Traditional behavioural methods and new advances in neuroscience have enabled the refinement of theories of the wandering mind. For completeness, a word of caution should be raised regarding certain aspects of the behavioural methodology. The methodological approach taken in this PhD thesis, which was based on experience sampling, is being increasingly used in the literature (e.g. Konishi et al., 2015; Smallwood et al., 2016). Using multidimensional experience sampling was highly efficient in capturing the complexity of self-generated thoughts, particularly when using principal component analyses. This enabled the identification of typical patterns of thoughts within self-reports with a data-driven approach. Nonetheless, some limitations regarding the number of questions and their topic should be kept in mind. Using thirteen probe questions, while being the strength of this method, might have also reduced the validity of the answers. The large number of questions, as well as the repetitiveness of their occurrence, may cause participants to generate automatic responses, therefore not reflect their actual experience. Additionally, in some cases, questions may not relate to participants' ongoing experiences, or may not be interpreted adequately. Participants are selecting an answer by default and are using it consistently thereafter. Finally, this set of questions was based on research with young adults and may not capture older adults' experiences (e.g. features left out or questions not relating to their experience). This could be overcome by using open-ended questions, allowing participants to describe in their own words the nature of their experience. The Multidimensional experience sampling method could therefore be improved and adapted to a population of older adults. Regardless of these limitations, the multidimensional approach is a unique tool which efficiently highlights patterns of thoughts within self-reported data.

Other limitations are related to the recruitment of older adults, which is critical when studying the ageing process. Convenience sampling, while useful and efficient, can induce certain biases when it comes to older adults. Older individuals taking part in research are often very cognitively and socially active compared to their peers. Such characteristics tend to have a protective effect on cognitive decline (Ball et al., 2002; Fratiglioni, Paillard-Borg, & Winblad, 2004; Seeman, 2000), meaning that participants may not be representative of general ageing population. This may be particularly true when recruitment of participants is carried out via internet (see limitations in Chapter 5). Additionally, older adults' often report substantial motivation to help science and scientists, suggesting more task engagement in this subgroup. On the other hand, younger adults' motivations are often more immediate (e.g. course credit, or financial compensation) and only relate to their participation as opposed to success. Motivation is a very powerful factor in task performance (Nicholls, 1984) and mind-wandering frequency (Lindquist & McLean, 2011; Smallwood & Schooler, 2006; Unsworth & McMillan, 2013), meaning that comparison between age groups may be biased (Frank et al., 2015; Krawietz et al., 2012). Such limitations are imbedded into cohort effects, driven by cross-sectional designs. Therefore, a longitudinal approach should be encouraged to minimise the effect of this individual difference. Indeed, comparing participants to their younger selves will exclude any cohort effects (i.e. motivation to take part) or selective bias (i.e. merely only active older adults engage in research), as well as reveal the evolution of thought content across the lifespan. Overall, and beyond the above-outlined limitations, this thesis presents a strong methodological approach. The use of a multidimensional experience sampling, a method capturing the complexity of thought content with good reliability, and convergent methods, largely overcomes the difficulties intrinsic to the study of mind-wandering and ageing. Thus, this program provides solid groundwork for future research.

7.5. Future directions

The understanding of self-generated thoughts still remains incomplete. Substantial efforts should be made to replicate the findings reported in this thesis, as well as extending our understanding of such central experiences. Several recommendations have been outlined throughout this project, and here, the focus will be on the key questions to address.

