Reading minds: expanding the toolkit for studying spontaneous thoughts

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Declaration

I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature: ....

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Contents

Declaration …………………………………………………………………………………. i

Acknowledgements ……………………………………………………………………… ii

Contents …………………………………………………………………………………... iii

Summary ………………………………………………………………………………… 1

Preface …………………………………………………………………………………… 3

Chapter 1 – General Introduction and Thesis Overview ………………………………… 5

Spontaneous thoughts: A working concept ……………………………………………... 6

Spontaneous thoughts: Ubiquity and contents …………………………………………... 15

Spontaneous thoughts: Why should we study? …………………………………………... 17

Spontaneous thoughts: How can we study? ……………………………………………… 19

Current thesis: Aims and overview ……………………………………………………… 27

Chapter 2 – I can see your thoughts: indexing the occurrence of salient thoughts and characterising the priority map for internal distraction ……………………………………… 29

Abstract …………………………………………………………………………………... 29

Introduction ………………………………………………………………………………… 30

Method ……………………………………………………………………………………... 34

Results ……………………………………………………………………………………... 43

Discussion …………………………………………………………………………………. 53

Supplemental Materials …………………………………………………………………... 58

Chapter 3 – Establishing psychophysiological markers of executive and affective thoughts ………………………………………………………………………………………… 66

Abstract ……………………………………………………………………………………. 66

Introduction ………………………………………………………………………………… 67

Experiment 1a & 1b …………………………………………………………………… 75

Experiment 2 ………………………………………………………………..…… 81

General Discussion ………………………………………………………...….. 92

Supplemental Materials ………………………………………………………….. 95

Chapter 4 – Pandemic brain: Task focus and affect across the COVID-19 pandemic …………………………………………………………..………...………………. 105

Abstract ………………………………………………………………………. 105

Introduction ………………………………………………………………… 106

Experiment 1 ………………………………………………………………… 111

Experiment 2 ……………………………………………………………..…….. 118

General Discussion …………………………………………………..……… 123

Chapter 5 – General Discussion ………………………………………………… 124

Implications ………………………………………………………..……… 128

Future Directions ………………………………………………..……… 132

Limitations ……………………………………………………...………………. 133

Conclusion ……………………………………………………………..………. 134

References ……………………...………………….……………………………. 135

Appendix ………………………...…………...………………………………. 180

Summary

A very common and characteristic experience in the human mental life is the propensity to disengage from the external environment, including an ongoing task, into focusing internally, to our own thoughts. This has been termed mind wandering and is now a fast-growing area of research across disciplines such as philosophy, psychology and neuroscience. However, as a relatively new area of research, with much of its growing starting only two decades ago, there is still a lot of scientific work to be done in the area, including on finding the most scientifically sound ways to manipulate and measure those episodes. This is more critical for science because of the private nature of the phenomenon, which has been widely forcing researchers to resort on either subjective reports of mind wandering, which heavy reliance on introspection and meta-awareness can pose reliability and validity issues, or a combination of subjective reports with some objective markers of on- or off-task focus, which despite being a enormous step to objectively determine the state of mind wandering, does not help in terms of predicting or decoding the contents of thoughts. Investigating the contents of thoughts is of prime importance because most of the detriments (and benefits) of mind wandering have been linked to particular categories of thoughts. Therefore, the aim of this thesis is to add to the currently available set of objective tools for studying the contents of mind wandering by establishing neuroimaging and electrophysiological measures to help decode and predict the contents of thoughts. Because of the heterogeneity of the phenomenon, I do this buy focusing on specific dimensions of thoughts, drawing from the well-established literature on external attention all the way to considering some of the reviewed phenomenological accounts of mind wandering. It has been shown that people engage in mind wandering episodes either deliberately or spontaneously. In this thesis, when referring to mind wandering, we focused on the latter, and on associated categories of thoughts that are irrelevant to and away from the task, involuntary, repetitive, and sometimes personally or motivationally relevant.

In Study 1 (Chapter 2), I address the research gap on mechanisms of internal attentional capture by own thoughts, as opposed to well-studied external mechanisms, by using perceptual reactivations of a specific 'planted' thought about a person, to track a specific thought in the brain, in order to 'see' the occurrence of an involuntary and intrusive thought. For this I resorted on both univariate and multivariate fMRI approaches and looked into the Fusiform Face Area. I also used connectivity analysis to investigate the parallels between external and internal attentional capture, finding common parietal regions implicated. Then, my Study 2 (Chapter 3) is both a behavioural and an electrophysiology study in which I establish the phenomenological characteristics of the executive and affective dimensions of thoughts and resort on a combination of EEG and facial EMG to establish the objective neural and muscular markers of executive and affective thoughts. On Study 3 (Chapter 4) I quantify and characterise the extent and nature of the impact of the COVID-19 pandemic on task focus, and the role of negative affect. The research presented throughout this thesis has methodological implications, and also implications on mental and educational settings, which are discussed on the General Discussion (Chapter 5).

Preface

The current thesis is presented in the ‘scientific article format’, with the three empirical chapters consisting of distinct research papers, which were written on APA format and in a style appropriate for publication in peer-reviewed journals. Besides these, the thesis starts and ends with one theoretical chapter on each end, an introduction and overview of the thesis and a discussion and summary of the findings. Publication titles and author contributions are as follows:

Study 1:

Manguele, P., Racey, C., Bird, C., & Forster, S. (in prep). I can see your thoughts: indexing the occurrence of salient thoughts and characterising the priority map for internal distraction.

S. Forster & C. Bird contributed to the study concept and design. P. Manguele performed data collection and analysis under the supervision of S. Forster. All authors provided critical revisions of the analysis. P. Manguele drafted the manuscript, and S. Forster & C. Racey provided critical revisions. This research was presented at the Society for Neuroscience Global Connectome meeting of 2021.

Study 2:

Manguele, P., Wiegert, F., Dyson, B., Forster, S. (in prep). Establishing psychophysiological markers of strategic and affective future thinking.

Experiment 1: P. Manguele and S. Forster contributed to the study concept and design. P. Manguele performed data collection and analysis under the supervision of S. Forster, who also provided critical revisions. Experiment 2: and all authors contributed to study concept and design. P. Manguele, F. Wiegert performed data collection, with the help of A. Korbacz, as

Research Assistant. P. Manguele conducted data analysis. Data collection and analyses were performed under the supervision of S. Forster. P. Manguele drafted the manuscript. S. Forster provided critical revisions. The draft of this research was approved for the Cognitive Neuroscience Society meeting of 2021.

Study 3:

Manguele, P. & Forster, S. (in prep). Pandemic brain: Task focus and affect across the COVID-19 pandemic.

P. Manguele and S. Forster contributed to the study concept and design. P. Manguele performed data collection under the supervision of S. Forster. Both P. Manguele and S. Forster performed data analysis. P. Manguele drafted the manuscript and S. Forster provided critical revisions. The pre-registration of Experiment 2 can be accessed on Open Science Framework: https://osf.io/vg86y/[1].

[1] During embargo, it can be viewed using this link: https://osf.io/vg86y/?view_only=7b42625c2c2e4eefb89f7e95a89d6330. Complete file also on Appendix.

Chapter I

General Introduction and Thesis Overview

"Our mental life, like a bird's life, seems to be made of an alternation of flights and perchings." – William James, 1884

As William James so beautifully observed more than a century ago, our minds are anything but immobile. When focused within, there seems to be a natural tendency of our minds to be dynamic, sometimes drifting from content to content. This William James' quote was used by Christoff and colleagues (2016), to point to the unconstrained and meandering nature of spontaneous thoughts. However, from what I see, it is also in the nature of birds to be repeatedly drawn back to their nests, an analogy that could mean that our minds can feel drawn to move back and around the same contents. For example, Edna could be driving home from work, intending to focus on the news on the radio, just to suddenly find that, once again, she has been unwillingly rehearsing the words that she should have said to a certain person, thinking of what she will tell them tomorrow, then planning the outfit she will wear to an upcoming meeting, and, with a sad feeling, thinking of how poorly she went at work today, and what she really must tell that person tomorrow… and so forth.

We could also agree that some spontaneous and involuntary sort of thinking is happening to her, even though this is a private phenomenon, with its depths unnoticeable to an external observer. But even if the observer could roughly tell that she is involved in some form of inward focus, because she looks absorbed, it would be almost impossible to tell with a naked eye what the contents of Edna's thoughts are. This concealed nature made this experience somehow largely overlooked by researchers, until the last few decades (Smallwood & Schooler, 2006), although succeeding inaugural work by names such as Singer (1966), Klinger (1971) and, Antrobus and colleagues (1966). The phenomenon of an automatic stream of thoughts has caught the attention of cognitive researchers, from philosophy to psychology and neuroscience. This blooming is vastly due to advances in more objective research methods (for a review see Smallwood & Schooler, 2015) to accompany the usually used subjective methods. Thus, further investigations started, most with an emphasis on establishing objective markers of the phenomenon's occurrence (e.g., Tusche et al., 2014; Braboszcz & Delorme, 2011; Gruberger et al., 2011; Christoff et al., 2009; Franklin et al., 2011; Mills et al, 2016).