One of the most critical gap in the literature is the identification of markers indicating the time course of mind-wandering experiences. Currently, researchers are catching participants while mind-wandering, or rely on participants' meta-awareness to report their attentional drifts. The difficulty is the lack of information regarding the onset of these experiences, leading to inferences in the time windows selected to represent mind-wandering experience (see limitations in Chapter 3), and this precludes the investigation of self-generated thoughts across time. To date few studies have used either eye tracking or the electroencephalogram to objectively predict mind-wandering experiences. This approach has demonstrated great promise and provided new information that can help in understanding the wandering mind. One study found pupil size to be the best marker of self-reported mind-wandering experiences (Grandchamp, Braboszcz, & Delorme, 2014), while another was able to predict probe-caught mind-wandering up to 72% by using changes in gaze direction and pupil size in a reading task (Bixler & D'Mello, 2016). Bixler and D'Mello (2016) identified patterns of eye gaze behaviour during mind wandering, namely longer fixations, longer reading times, more skipped words and larger variability in pupil diameter. More recently, based on electrophysiological measures, Kawashima and Kumano (2017) identified regression models predicting mind-wandering intensity during a sustained attentional task. Five models (i.e. SVR; Support Vector machine Regression) were identified each presenting different characteristics (e.g. linearity, number of electrodes). Overall, the highest correlation coefficient was achieved based on beta (21.5-30Hz) coherence between parietal midline and occipital areas. This is in line with findings from Chapter 3 showing the involvement of beta band in off-task thoughts and mental time travelling. Together, these encouraging successes are paving the way toward more objective measures of mind-wandering experiences. Future work may use real time machine learning and measure of spectral power to identify the onset of the decoupling process. Using continuous self-report of mind drifts to perpetually improve the efficiency of the predictive model.

Secondly, investigations of self-generated thoughts in ageing urgently need more ecological and naturalistic approaches. The environment of the laboratory (i.e. university campuses), while relatively familiar to young adults, can generate stress responses in older adults. For example, older adults' memory performances appear highly sensitive to the testing environment (Sindi, Fiocco, Juster, Pruessner, & Lupien, 2013). This sensitivity may be explained by the activation of ageing stereotype threat, stating that older adults inevitably display poor cognitive performances. The ageing stereotype was previously found to increase task-related interferences (Jordano & Touron, 2017). In this respect, researchers are encouraged to explore age-related changes in self-generated thoughts in different contexts, more favourable to older adults. For instance, using meaningfull information such as characters in photographs, rather than random words with no significance for older adults, showed to remove age-related deficit in memory (Rahhal et al., 2002; Fung and Carstensen, 2003; Sindi et al 2016). Considering how cognitive tests, as well as computer devices, can be perceived as threatening to older adults', the use of motor-based task could be beneficial. For example, experience sampling could be conducted while participants are folding pieces of paper in a simplistic and more complex manner (e.g. origami).

To illustrate the importance of an ecological settings it is worthwhile considering the example of prospective memory performance. Prospective memory corresponds to the memory to perform actions in the future (Einstein & McDaniel, 1996). Although prospective memory was first found to decrease with age (Craik, Klix, & Hagendorf 1986), later investigations using naturalistic settings showed preserved or even improved abilities in ageing (e.g. Devolder, Brigham, & Pressley, 1990; for a review see Henry, MacLeod, Phillips, & Crawford, 2004). This contradiction is known as the 'ageing paradox' (Bailey et al., 2010; Rendell & Craik, 2000). Together with the impact of the environment, this stresses the need for studies in naturalistic settings. For example, using a similar experience sampling method, once during a mundane task in the laboratory and once during everyday life, will give a wider understanding of self-generated thoughts in ageing. Preliminary evidence from a diary study, where participants were probed for a week 5 times a day at random occasions, (work in progress in collaboration with Dr. Smallwood) is pointing towards different patterns of age-related changes in self-generated thoughts.

A final recommendation, given our evaluation of individual differences, is the consideration of other populations, particularly ones presenting changes in the integrity of the DMN and related abilities (e.g. memory, attentional control, introspection, reference to the self). Research has mainly focused on ADHD and depression due to their attentional deficits illustrated by, respectively, high distractibility and intrusive thoughts (for further detail refer to Chapter 1). Preliminary work has also investigated self-generated thoughts in Alzheimer patients, and reported a further decrease of such experiences when compared to healthy older adults (Gyurkovics et al., 2018). This seems to further corroborate findings from this thesis that the DMN is at the centre of the age-related change in mind-wandering since Alzheimer patients present worsen DMN connectivity than healthy older adults (Greicius et al., 2004). Further work with

Alzheimer patients following the strategy and methodology used in Chapter 3 and 4 should confirm such claim.