However, as this is a very heterogeneous phenomenon (Wang et al., 2018) and a young science (Irving & Thompson, 2018), methodologically there is still a long way to go, especially concerning not only tracking the occurrence but also decoding the contents of thoughts. As such, the overall aim of this thesis is to contribute to the toolkit of research methods to study spontaneous thoughts and mind-wandering, with a focus on the contents and objective measures. In this introductory chapter, I will start by establishing a working definition of the phenomenon for the context of this thesis and offer an overview of relating and, sometimes, overlapping concepts. I will then delve into how characteristic this phenomenon is for humans, offer a rationale for researching into this, and explore how it has been investigated thus far. To close this introduction, I present a more comprehensive purpose of the thesis and an overview of the upcoming chapters.

1.1.Spontaneous thoughts: a working concept

In this thesis, I use the term "spontaneous thoughts" to investigate a phenomenon that has been studied under a few parallel and somehow overlapping terms. I do not aim at coming up with a conclusive definition of this phenomenon, as the scientific field is in its early stages and no definitive consensus has been reached thus far (e.g., see Irving & Thomson, 2018; Christoff, 2012; Metzinger, 2013; Seli et al., 2018a, 2018b). However, even without a conclusive definition, the field is growing (Seli et al., 2018b) and there is no denying its importance (Smallwood & Schooler, 2015). Therefore, for this thesis, I am next going to establish the definition that best encompasses the aspects of the phenomenon as they are being investigated in the empirical chapters of this thesis, mainly from the perspective of the fields of mind wandering and spontaneous thoughts research, to offer my methodological contribution for further research. I will also offer an overview of analogous or related concepts that, even when studied from different fields, sometimes coincide, or partly covers, what is being studied by mind wandering researchers.

1.1.1. Definitional proposals

Since the blooming of the research field in the early 21st century, there have been many attempts, ranging from philosophy to psychology and neuroscience, to define and delimitate the borders of the phenomenon experienced in the example of Edna's thoughts described earlier. Nowadays, an attention researcher could argue that it is a form of mind wandering (Smallwood & Schooler, 2006; 2015) because the traditional mind wandering content-focused defining traits are present: Edna is involved in a form of task-unrelated thought (TUT; Smallwood et al., 2011; Kane et al., 2007; Killingsworth & Gilbert, 2010), i.e., she is not focused on her current intended task, which is hearing the news; and she is having stimulus-independent thoughts (SITs; Smallwood, 2011; Smallwood & Schooler, 2006; Stawarczyket al, 2011), i.e., her thoughts are detached from her immediate external environment. However, in the example, there are other characteristics of the phenomenon that could be argued to pertain to a broader grouping of classes of thought, e.g., rumination or future planning, of which mind-wandering is also part (Seli et al., 2018a) but which is perhaps not the full story (Irving & Thomson, 2018; Christoff et al., 2016).

There have been two main and conflicting lines of definitions of mind wandering and spontaneous thoughts by researchers. There is the 'Family Resemblances Framework', proposed by names such as Seli, Kane, and Smallwood (Seli et al., 2018a, 2018b), and the 'Dynamic Framework', including names such as Christoff and Irving (Christoff et al., 2016; Christoff et al., 2018). In the context of this thesis, we see the advantages and disadvantages of both. The 'Family Resemblances Framework' proposes that, given its intrinsic heterogeneity and multidimensional nature, researchers should distinguish between types of mind wandering when studying the phenomenon, and disclosure what facets are under examination on given research (Seli et al., 2018a). They suggest that the different facets of thoughts that are usually treated as within the umbrella of mind wandering do not challenge one another (Seli et al., 2018a; 2018b). The proponents have specifically into account examples that include task-unrelated thoughts (e.g., Smallwood & Schooler, 2006; Mills et al., 2017), stimulus-independent thoughts (e.g., Smallwood, 2011; Smallwood & Schooler, 2006), a combination of both stimulus-independent and task-unrelated thoughts (SITUTs; Stawarczyk et al., 2011), unintentional thoughts (Seli, Risko, & Smilek, 2016), and even unguided thoughts (Irving, 2016; Irving & Glasser, 2019; Irving & Thomson, 2018); all of this without excluding task-related thoughts, thoughts that are initiated from an external stimulus, intentional mind wandering, nor perseverative thoughts (Seli et al., 2018a). Attempting to define a concept in such broad ways seems problematic and even counterintuitive with what a definition is supposed to be "making something definite, distinct or clear" (Collins English Dictionary, n.d.). However, this does not contradict the special nature of the phenomenon at hand: heterogeneous (Wang et al., 2018). And this nature does not seem to impede advances in research. Therefore, even if not entirely helpful, this framework is a recognition that overlapping types of thoughts have their space on the research of mind wandering, and it is a reasonable request to specify the types of thought at play in the context of each research.

Off all the aforementioned types of thoughts, however, the 'Dynamic Framework' only considers as mind-wandering thoughts that are specifically unguided (e.g., Christoff et al., 2018; Irving, 2016; Irving & Glasser, 2019), and that mind-wandering is only one exclusive situation of spontaneous thoughts, the range of other situations including even dreams, but excluding what they consider constrained thoughts, such as ruminations and goal-driven thoughts (Christoff et al., 2016). This view of mind-wandering is very specific also because it challenges the standard traditional definitions. For example, Irving (2016), a pioneer on proposing mind wandering as 'unguided attention', considers that the defining trait of mind wandering, instead of being task unrelated or stimulus-independent, or even the combination of both (SITUTs; Stawarczyk et al., 2011), is its very moving and dynamic aspect (such as described for example in Christoff, 2012). Irving suggests that, by its literal meaning, mind wandering should point to thoughts that move unconstrained from one topic or content to another (e.g., Irving, 2015; Irving & Thomson, 2018; Irving & Glasser, 2019). The popular definition of mind-wandering as task unrelated thought, in the sense that it is a deviation from a current task (e.g., Smallwood & Schooler, 2015; Kane et al., 2007), has hence been challenged (Irving & Thomson, 2018) on the grounds of its very name (i.e., wandering) and on the further grounds that there are both task-related thoughts that should be classified as mind wandering, for example, appraisal of the current task, and there are task unrelated thoughts that are not mind-wandering, such as rumination and perseverative cognition, because these are not unconstrained as the person keeps being driven back to them. The 'Dynamic Framework' also disputes the second aspect of the traditional definition of mind wandering, in which it is stimulus-independent or also decoupled from perceptual input (Smallwood and Schooler, 2006; Smallwood et al., 2008; Schooler et al., 2011), since mind-wandering can be triggered by the environment (e.g., Christoff et al., 2016). Despite challenging traditional views and excluding the majority of thoughts that have, thus far, been studied as mind wandering

(Smallwood & Schooler, 2015), this framework is corroborated by neuroscience investigations, in particular, those focused on dynamic brain interactions, for example, Kucyi (2018) suggest that dynamic functional connectivity best captures interactions between networks during mind wandering as they fluctuate over time. Zabelina & Andrews-Hanna (2016) has found this to be true more broadly for internally directed attention. In contrast to the classical definition, they propose that only thoughts that meander without guidance or control should be treated as mind wandering (Irving & Thomson, 2018). A problem with this definition is that it represents a narrower subset of thoughts, and would thus exclude thoughts with motivational or affective salience, such as involuntary intrusive thoughts (Maillet & Schacter, 2016), worries and ruminations (Ottaviani et al., 2015), and goal-directed or personally relevant thoughts (e.g., Klingler, 2009; Baird, Smallwood & Schooler, 2011), current concerns (Klinger, 2009) and many other categories of thoughts that have been researched under the term mind wandering. Besides, there are views that mind-wandering can be both uncontrolled and involuntary, and revolving around the same topics (Baars, 2010; Berntsen, 2019). This framework attempts to be more definite when conceptualizing both mind-wandering and, more broadly, spontaneous thoughts, and they seem to attempt to avoid the heterogeneity of the former framework (Christoff et al., 2018). But even when defining spontaneous thoughts there are important categories of thoughts that are left behind, those same categories that are included in the Family Resemblances Framework (Seli et al., 2018a), because those are not considered unconstrained, freely moving cognitions. Nevertheless, a debate by Seli et al. (2018b) raises the controversial issue that a definition-based thought being unconstrained points back to its heterogeneity, which is a reason to have an umbrella definition and to specify the limits of what thoughts are included in each research.

Therefore, in this thesis I focus on off-task and stimulus-independent thoughts (in all chapters), also thoughts that could fall into the category of involuntary and intrusive (Chapter

2), and thoughts that are related to our current concerns (Chapters 3 & 4). Therefore, the umbrella concept of 'spontaneous thoughts' seems to be the most adequate as our working term. In the EEG study of chapter 3, we also develop a guided, i.e., non-spontaneous thought paradigm to establish markers to be expanded to the study of specific spontaneous thoughts, because a guided paradigm offers the methodological control that sometimes the direct study of spontaneous thoughts lacks. For the sake of this thesis, I consider spontaneous thoughts as broader than the working definition used by Christoff et al. (2016), as I also include what they consider constrained thoughts: ruminations and goal-driven thoughts. In this work, I take spontaneous thoughts as thoughts that arise involuntarily, as opposed to voluntary or guided thoughts. My definition of spontaneous thoughts is more in line with that of Marchetti et al. (2016), in which spontaneous thoughts are an umbrella concept that ranges from mind wandering and daydreaming (Singer et al., 1975; Klinger, 2009) to other involuntary cognitions, but that do not exclude maladaptive cases such as rumination and intrusions, which are uncontrollable by nature (England & Dickerson, 1988) and involuntary retrieval. I also draw from the distinctions, in terms of intentionality (O'Neill et al., 2020), between spontaneous and deliberate (i.e., involuntary versus voluntary) thoughts that have been suggested by Seli et al. (2014; 2016).

In the current work, the definition of spontaneous thoughts is used in a broader sense than that established by Christoff et al. (2016) and Andrews-Hanna et al. (2018), who understand spontaneous thoughts as a family of mental phenomena that is characterised by their dynamic nature, their spontaneity and their unguidedness, and as such, as being relatively free from deliberate and automatic constraints, which could the mental state both in its fluidity and contents (Kongedi & Maleeh, 2021). Deliberate constraints are top down and related to cognitive control and the fronto-parietal control network (Miller, 2000; Dixon et al., 2014), whereas automatic constraints are bottom-up and related to salience, this being sensorial or affective (Kongedi & Maleeh, 2021; Andrews-Hanna et al., 2021). In this manner, the authors different spontaneous thoughts from goal directed thoughts (deliberately constrained, even if internally) and from rumination or obsessive thoughts (automatically constrained). And by considering mind wandering thoughts as being unintentional, they come close to that categorisation of mind wandering made by Seli et al. (2014; 2016), in terms of intentionality. For Seli et al. (2014; 2016), mind wandering can be intentional or unintentional, the former being formed of thoughts with a deliberate origin, usually a goal-directed thought (including personal concerns), whereas unintentional mind wandering would arise spontaneously.

For the sake of this thesis, and unless otherwise specified, I use the term mind wandering interchangeably with spontaneous thoughts, and I also consider those to be self-generated thoughts that can both be unguided, as in Christoff et al. (2016) classic definition of spontaneous thoughts, as well as those thoughts that they consider as having automatic constraints, such as ruminations and intrusive thoughts. All of them pertaining to the category of unintentional mind wandering, as considered by Seli et al. (2016).

1.1.2. Definitions and associated concepts

In this context, some of the associated or even overlapping concepts to spontaneous thoughts include intrusions or intrusive thoughts, a class of involuntary thoughts that are by nature repetitive (Parkinson & Rachman, 1981) and unwanted (Clark & Purdon, 1995), uncontrolled (Berntsen, 2019; Brewin, 2010), and which are usually more frequent with attempts to suppress (Salkovkis & Campbell, 1994; Berry et al., 2010), therefore experimental paradigms of intrusive thoughts usually use thought suppression. Seli and colleagues (2017) have recently explicitly associated intrusions to mind wandering research. The authors have shown that intrusive thoughts are positively related to spontaneous mind wandering, and not to deliberate (Seli et al., 2017). Ruminations are another type of thoughts that offer some controversy on whether they should be classified as part of the mind wandering umbrella or not. Regardless, this controversy points to some associations. Ruminations or ruminative thoughts have been considered an extreme category of negatively valenced task-unrelated thoughts (Fredrick et al, 2020), which, alongside mind-wandering are correlated to inattention in ADHD symptomatology (Yeguez et al., 2018), and it has also been linked to anxiety and depression (McLaughlin & Nolen-Hoeksema, 2011), but also arising in non-clinical contexts (DuPre & Spreng, 2018). The perseverative nature of ruminative thinking (Ottaviani et al., 2015; Ottaviani, Shapiro, & Couyoumdjian, 2013) is what brings some dispute on whether this should be classified as mind wandering, and even spontaneous thoughts, or not. DuPre and Spreng (2018) have defined rumination as a constrained type of cognition, in line with the 'Dynamic Framework', but also considering it within the umbrella of spontaneous thoughts; and it has been positively linked to mind wandering frequency (Shrimpton, McGann & Riby, 2017).

Spontaneous prospective thinking or spontaneous future cognitions are also concepts that have recently been associated with mind-wandering and spontaneous thoughts. Berntsen (2019) proposes that spontaneous future thinking, even though coming from mental time travel research, and not from attention research as mind wandering, could conceptually be a special case of mind wandering about the future. This would be both in line with accounts of mind wandering as mental time travel. Tulving (1985) termed mental time travel (MTT) to the human capacity to mentally re-experience personal past events or pre-experience future ones. It has been repeatedly shown that this happens during mind wandering (e.g., Miles et al., 2010; Karapanagiotidis et al., 2017; Corballis, 2012), and with a specific propensity of mind-wandering thoughts to be oriented to the future (i.e., prospective bias; e.g., Grant & Walsh, 2016; Smallwood et al., 2009; Spronken et al., 2016; Stawarczyk et al., 2011) as opposed to the past or present. Grant and Walsh (2016) have shown that 20% of everyday life mental time travel is made of episodic thoughts about one's future. However, mind wandering has also been linked to involuntary retrieval of episodic memories (Maillet & Schacter, 2016; Riby, Smallwood, & Gunn, 2008), and which has been shown to result in fewer thoughts about the past in individuals with hippocampal damage (McCormick et al., 2018). This bias has been suggested to be an adaptive trend since the future can be changed, but the past cannot (e.g., Burns et al, 2019).

This inclination to engaging in thoughts that are away from the present moment has been considered to have some adaptive functions, such as helping people preserve their sense of self-continuity across their personal timeline (autonoetic consciousness; Tulving, 1985). Most researchers, however, agree that a key function seems to be future planning, personal goal setting, and even duelling with personal concerns and worries (Stawarczyk et al., 2011). The current concerns framework is an explanation to mind wandering drawn from Klinger's current concern hypothesis (e.g., 2004; see also McVay and Kane's 'control failures versus current concerns' framework, 2010) suggesting that mind wandering and daydreaming are commonly associated to a person's unfulfilled goals and personally relevant preoccupations.

These overlapping and associated concepts come to reinforce the idea that mind wandering, and spontaneous thoughts are a heterogeneous and multidimensional field of research (Wang et al, 2018; Gonçalves et al., 2020) even overlapping with other fields of research. In this thesis, I acknowledge this heterogeneity, and present work on spontaneous thoughts and mind-wandering, from the perspective of attention research, as I mentioned before, as involuntary task-unrelated thoughts. However, the same way as we can draw from deliberate or voluntary cognitions to help understand spontaneous thoughts (Chapter 3), in attention research we can also look at spontaneous thoughts as a form of internally focused attention or distraction, as opposed to externally focused attention or distraction, with the possibility of drawing from the latter to understand the former (Chapter 2). Regardless of whether it has a conclusive definition or not, one thing that mind wandering and spontaneous thoughts researchers seem to agree upon is that this phenomenon is very pervasive in human experience. We will delve into that next.

1.2. Spontaneous thoughts: ubiquity and contents

The rather recent scientific interest in mind wandering and spontaneous thoughts contrasts with how ubiquitous and frequent this phenomenon is for human minds. The ubiquitous aspect was acknowledged from the early stages of scientific research in the field, suggesting that we spend about half of our waking lives immersed in daydreams (Singer, 1966). Research has now shown that we spend around 30-50% of our daily lives in self-generated thoughts and feelings (Killingsworth & Gilbert, 2010; Kane et al., 2007) which seems to be consistent with both laboratory and experience sampling experiments. The rated frequency of mind wandering episodes can, however, show variance depending on several aspects. For example, the familiarity of or level of practice with the current task is positively correlated with mind-wandering episodes (Mason et al., 2007; Smallwood & Schooler, 2006). The same is true of levels of task difficulty (Feng, D'Mello, & Graesser, 2013), and time on task (Thomson et al., 2014; Krimsky et al., 2017). Experimental manipulations also seem to play a role in variations of mind wandering frequency. For instance, the addition of verbal cues has been shown to increase mind wandering rates (Vannucci, Pelagatti, & Marchetti, 2017; McVay & Kane, 2013). Manipulations that involve increasing negative affect and current concerns also seem to boost the occurrence of mind wandering (Stawarczyk, Majerus, & D'Argembeau, 2013). Cognitive researchers have also shown that rates of mind wandering vary with changes in perceptual demands (Forster & Lavie, 2009), and individual differences in with working memory capacity (WMC), in which subjects with lower WMC have been shown to present increased mind wandering (Kane et al., 2007; Kane & McVay, 2012; Kane et al., 2017). In adult samples, age seems to be negatively correlated to the frequency of mind wandering

(Jackson & Balota, 2012; Lindquist & McLean, 2011; Maillet & Rajah, 2012; Maillet et al., 2018; Jackson & Balota, 2012; Krawietz et al., 2012). It is also shown to be increased in persons with some clinical symptomatology, such as depression (e.g., Smallwood et al., 2004) and dysphoria (e.g., Carriere et al., 2008), anxiety (Figueiredo et al., 2020), and especially ADHD (Seli et al., 2015; Figueiredo et al., 2020). Time of day and circadian rhythms also have been shown to affect mind wandering frequencies (Smith et al., 2018). Whether a person engages in mindfulness activities and meditation also seem to impact the occurrence of mind wandering (Brandmeyer & Delorme, 2018). Even the usage of oral contraceptives has been shown to increase the frequency of mind-wandering in women when compared to women that did not use any contraceptives and with men (Raymond et al., 2019). In academic settings, the mind wandering occurrence is also affected throughout the semester (Wammes et al., 2016) and even by where a student seats during class (Lindquist & McLean, 2011). When reading, it is increased if the text is less interesting (Smallwood & Schooler, 2006). Besides all of this, previous research comparing spontaneous and deliberate mind wandering has also seen differences (e.g., Robison & Unsworth, 2018; Vannucci & Chiorri, 2018; Seli, Risko, & Smilek, 2016; Robison, Miller, & Unsworth, 2019). For example, Seli et al. (2015) has shown that rates of intentional and unintentional mind wandering differ in the presence of ADHD symptomatology comparing to controls, with higher rates of unintentional MW linked to ADHD.