Several other pathologies could inform the component processes account of mind-wandering. For example, individuals with Autism Spectrum Disorder present difficulties in executive function, theory of mind, emotion perception (de Vries & Geurts, 2015; Ozonoff, Pennington, & Rogers, 1991), and trouble with social interactions and introspection. ASD patients also experience more ruminative self-focus events (Crane, Goddard, & Pring, 2013), and tend to have a higher level of egocentrism (Frith & de Vignemont, 2005), despite impairments in introspection (Lombardo & Baron-Cohen, 2011). The distinctiveness of their relation to the self and to others could refine theories regarding the functionality of self-generated thoughts and particularly with regard to social problem solving. Additionally, difficulties in introspection may induce lower meta-awareness of mind-wandering experiences. Such investigation would clarify our understanding of the management process of self-generated thoughts in this developmental disorder.

Another suggestion is the investigation of patients with Schizophrenia Disorder. Somewhat in opposition to the older adults' profile, this pathology shows overactivity and overconnectivity within the DMN (Garrity et al., 2007; Whitfield-Gabrieli et al., 2009). Critically, patients' profile, namely poor self-consciousness (Danion et al., 2005; Potheegadoo, Cuervo-Lombard, Berna, & Danion, 2012), deficit in self-identity (Raffard et al., 2010), and mentalising (Dimaggio, Salvatore, Popolo, & Lysaker, 2012), could inform the self-referential feature of mind-wandering. One study found an increase of mind-wandering experiences in this population (Shin et al., 2015), which was related to the stronger manifestation of positive psychotic symptoms (i.e. severer presence of inner speech and delusional beliefs). The authors suggest that this could be mediated at a neural level, since frequent mind-wandering was inversely related to connectivity within the DMN in schizophrenia patients. Ultimately, several other pathologies presenting impairments in the integrity of the DMN could inform our understanding of these complex experiences, including Obsessive-Compulsive Disorder (Stern, Fitzgerald, Welsh, Abelson, & Taylor, 2012), Down syndrome, and Williams syndrome (Vega, Hohman, Pryweller, Dykens, & Thornton-Wells, 2015). The systematic study of self-generated thoughts in population with atypical DMN activity and connectivity will bring different visualisations of the complex relation between mind-wandering and the DMN. This could, then, lead to more applied research and the development of interventions targeting specifically the difficulties of these populations.

Overall, because of the recency of the mind-wandering literature, a plethora of recommendations can be formulated. In general, researchers should pursue the converging methods dynamic to refine and extend the knowledge gathered in this thesis.

7.6. Conclusion

To conclude, this project contributed to the understanding of mind-wandering experiences in ageing in a number of ways. Essentially, four salient findings were identified from this programme of work. First, evidence that age-related changes in mind-wandering experiences are bound to changes in the recruitment of the default mode network were provided. Second, age-related changes in mind-wandering experiences were found to go beyond a simple decrease in frequency. Older adults reported stable rates of positively oriented thoughts, a decrease of negatively biased thoughts, and more visual thoughts as well as task-related interferences. Third, mind-wandering experiences were highly sensitive to intrinsic and extrinsic factors. At an intrinsic level, cultural affiliation affected thought content, with the French culture favouring self-reflection. At an extrinsic level, experience sampling supporting meta-awareness was merely targeting temporal thoughts, difficult tasks tended to increase verbal rehearsal thoughts, and meditation specifically reduced negatively oriented past-oriented thoughts. Finally, thought content was experimentally modulated by the practice of meditation and activities hindering self-reference. This has opened the field for future research aiming to construct interventions targeting the negative effects of mind-wandering on task performance and mood. Overall, by the successful use of convergent methods, these findings have added to the theoretical understanding of the wandering mind, advancing our knowledge of age-related changes regarding behavioural and neural characteristics of self-generated thoughts.