Although for a long time focus on off-task thoughts or SITUT ignored the contents of thought, more research has put much more focus on this, highlighting not all forms of off-task thoughts are equal in terms of their experience or impact. The contents of spontaneous thoughts can be as vast as the human imagination, but research has allowed us to find consistent dimensions around which mind-wandering can move (e.g., Klinger & Cox, 1987; McVay, Kane & Kwapil, 2009; Smallwood et al., 2016; Mills et al., 2018). Some of those dimensions include imagery, temporal orientation, temporal distance, emotional valence, level of strategy (i.e., how strategic and goal directed a thought it, as opposed to passive imagination), and social-related content. Those dimensions must be taken into account to better understand the impacts of mind wandering on people's lives, as consequences seem to depend on both the context of occurrence, for example, during car driving or aviation piloting, and the content mind wandering, for example negative, repetitive thoughts (Smallwood & Andrews-Hanna, 2013). In upcoming chapters, I will propose methods that focus on the contents of thoughts, in contexts such as a lecture (Chapters 3 and 4) and during a personally stressful time (Chapter 4), and during a vigilance task (Chapter 2). In the next section, I present a rationale for the study of spontaneous thoughts, including in contexts like the ones I have just described. In the following section, I review current research methods as focused on either the contents or the occurrence of mind wandering.

1.3. Spontaneous thoughts: why should we study?

One important reason to investigate mind wandering has to do with the potential negative impacts of this very ubiquitous phenomenon. The interplay between costs and benefits of mind-wandering is complex, and a better comprehension of the phenomenon has the potential to reduce the impacts of its downsides while boosting its functions (Smallwood & Schooler, 2015). In terms of comparing negative and positive consequences, there have been a much higher amount of studies reporting negative results than positive ones (Mooneyham & Schooler, 2013), which could lead to the speculation that perhaps the costs of mind wandering outrun the benefits. Some of the documented positive consequences of mind wandering include functions such as future planning (e.g., Baird, Smallwood, & Schooler, 2011), with the potential to help on goal attainment, and creative problem solving (Zedelius & Schooler, 2015; Yamaoka & Yukawa, 2016; Tan et al., 2015). Here we will focus on the negative impacts, namely the detriments to a current task and the maladaptive types of thoughts.

Disruptions on an ongoing task focus, usually assessed by performance (e.g. Smallwood, 2011) range from negative impacts on driving (e.g., Berthié et al., 2015; He, Becic, Lee, & McCarley, 2011; Pepin et al., 2020; Yanko & Spalek, 2014), aviation (Gouraud, Delorme, & Berberian, 2017; Casner & Schooler, 2013), on medical practice (Smallwood, Mrazek, & Schooler, 2011), and other tasks that require vigilance and monitoring (Thomson et al, 2015; Casner & Schooler, 2015;), all of which can cause life-threatening accidents. It has also been shown to have negative impacts on education (Wammes et al, 2016; Smallwood, Fishman & Schooler, 2007; Szpunar, Moulton, & Schacter, 2013), specifically on reading comprehension (Feng, D'Mello, Graesser, 2013; Kopp & Mills, 2015; Franklin, Smallwood, & Schooler, 2011; Uzzaman & Joordens, 2011), and task performance (Brosowsky et al., 2020; Dane, 2018). There are costs in sustained attention in general (e.g., McVay & Kane, 2009), and memory costs (e.g., Risko et al., 2012; Mrazek, Smallwood, & Schooler, 2012; Smallwood et al., 2007). It has also been shown to impair response inhibition (Kam & Handy, 2014; Smallwood, McSpadden, & Schooler, 2007). Finally, it has also been shown to impair performance in everyday tasks in general (McVay et al., 2009). These disruptive effects are consistent with the status of attention as a gateway to information processing, well known that reducing attention powerfully reduces neural processing of external stimuli and current tasks (e.g., Hove et al., 2015; Head & Healton, 2013) hence, when attention is misdirected to a thought instead of the task, reduce neural resource allocated to task processing (Smallwood & Schooler, 2006).

Besides these task disruptions, mind wandering has also been linked to mental health and psychopathology symptomatology (see some reviews: Brewin et al., 2010; Clark et al., 2015; Holmes & Mathews, 2010), for example in depressive rumination (e.g., Shrimpton, 2017; see Associated Concepts on Section 1.2.2), and intrusions of threat in anxiety (e.g., Beck, Laude & Bohnert, 1974; Ottaviani & Beck, 1987) and OCD symptomatology (Seli et al., 2017). Marchetti, Van de Putte, and Koster (2014) have also shown a broader association between spontaneous thoughts and depression, and personality traits that increase psychopathology proneness (Zhiyan & Singer, 1996). Therefore, as a phenomenon with profound real-world consequences, it is important to be able to both track and understand mind wandering.

1.4. Spontaneous thoughts: how can we study?

Before answering "how we can study" spontaneous thoughts, the first question could be "what can we study", whether we will be measuring thought contents or the context of the occurrence (Smallwood & Andrews-Hanna, 2013). A lot of the initial research focused on establishing the occurrence of a broadly defined concept of mind wandering (see Section 1.1.1). yet, phenomenological research highlights the existence of different types of thoughts, that can be aggregated into specific dimensions that facilitate research. For example, those dimensions can each have different impacts and neural signatures (see Section 1.2). Below I will review each method as used to study either the occurrence or contents of thoughts.

1.4.1. Subjective measures

Given its private nature, MW is usually approached using subjective reports. Research using subjective measures faces the problem of verification due to a weighty reliance on introspection and meta-awareness, but until methodological advances allow for more objective techniques that allow for better access and manipulation of such a private, introspective, and spontaneous phenomenon, the following are the methods through which spontaneous thoughts have been subjectively studied.

Questionnaires and surveys. Self-reports in the form of surveys have been long used to study both the occurrence and contents of mind wandering, as it allows subjects to not only confirm whether they were engaged in mind wandering but also to explain, to some degree, the contents by ticking on certain categories pre-determined by the researcher. This was the most adopted method from the early days of mind wandering investigations, in the 1960s and 70s.

Some examples are the Daydream Questionnaire (Singer & McRaven, 1961), and more modern ones including the the Amsterdam Resting-State Questionnaire (ARSQ; Diaz et al., 2013), and the Thought Characteristics Questionnaire (TCQ; Stawarczyk et al., 2011).

Thought probes. This is another category of favourite methods from an early stage of investigating mind wandering, pioneered by Klinger (e.g., Klinger & Cox, 1987). Two variations of the method are used currently, either 'probe-caught', in which the subject is intermittently interrupted during a task to report on their focus, and 'self-caught', in which the subject reports each time they catch themselves mind wandering (Stawarczyk et al., 2011. Martinon et al., 2019. Weinstein, 2018). This method can also be used to investigate both the contents and the occurrence of off-task thoughts, depending on how the researcher phrase the instructions and questions.

Self-recording. Finally, another subjective method to investigate mind wandering is through self-recording (Wheeler & Reis, 1991), in which subjects are invited to keep records, for example a diary, of their thoughts either at a given time of the day or when they notice. This method can be very free for subjects, in terms of what they include in the record, and can record both off-task by its occurrence and contents, it still requires some degree of instructions, but with less reliance on very constrained categories pre-established by the researcher.

1.4.2. Objective measures

Objectively, MW experience have been measured using behavioural measures, such as reading comprehension and eye movements during reading, both showing attention as being decoupled from perception. Schooler et al. (2011) found MW to be negatively correlated with precision of comprehension during a reading task. Other studies have found that variations in reaction time (e.g., Franklin et al., 2011) and in accuracy (e.g., Bastian & Sackur, 2013) are good indications of task disengagement and inwards focus during mind wandering.

In terms of oculometry, Reichle et al. (2010) have shown that SITUTs during reading have influences in patterns of eye movements, usually marked by longer fixation and being sensitively decoupled from the text. Some techniques include tracking gaze (Mills et al, 2016), and even fixation lengths (Foulsham, Farley, & Kingstone, 2013; Reichle, Reineberg, & Schooler, 2010). Presence of SITUTs also attenuates the amplitude of task-evoked changes in pupil diameter (Smallwood & Schooler, 2015; Grandchamp, Braboszcz, & Delorme, 2014; Konishi et al., 2017).

Both the behavioural and eye-tracking methods seem to be valid markers of on- versus off-task engagement, to detect the occurrence or state of mind wandering as opposed being on-task but are difficult stand-alone methods for investigating the contents of thoughts.

Neurocognitive measures, such as neuroimaging through fMRI and electrophysiology through EEG, have also been shown to be accurate objective measures. SITUTs have been found to reduce the amplitude of neural response signalled by ERPs, in opposite to externally-focused attention, and diminishing the auditory and visual cortical processing at sensory level (Schooler et al., 2011) In particular, the amplitude of some ERP components, such as the early perceptual ones like the visual P1, have been shown to be reduced during internally-focused attention (e.g., Clayton, Yeung, & Kadosh, 2015; Braboszcz, & Delorme, 2011; Villena-González, López, & Rodríguez, 2016). Time-frequency analyses have also shown that we can reliably predict the state of mind wandering or internal attention by looking at increased alpha (e.g., Braboszcz, & Delorme, 2011; Brandmeyer & Delorme, 2018; Tasika et al., 2020; Kam et al., 2021)

Regarding fMRI, a wide amount of studies have shown links between mind wandering state and the Default Mode Network (DMN; Gusnard & Raichle, 2001; McGuire et al., 1996) which was at the time named as ‘task-negative’, and which has been consistently found to be active during mind wandering, in particular the medial prefrontal cortex (e.g., Andrews-Hanna, Smallwood, & Spreng, 2014; Christoff et al., 2009; Andrews-Hanna, 2012; Gruberger et al., 2011; Benedek, 2016; Murphy et al., 2019; Mo et al., 2013; Danckert & Merrifield, 2018; Poerio et al., 2021; Smallwood et al., 2021), other areas consistently active include the medial temporal lobe, the dorsolateral pre-frontal cortex, and the anterior cingulate (for reviews and meta-analyses see: Smallwood et al., 2021; Fox et al., 2015). Other studies have investigated dynamic connectivity across areas to capture the free-floating nature of spontaneous thoughts (e.g., Kucyi et al., 2017; Zabelina & Andrews-Hanna, 2016; Denkova et al., 2019).

These mostly neuroimaging and electrophysiological findings facilitate the study of mind wandering by detecting their occurrence. Specifically, by establishing whether the person is on- or off-task, for example by increased EEG alpha or decreased perceptual ERPs, or fMRI activation of the DMN. Currently, however, there has been a surge on multivariate and brain decoding methods, that help investigate the contents of mind wandering (e.g., Zhigalov et al., 2019; Weng et al., 2020; Polychroni, Ruiz, & Terhune, 2021; Jin et al., 2019, 2020; Putze, Scherer, &, Schultz, 2016; Dhindsa et al., 2019; Tusche et al., 2014). These methods have a lot of potential for the advancing research on phenomenological aspects of mind wandering. For example, Tusche et al. (2014) used MVPA of fMRI to classify affective mind wandering during rest in terms of contents. However, in terms of EEG, most of these methods are still being used to classifying between states of internal versus external attention, and not so much to distinguish contents within internal attention (for example, Dhindsa et al., 2019). Hence, one of the aims of this thesis is to bridge that research gap and see if we can allow ourselves the possibility of studying specific phenomenological dimensions within the mind wandering state using electrophysiology. I address this on Chapter 3. However, I also understand the importance of drawing from well-established external attention literature in order to investigate mind wandering. Finding sound parallels could not only help us understand the phenomenon better, but has also the potential to spare time on brand new interventions for attentional capture by internal stimuli when we could follow ones already established for distraction and attentional capture by external distractors. In Chapter 2, I sought to do this, and I also attempted to make use of advances in multivariate neuroimaging to see a particular type of thought.

1.4.3. Reducing reliance on subjective reports

As we saw above, there are sound research methods to investigate mind wandering, from subjective to objective, depending on the research interests. Because of the private aspect of mind wandering, subjective measures have been widely used. Research using subjective measures faces the problem of verification due to a weighty reliance on introspection and meta-awareness, making it pertinent to assess the validity of the reports (e.g., Smallwood et al., 2021). The accuracy of the reports can be verified through triangulation (Smallwood & Schooler, 2015), in which the experimenter obtains data from further sources, e.g., using the behavioural and neuroimaging methods above. The limitations of self-report measures are particularly heightened in populations that cannot offer subjective reports, as is the case of little children. This could explain why there are currently very few mind wandering studies having children as subjects. But before we delve into the current difficulties of studying mind wandering in children, I will focus a bit more on the problems and promises of subjective reports.

As I mentioned earlier, mind wandering is highly private, and subjective by its very definition (Seli et al., 2013). The current subjective experience sampling methods used, and in particular the probe caught method which is the main method (see above and also Weinstein, 2018), have reliably and consistently been shown to be associated with task performance, therefore we should not disregard this as a valid method (Seli et al., 2013). The other type of commonly used self-report in the study of mind wandering, the self-caught method, is a bit more problematic because of the reliance on meta-awareness (Weinstein, 2018; Smallwood &

Schooler, 2015). Regardless, self-reports, in the way that they have been used and in the context of mind wandering present some challenges that span from how we design the probe rates (i.e., how frequently participants are asked to report; see Seli et al., 2013), and even how the probe is framed, for example if is it just a dichotomous question of whether the subject is on-task or not (Weinstein, De Lima, & van der Zee, 2017). Overall, and as explained by Zedelius, Broadway, & Schooler (2015), the mere fact of asking subjects to report on this mental phenomenon might per se change its nature, besides potential subjects' discomfort regarding disclosure of their mental state, especially when being made aware of their mind wandering frequency through self-reporting probes (see Schubert, Frischkorn, & Rummel, 2020). Even though triangulation with objective measures has been suggested to assist on the challenges of subjective measures, the latter still remain extremely important to the study of such a subjective experience, but there is an opportunity through triangulation and through the implementation of subjective measures to expand our understanding of the phenomena in ways that subjective reports could not alone reach. For example, triangulation or the use of objective measures could potentially open ways to further the study of mind wandering in children populations.

Regardless of being repeatedly acknowledged that MW can have detrimental effects on learning, very few studies have focused on school-aged children's MW experiences. From the scarce research that can be found, there is the study conducted by Ye et al. (2014), exploring the temporal orientation of MW in children and its relationship with executive functions. Their study focused on mental time travel in 8-year-old children and above because, as per their review, children below this age were unable to report with precision on their introspective experiences (Ye et al., 2014). This could be a major reason for the current lack of studies on children's MW. Self-reports to be accurate require from children meta-awareness abilities (Schooler et al., 2011), which depending on their age can still be underdeveloped. Flavell et al. (2000) conducted a research on children's ability to introspect and communicate thoughts, finding that 8-year-olds performed better on introspective tasks than younger children, but much worse than adults. Nevertheless, the shortage of MW studies extends to children from all age groups. Recently, one investigation has been conducted by Zhang et al. (2015) to assess the validity of children's MW reports in relationship to their attitudes towards MW, finding that positive attitudes have led to invalid reports. This result could fit into the fact that children are not exempt from subjective biases and shows the pertinence of assessing the validity of self-reports using more objective measures.

It would also be very interesting to further explore the contents and phenomenology of mind wandering in children, and the links to school performance and mental health. Previous research in mind wandering with adults has shown a bias to future thinking (e.g., Baird et al., 2011). However, there is little information on this prospective bias from a developmental perspective. For example, to our knowledge, only three studies have investigated prospective bias in children, and have had contradictory results. Both Ye et al. (2014) and Zhang et al. (2015) have found that children engage in mental time travel to the future during mind wandering, whereas McCormack et al. (2019), also investigating possible developmental changes in this bias (in children, adolescents, and adults), only found the tendency for spontaneous prospective thinking in adults, and not in the other age groups (children and adolescents). Contradictory finding like this should be further explored, especially having into account the functions attributed to mind wandering in adults, such as future and autobiographical planning, and it would also help understand if, when focusing within themselves during class, a particular child is engaged in strategic thinking or passive imagination, and what are the emotional outcomes of this episode.

Assessing the truthfulness of children's subjective reports can inform future research and practices related to mental health and learning process. Besides, identifying contents and patterns of SITUTs can be of value to understanding children's mental experiences, and their own account of those. Ellingsen et al. (2014) make a contrast between having children as objects and as subjects of an experiment and consider that it is necessary to allow them as subjects, to gather their perspectives as expressed in ways that are possible for them. Subjective reports are of value for accessing children's mind, yet only relevant if the accuracy is well controlled. This is where objective measures come as very useful.

Besides allowing for the study of mind wandering in broader samples, i.e., including populations whose self-reports would be less reliable such as children and some clinical populations. Even though some problems with subjective reports include the fact that we cannot be sure that it is completely accurate, that it can disrupt the flow of the activity at hand (Konishi & Smallwood, 2016; Faber, Bixler, & D'Mello, 2018), and that we are limited on the amount of probes (Seli et al., 2013), there is no questioning of it's importance to get a personal account on what is a highly subjective mental state. However, objective measures can offer an access to this phenomenon in a way that can either corroborate or further an objective measure. The first because objective measures can be more directly observed and verified, and are less susceptible to subject manipulation, and the latter because it could allow the capture of mind wandering occurrence, (i.e., in terms of onset and offset; Shad, Nuthmann, & Engbert, 2012), and the potential to catch the mind in flight, i.e., its dynamic transitions, potentially in a way that would not interfere much with task performance, by measuring MW in a less obtrusive manner (Faber, Bixler, & D'Mello, 2018). However, to get a better grasp of what goes within the mind wandering mental state, both an objective and a subjective measure, together, have the potential to inform on the contents of thoughts, especially pairing reports with neurocognitive measures and thus maximizing the strengths and reducing the limitations of both types of measures. Therefore, triangulation can be a very powerful method of studying mind wandering (Konishi & Smallwood, 2016). However, both in parallel and as an alternative to subjective reports, using some neurocognitive measures such as those that imply on the assumptions of neural markers of subjective experience should be done with the awareness of such assumption. Because even though nowadays these can be used to detect some mental states with reliability, for example, some categories of sensory experience and imagery, such as places and faces, in the parahippocampal place area (PPA) and the fusiform face area (FFA) respectively and, more broadly, internally directed attention, in the default network (DMN), the question remains on the limits of this assumption: to which extent can we reliably and consistently assume that simultaneously occurring complex mental events, such as those in the mind wandering state, and changes in the nervous system are linked, and even more complicated is the attempt to find causality. This question touches on neural specificity which in most cases can only be measured by exhaustive neuroimaging investigations (Bachmann, 2015). When interpreting the finding of this thesis, I have these limitations into account.