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APPENDIX A: Instructions given to participants in both the control and experimental condition.

Control condition:

Please write down a short summary of the story you just listen to. Expand by adding any details, information that you remember, there is never too much information.

Experimental condition:

Please write down any thoughts, emotions, feelings, sensations that came to you during practice. Expand by reflecting on how this informs you further on your knowledge of yourself, your values, what is most important for you in life. Also, feel free to write anything that comes to your mind that you feel is important.

APPENDIX B: Transcript of one of the four guided meditation used in the experimental condition (Toe-Head).

Settling down into a comfortable position, taking your place on the floor and perhaps shifting hips, shoulders allowing the spine to straighten, opening the hands, letting your feet flop out gently to the sides. ***Before we begin the practice, be aware that your mind will wander during the meditation. Try to offer yourself compassion and just gently notice when you have wandered, and bring your mind back to the guidance, picking up where you left off.*** Letting your eyes close softly, softly becoming aware of your breathing, centering yourself there on the floor. Noticing how the breath moves gently in, and is held within, the body, and then how it is released, and held there outside the body. Noticing that the next breath comes quite naturally, that the body knows exactly how to pace the breath, enabling you to soften and come to stillness here on the floor. ***Feel the warmth of your body, the gift of the breathing, and bringing compassion to your body and yourself. During the meditation each time your mind wanders, just noticing that, and bringing a feeling of loving kindness and compassion for yourself, then gently coming back to the meditation practice.*** On the next in breath, just bring your attention to sensations around the heel of the right foot, where your foot meets the floor, resting attention gently, just noticing sensations of pressure from the floor, warmth of clothing or coolness, allowing sensations of urges to move or adjust your position, just noticing sensations and urges, ***offering thanks for the messages your mind and body give to you***, without having to act on them. J***ust letting the wisdom of your body let you know what's going on there*****.** Bringing your attention up and across the sole of the *hard working* right foot, bringing attention inside and through the *perfect* right foot, through the heel of the right foot, the arch, around the toes of the right foot, and being able to come back to the in breath, each time you notice that you've become distracted or led away by wandering thought, ***practicing softness and forgiveness around those distractions, accepting and letting go and then*** bringing attention back, to the whole of the right foot, with the next in breath. Sweeping attention up now through the right ankle, the right calf, noticing sensations of the floor beneath, support from the floor, feelings of temperature, of comfort or discomfort, urges to move or to be still, noticing without needing to respond and react, just noticing, then bringing your attention up over the right shin, on the next in breath, over the right knee cap and through the knee joint, back of the right knee, over and through the lower right leg, right ankle and right foot. ***Releasing, perhaps noticing thoughts of gratitude and thanks, of loving kindness for the hard working lower right leg and foot.*** On the next in breath, just notice sensations around the back of the right thigh, bringing your ***compassion and*** attention lightly, resting on the right thigh. The sensations of clothing, floor, temperature, allowing thoughts and sensations to arise, ***forgiving and thanking each one lightly, with loving kindness you can bring your attention back to the right thigh,*** right knee, right shin, calf and ankle, right foot. On the next in breath becoming aware of sensations through the left leg, perhaps of heaviness or light, on the next in breath you might like to rest ***your loving attention*** in turn, onto the left foot, heel of the left foot, through the arch of the ***hardworking*** left foot, the toes of the left foot, attention and awareness lighting on the left ankle, on the in breath moving awareness through the ankle joint up through left calf, over and through left shin, ***offering thanks and acceptance, giving love back, perhaps, and gentleness, to any thoughts, memories, internal dialogues that you just notice, can accept for later attention, and gently bring your loving attention back with the next in breath to the left knee.