1.5. Current thesis: aims and overview

There are two main purposes for this thesis. The first is to establish three new methods for studying the contents of spontaneous thoughts. The other is to use these methods to address specific questions, presented throughout the chapters.

1.5.1. Establishing new methods for objectively study thought contents

The research presented in this thesis establishes three objective methods:

i. And fMRI method using perceptual reactivations to track a specific thought. This method allows us to 'see' the occurrence of spontaneous thought.
ii. Using EEG to establish objective markers of the strategic dimension of thoughts.
iii. Using facial EMG to establish objective markers of the affective dimension of thoughts.

1.5.2. Addressing specific research questions

My research questions are:

i. How similar to external distraction (in terms of bottom-up attentional capture) is the internal distraction? I answer this question in Chapter 2, using a combination of fMRI connectivity and my novel method for trackability of thoughts via perceptual reactivations.

ii. What are some relevant phenomenological characteristics of strategic and affective thoughts during mind wandering? This question is answered via a behavioural study in Chapter 3 followed by an EEG study in which we establish its neural correlates resorting to a guided thought paradigm.

iii. In my final empirical chapter (Chapter 4) I report an unexpected but important discovery that arose during my PhD research, with key methodological implications for the field of MW research, as well as for the real-world pandemic impact on productivity, wellbeing, and mental health.

I conclude the thesis with a general discussion (Chapter 5), in which I highlight the implications of this research to the methodological advancement of mind-wandering research.

CHAPTER II

Study 1 - I can see your thoughts: indexing the occurrence of salient thoughts and characterising the priority map for internal distraction

Abstract

In daily life, our attention may be involuntarily distracted from ongoing tasks by both irrelevant sensory information and our thoughts. In contrast to the well-studied mechanisms of external attentional capture, the mechanisms regarding the involuntary capture of attention by a salient thought are unknown. In this paper, we address this with a novel approach to investigating attentional capture by thoughts by using a planted 'marker' thought (about a person). Twenty-four participants performed two tasks measuring (1) external distraction by salient visual distractors and (2) internal distraction by a specific, suppressed thought. Using both univariate and multivariate approaches, we were able to track the occurrence of spontaneous thoughts via reactivation of perceptual representations of the target person in the fusiform face area (FFA). Our findings reveal common activation of lateral posterior parietal regions concerning internal and external forms of distraction and implicate a medial parietal region, the precuneus, in internal attentional priority. More broadly, our findings demonstrate that perceptual reactivations associated with specific spontaneous thoughts can be decoded and tracked, allowing the study of involuntary thought without reliance on subjective measures.

I can see your thoughts: indexing the occurrence of salient thoughts and characterising the priority map for internal distraction

In daily life our attention may be involuntarily distracted from our tasks by either external sensory information or our thoughts. Attentional capture by external sensory information has been vastly studied (e.g., Yantis, 1993; Theeuwes, 2004, 2005; Fockert et al., 2004; Luck et al., 2021), but it remains unclear what draws attention to particular thoughts. For example, you might be trying to focus on a task, such as studying, only to find yourself thinking about an old friend. What is it about this person that makes them capture your attention away from your task and intrude into your consciousness? Could this phenomenon involve the same mechanisms that lead an external perceptual stimulus to involuntarily capture your attention?

The phenomenon of involuntary task-irrelevant thoughts could refer to both general involuntary mind-wandering (Seli et al., 2016; Robinson & Unsworth, 2018) or specific intrusive thoughts (May et al., 2010; Seli et al., 2017; Mailet & Schacter, 2016). Such thoughts occur for most people at some point but also a play role in clinical disorders, e.g. in anxiety and depression (Clark & de Silva, 1985; Ladouceur et al., 2000; Figueiredo et al., 2020; Seli et al., 2019), addiction (Moss et al., 2015), maladaptive eating behaviour (Maya et al., 2010; Berry, Andrade, & May, 2007; Garcia et al., 2014), or even in attention deficit/hyperactivity disorder (ADHD; e.g., Mitchell et al., 2013; Abramovitch & Schweiger, 2009; Weyandt et al., 2003). Interestingly, both general involuntary mind-wandering and intrusive thoughts have been shown to be inflated in ADHD (Weyandt et al., 2003; Lanier, Noyes & Biederman, 2019), raising the possibility that both phenomena might be driven by a common determinant of involuntary attentional capture by thoughts. Certain categories of thoughts are widely documented to occur as intrusive thoughts: For example, those with negative affect (e.g. in the context of anxiety disorders), or appetitive associations (e.g. those associated with food cravings or in addiction, (Moss et al., 2015; May et al., 2010; Berry, Andrade, & May, 2007;

Hamilton et al., 2010; Morris et al., 2020). These thoughts hold properties widely argued to increase salience in relation to external stimuli, e.g., reward or threat associations (Anderson, Laurent & Yantis, 2014; Kim & Anderson, 2020; Brown, Berggren, & Forster, 2020). As such, intrusive thoughts about reward in addiction, or threat in anxiety, can be seen as internal analogues of the established external attentional biases for reward and threat in addiction and anxiety respectively (e.g., Field et al., 2009; Bar-Haim et al., 2007). Given these parallels between involuntary thoughts and attentional capture by external stimuli, we asked whether the well-studied neural mechanisms underlying the allocation of involuntary external might also be involved in involuntary thoughts.

In attentional capture by external stimuli, it has been suggested that a stimulus, salient due to its features (Itti & Koch, 2001; Ptak, 2012), is processed by a combination of brain areas considered to comprise a priority map. These regions have been suggested to include the visual cortex (Zhang et al., 2012), the prefrontal cortex (Corbetta & Shulman, 2002; Kincade et al., 2005) and, especially, areas of the ventral frontoparietal network, formed by the posterior parietal cortex (PPC), including the intraparietal sulcus (IPS) (Corbetta & Shulman, 2002). Hodsoll, Mevorach and Humphreys (2009) provided particularly strong evidence for a causal role of posterior parietal cortex in involuntary attentional priority, by demonstrating that transcranial magnetic stimulation of this region reduced bottom-up attentional capture by a salient perceptual stimulus. There remains debate on the roles of specific posterior parietal regions such as intraparietal sulcus (IPS), posterior IPS/SPL, and temporoparietal junction (TPJ), Whereas some accounts propose the intraparietal sulcus (IPS) and the posterior IPS/SPL to be related to top-down allocation of attention (Corbetta & Shulman, 2002) and the TPJ bottom-up (Corbetta & Shulman, 2002; Kucyi, Hodaie & Davis, 2012; Asplund et al., 2010), the IPS and SPL have also been implicated in bottom-up orienting (Chen et al., 2020; Gottlieb et al., 1998; Kusunoki et al., 2000), for example in attentional capture by a visual singleton (de

Fockert et al., 2004). Notably, the IPS has been involved in attentional allocation driven by not only perceptual salience, but also motivational factors such as reward (Anderson, 2016, 2019; Anderson, Laurent & Yantis, 2014) including in monkeys (Rorie et al., 2010; Platt & Glimcher, 1999; Sugrue et al., 2004; Gottlieb, Kusunoki & Goldberg, 1998; Grefkes & Fink, 2005; Peck et al., 2009; Bisley et al., 2011; Failing & Theeuwes, 2018), punishment (Kim & Anderson, 2020) and personal relevance (Sui, He & Humphreys, 2012), which might be of importance to thoughts. Thus, a question we sought to address is whether these regions might also be involved in involuntary attentional capture by motivationally salient thoughts.

Initial support for the idea of common mechanisms underlying internal and external attentions can be drawn from research implicating overlapping role of parietal regions (IPS and SPL) in top-down attention orienting for mental representations in working memory and for external perception (e.g., Nobre et al., 2004; Myers, Strokes & Nobre, 2017). This overlap between top-down internal and external shifting of attention in parietal areas is also recognised by Nee and Jonides (2009), although with the suggestion that these regions are more sensitive to external attention orienting. All of this raises our specific question of whether these lateral parietal regions could be involved in involuntary orienting to salient thoughts.

On the other hand, it might be that other parietal regions are more specialised for the prioritisation of mental representations such as thoughts. One candidate region for the internal attentional priority map is the precuneus, a more medial parietal region, that is consistently activated during experience sampling studies of spontaneous thoughts (see Fox et al., 2015, for meta-analysis), and has been argued to play a key role in internal representations and mental imagery (for a review, see Cavanna & Trimble, 2006).

To address this question, we devised and tested a novel 'internal distraction' paradigm for studying attentional capture by thoughts, adapting the 'white bear' thought suppression paradigm (Wegner, 1989) to plant specific involuntary thoughts about a person (the Clue characters ‘Miss Scarlett’ and ‘Mrs Peacock’), and to track the occurrence of these involuntary thoughts using both univariate and multivariate reactivations in Fusiform Face Area (FFA). To increase the motivational salience of the thoughts, we adapted a procedure established by Anderston and colleagues to create reward associations with the character’s faces. Using this approach, we were able to compare parietal recruitment during internal distraction by a salient thought (as indexed via FFA reactivation) with that during external distraction by a salient perceptual stimulus, the latter measured using a task that has been used to demonstrate a between subject behavioural correlation between irrelevant external distraction and propensity to mind wandering (Forster & Lavie, 2014). We expected to see activations circumscribed within the same parietal regions for both the external and internal attentional capture by involuntary thoughts. Furthermore, we expected the internal attentional capture to also show activations on the precuneus, in accordance with previous studies (Fox et al., 2015). Lastly, given the reward associations of our thoughts, we expected activations in the striatum of the basal ganglia: globus pallidus, putamen, caudate, as in previous research with a similar manipulation (Anderson, Laurent & Yantis, 2014).

Method

Participants

Twenty-four participants (14 females, age range 19-33 years, mean age = 24 years, SD = 4.35 years) were recruited using a combination of volunteer sampling, from the University of Sussex participant pool and community. We targeted right-handed subjects within 18-35 years, enrolled at the university or residing around the university's community, with normal or corrected to normal vision, and native or fluent as native English speakers. Participants signed a written informed consent in accordance with the ethical procedures approved by the Brighton and Sussex Medical School (BSMS) Research Governance and Ethics Committee (RGEC) and received a compensation of £15. There was a different number of participants per analysis. The specific inclusion criteria for each analysis are underlined in the relevant sections below.

General stimuli and procedure

Participants first completed a pre-scan session, in which they performed a value-training task intended to increase the salience of the suppressed thoughts (see Figure 1a), followed by practice blocks of each of the in-scanner tasks. The ~one hour in-scanner session included acquisition of anatomical scans, as well as the following tasks in order: a face viewing task (Figure 1b), an internal distraction task (Figure 1c), and an external distraction task (Figure 1d).

All tasks were programmed in E-Prime® 2.0 (Psychology Software Tools, Inc.). During the pre-scan, tasks were displayed on a 23" monitor, and 70 cm of viewing distance, while in-scanner stimuli were back-projected onto a screen behind the bore of the scanner and viewed via an angled mirror on the head coil. An in-scanner response device collected subjects' answers, using their right hand, with buttons 1 to 4 aligned under fingers from the index to the little finger, respectively (see Figure 1c).

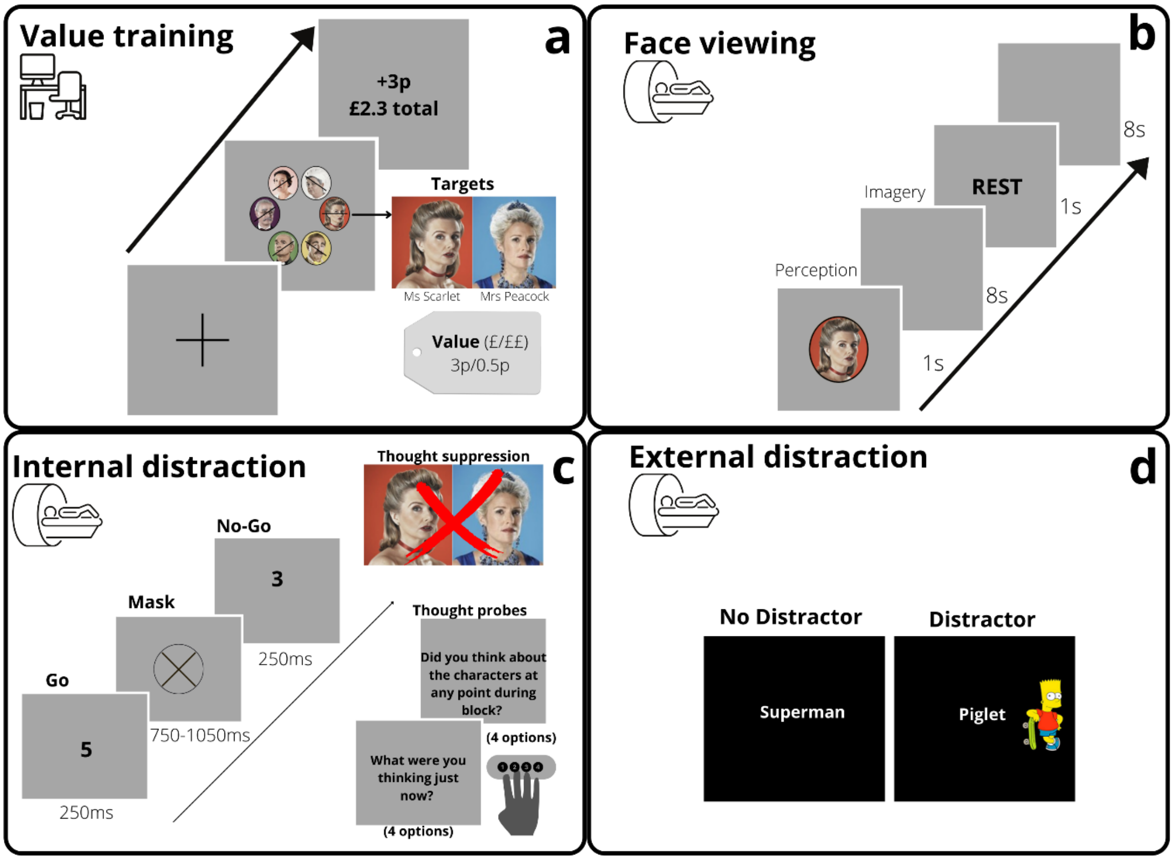

Figure 1. **Schematic of experimental setup. (a) Value training task took place in a testing room, prior to scanning, and subjects were engaged on the visual search of two target faces that were associated to monetary rewards. All other tasks were in-scanner. (b) In the face viewing subjects were asked to passively briefly view the previous target faces and hold the thought in their mind's eye. (c) In the internal distraction task subjects were asked to suppress any thoughts of the two target characters, while completing the Sustained Attention to Response Task (SART) with intermittent thought-probes. (d) In the external distraction task participants classified target words as superheroes or Disney characters, while ignoring distractor cartoon images on a subset of trials.**

Value training task

The value training procedure lasted 25 minutes and was closely based on the value training task used by Anderson (2011) to increase the salience of external stimuli by creating associations between the face and reward. The intended purpose of this task was to familiarise the participants with the characters that would later be used as internal distractors in the internal distraction task and boost the salience of internal representations of these characters. The target faces were characters from Cluedo board game, Ms Scarlett (with a red background) and Mrs Peacock (with a blue background), see Figure 1. This task involves searching an array of six characters for the two target faces that, through feedback following each response, become associated with high or low monetary rewards. Further experimental details are in the Supplemental Materials.

Face viewing/imagining

Participants completed six blocks of viewing of each of the character faces (3 for Miss Scarlett, 3 for Mrs Peacock, order counterbalanced between subjects), alternated with six rest blocks. This was intended to serve as localiser of the fusiform face area (FFA) region of interest (Kanwisher, 2010) and a template of multivoxel pattern of activation of each of the target characters within the FFA, for the representational similarity analyses (RSA). In each face viewing block, subjects were presented with one of the two characters (Miss Scarlett and Mrs Peacock) for 1 second and then asked to hold the mental image of the face for the subsequent 8 seconds. In rest blocks participants were presented with a 1-second display of the word 'REST' followed by a rest period of 8 seconds, see Figure 1b.

Internal distraction task

During this task participants were asked to suppress any thoughts of the characters Ms Scarlett and Mrs Peacock, while completing three runs of the Sustained Attention to Response Task (SART; Robertson et al., 1997), which is a Go/No-Go task that has been widely used in the study of mind-wandering (e.g., Christoff et al., 2009; Forster et al., 2015). In the SART, participants responded, via a single button press, to frequent digits from “0-9” except “3”, the infrequent No-Go target toward which response must be withheld (Figure 1c). Each of the three runs of the SART contained ten blocks, during which 27 digits were presented for 250ms each, with 750-1050ms of a mask presentation between each digit (mean = 900ms). The mask was an “x” within a circle, with 3° x 2.9° of visual angle. The size of the digit stimuli differed between trials, forming a visual angle varying from 1.4° x 1° to 3° x 2.1°. The infrequent No-Go target appeared 2 or 3 times per block.

A thought-probe interrupted the task at the end of each block, with the questions “What were you thinking just now?” (response options “1-Ontask”, “2-Ms Scarlett”, “3-Mrs Peacock”, and “4-Something else”), followed by “Did you think about the suppressed characters at any point during the last block?” (response options “1-Both”, “2-Ms Scarlett”, “3-Mrs Peacock”, and “4-None”). Responses to the SART and the thought probes were thoroughly practiced during the pre-scan. The option of “Something else” was our general mind wandering variable. To answer to that question, participants received the following instruction: *Press the right button (little finger) if you were thinking about something else (neither the task nor the target)*. See Supplemental Materials for all instructions.