*** From the back of the left knee, through the joint to bring awareness to the left knee, sweeping attention up and over the left thigh, through the left thigh, sensations of support from the floor beneath the left thigh, and allowing your attention, on the next in breath, to move ***compassionately, with kindness*** and light through the upper left leg, left knee, the left calf and shin, the left ankle and leg foot. On the next in breath you're able to let your awareness encompass both legs, both knees, both ankles, both feet. On the next in breath you can bring your attention to sensations through the groin and seat, through the hips and belly, noticing and letting go of distractions, ***forgiving and offering loving kindness, acceptance in*** naming and deciding to bring your attention back, on the next in breath to sensations through the lower back, up through the navel, attention encircling the waist, without having to follow thoughts and distraction, you can just bring your attention back, on the next in breath to sensations across the ribs and through the ribs, sensations across the chest and breathing in, noticing sensations through the heart beat and lungs, breathing in, and allowing your attention to rest lightly on the movement of the chest, tummy and ribs, and breathing out, noticing sensations through the spine and you gently bring your attention through the body to the upper back, allowing your attention to move up and through the spinal column, through and between each rib. ***If your mind has wandered, just sending the thought or feeling a note of kindness, you can revisit this later, and coming back, to notice*** the support from the floor beneath you, bringing your ***compassion*** to the shoulder blades, each in turn, around the edges and deeper, to pockets of heat or tension under and through the should blades ***practising kindness around any areas of tension or heat, offering softness where tightness might be***. Letting your attention rest on the tops of both shoulders now, through the collar bone and base of the neck, moving ***loving kindness and compassionate*** attention through the upper arms, through skin, sensations of clothing, allowing yourself to notice when your thoughts have drifted away and ***with kindness, with love,*** gently bringing your attention back to the muscles of the upper arms, through the elbows, the inside of the elbows, breathing in and bringing attention through both forearms, taking each wrist in turn to visit first the right wrist, letting yourself become aware of sensations through and upon the wrists, the back of the right hand and the left hand, temperature, floor, comfort, softness, just letting thoughts arise without having to follow them, and on the next in breath bringing attention right through the bones of the hands, across and over the palms of the hands now and the fingers and finally the thumbs of the right hand and left hand. Able to attend, ***with love,*** lightly, breathing, upon any sensations through both hands, both arms, the elbows, breathing and allowing sensations through the shoulders and chest, through the ribs and spine, breathing and noticing, just noticing, and letting go of sensations through heart and lungs, navel and waist***. Allowing the wise body to notice any areas of tension or discomfort, allowing the distractions to be named, accepted and gently let go***. On the next in breath bring your attention to the neck and throat, swallowing and breathing, noticing and moving attention lightly, just noticing the thoughts or feelings that may come up and bringing your attention back ***with kindness, with thanks for the wisdom of the body. H***ere the lower jaw, through the jaw, the nape of the neck, tongue resting softly in the mouth, sensations across the chin, lips, through and over the nose, the cheeks and around to the back your head, breathing in, you can let your awareness rest upon the sensation of the breath moving through the nose, the sensations round the temples, the feelings around eyes, eyebrows and up and over the forehead to the very crown of your head. ***Allowing thoughts and feelings that arise as you hold your face gently in awareness, cradling the head, the neck the body in loving kindness, awareness giving way to forgiveness and loving compassion.*** On the next in breath you can gently bring your attention back to breathing and letting go of any sensations through the head and face, neck and shoulders, the arms and hands. On the next in breath just noticing and letting go of sensations through the shoulder blades and ribs, through the belly and lower back, breathing in, lighting upon the hips and groin, the thighs, knees, lower legs and feet, breathing in, aware of sensations through the whole body, breathing out and letting go, ***with loving kindness, with gratitude for the wisdom of the body, before*** bringing attention just to the next breath. Breathing. In a few moments a bell will ring to end the practise. For now, just breathing, awareness, ***acceptance, compassion and loving kindness, before bringing your attention back to the next inbreath***. ***Remember to breathe and smile.***