External distraction task

This task closely followed the methods of Forster and Lavie (2016). In each trial a name of a well-known cartoon character was displayed on screen in grey text on a black background (subtending 0.5º vertically by 0.9˚-2.3º horizontally), with equal probability in one of six locations 0.3, 1.3, or 2.3 degrees of visual angle above or below fixation. These were six superhero characters (Batman, Hulk, Robin, Spiderman, Superman, Wolverine) and six Disney characters (Donald, Mickey, Piglet, Pluto, Pooh and Tigger). Subjects were asked to classify the names as either a superhero, pressing 1, or a Disney cartoon, pressing 2, responding as fast as possible while maintaining accuracy.

On most trials, the name was presented alone, but on 20% of trials it was accompanied by a distractor image either to the left or the right (4.4˚ from fixation, minimum of 0.7º nearest edge to edge of target name). Distractors were full colour cartoon images subtending 3.8º-5º by 2.4º-3.8º. There were two main conditions of interest: no distractor condition and external distractor condition (see Figure 3d). The external distractor condition was subdivided into three types of distractors, with the same likelihood of appearance: congruent distractor, i.e. compatible with target word (e.g., image of Piglet, when target word is Piglet or another Disney character), incongruent distractor, i.e. incompatible with target (e.g., image of Piglet when target word is Superman or another Superhero), or irrelevant distractor (e.g., image of a Pokémon, an Angry bird, Hello Kitty or Sponge Bob, which are neither Disney characters, nor a superheroes. Participants performed six blocks of 60 trials in the scanner (the practice block, during the pre-scan session, consisted of 72 no distractor trials, which were repeated until subjects arrived at 65% accuracy rate).

Neuroimaging acquisition

Functional MRI data were collected using a Siemens Magnetom Avanto 1.5 Tesla MRI scanner, with a 32-channel phased-array head coil, at the BSMS Clinical Imaging Sciences Centre (CISC), University of Sussex. Participants were placed in the scanner in a supine position. Functional images were acquired using a T2*-weighted gradient-echo EPI sequence

(TR = 2520ms, TE = 43, flip angle = 90°, FOV= 192 x 192mm, matrix = 64 x 64). Each functional volume consisted of 34 contiguous 3 mm thick axial slices with 3.0 x 3.0mm in-plane resolution. In addition, a high resolution (1mm^3) T1-weighted whole brain anatomical volume was collected with a magnetisation-prepared rapid gradient-echo (MPRAGE) sequence for purposes of co-registration and standardisation to a template brain. Field maps were collected to allow for correction of geometric distortions induced by field inhomogeneities.

Neuroimaging preprocessing

The fMRI data were preprocessed and analysed using a combination of SPM12 (Statistical Parametric Mapping; Wellcome Trust Centre for Neuroimaging, London, UK; Friston et al., 1994) and FSL 5.0.8 (Oxford Centre for Functional Magnetic Resonance Imaging of the Brain [FMRIB] Software Library; Jenkinson et al., 2012; www.fmrib.ox.ac.uk/fsl). The first four volumes of each run were discarded to correct for initial signal fluctuations. High pass temporal filtering (128s) was applied to remove low frequency signals relating to scanner drift Each T1-weighted structural image was segmented and used to compute a group template image using the DARTEL toolbox. EPI data were warped to 2mm MNI space with transformation parameters derived from the group template image (Ashburner, 2007). Functional volumes were slice time corrected and realigned using the middle slice as reference and volumes were spatially realigned to the mean volume. Functional data were aligned to the corresponding single subject structural MNI volumes using an affine alignment, with 12 degrees of freedom. Functional volumes were smoothed using an 8mm FWHM isotropic Gaussian Kernel.

fMRI Imaging analyses

Univariate neuroimaging analyses

For each task, the fMRI time series were modelled by a GLM that included nuisance regressors of subject head motion and their derivatives. A canonical hemodynamic response function (HRF) was used as the basis function to model changes in the signal due to hemodynamic response timing delays (Della-Maggiore et al., 2002). No Global Normalisation was used.

Face viewing task. An initial model was constructed to localise face selective voxels within the fusiform face area (FFA). These were then used to construct individual subject ROIs for further analyses (see Definition of ROIs below). Trials were modelled in a design that included the onsets of face perception, with 1s duration, the 8s imagery period, the onset of the word 'REST', 1s duration, and rest period, with 8s duration. A second model was constructed for each character face separately to be used as exemplar templates in subsequent representational similarity analyses. For the two models, we contrasted face regressors against baseline. The full sample size of 24 subjects was included for the group level analysis.

Internal distraction task. The univariate model for this task was used to examine neural activity in the period immediately prior to subjective reports of salient involuntary thoughts (measured via reports from probe 1 "What were you thinking just now"). The model included the 2s prior to thought probe, as a function of the probe response (focused on-task, thoughts about Ms Scarlett/Mrs Peacock, or general mind wandering). Each of these variables were modelled with 2s of duration, across the three runs. The main contrast of interest was [involuntary thoughts > on-task] but also [general mind wandering > on-task]. Fourteen subjects were included in the analysis, those were the subjects that had at least one event of reports of being on-task and of thinking about either/both characters. Those fourteen subjects were included in a group level univariate analysis. See below for details of multivariate and connectivity analyses using this task.

External distraction task. This task was used to identify the neural correlates of attentional capture by external visual stimuli, to be used as ROI definition for the lateral posterior parietal region (LPP; further explained in Definition of ROIs below). This was an event-related design in which we modelled each of the external distractor conditions (congruent, incongruent and irrelevant) and the no distractor condition. The main contrast of interest was [external distractor > no distractor]. Twenty subjects were included in this analysis, as there was a computer error that did not allow the use of data from four subjects.

Functional connectivity analyses

A PPI analysis was computed with data from the internal distraction task between the intervals when subjects reported involuntary thoughts about the characters contrasted by reports of being on-task, during the three runs of the internal distraction task, and the bold signal at the fusiform face area. Fourteen subjects were included in the analysis, those subjects that reported at least one thought about the characters.

Representational similarity analyses

RSA analyses were performed using an adapted script from CosmoMVPA (Oosterhof et al., 2016), following the steps described in Staresina et al. (2013), and using the data obtained from the Probe 2 of the internal distraction task "Did you think about the characters at any point during the last block?". To answer the question of whether each character is more similar to its relative multi-voxel template (estimated from a separate run), we correlated the multi-voxel activation spatial patterns (t-scores) of BOLD activity from each character template (Miss Scarlett and Mrs Peacock), obtained from the face viewing task to intervals when subjects reported spontaneous thoughts about those characters (during the three runs of the internal distraction task), block by block, obtaining reactivation indexes per block. This was then compared to blocks when subjects did not report thoughts about the given face. We then looked at the Pearson's correlations (Fisher z-transformed) between each face template and the reports of either being on-task or thinking about the face corresponding to the template. We called this analysis “Mean similarity across runs” (Staresina et al., 2013). Next, we assessed discrete reactivation events in condition-specific blocks, relative to the baseline noise distribution defined following (Staresina et al., 2013): We computed a baseline noise distribution by correlating each template with intervals when the corresponding face was not reported, and then calculated an average of those correlations per block for each template. In the actual blocks in which the corresponding face was reported, we compared each of the reactivation values (in each volume within the blocks) with the baseline noise distribution, converting each reactivation index within the block into a *z*-value $[(x_i\text{-}M(x))/SD(x)]$. Thus, we were able to define discrete reactivation events with *z*-values>2 (*p*-value<0.05), as local peak reactivations relative to baseline noise (Staresina et al., 2013).

The results of the RSA analysis were also used as the basis of a univariate ‘probe-free’ analysis, in which the timings of the multivariate discrete reactivation events (defined as above) were modelled as events. For this, we modelled the reactivation onsets as the timing of the actual reactivation volumes plus the volumes immediately before and after (3 volumes total), as events of interest.

Definition of ROIs

Regions of interest were chosen a priori and used to constrain the results of internal distraction task analyses: fusiform face area (FFA); anterior precuneus (AntPrec), lateral posterior parietal (LPP) regions, including the superior parietal lobule (SPL), the inferior parietal lobule (IPL), and more specifically the intraparietal sulcus (IPS); and reward network regions, in particular regions on the striatum (globus pallidus, putamen and caudate).

Lateral posterior parietal (LPP). The LPP ROI mask was functionally defined based on the significant (*p* > .05 FWE) clusters derived from the external distraction task (contrast: all distractors > no distractor) on SPM12, within a SVC corrected …using a combination of SPL and IPL from the AAL template on the WFU Pickatlas toolbox version 3.0.5 (Maldjian et al., 2003; https://www.nitrc.org/projects/wfu_pickatlas/).

Anterior precuneus (AntPrec). The AntPrec ROI mask was defined based on a review paper on the functional correlates of the precuneus (Cavanna & Trimble, 2006). We obtained the range of XYZ-axis values in MNI space across functional imaging studies of visuo-spatial imagery, episodic memory retrieval and self-processing reported in the review as showing anterior left and/or right precuneus (Cavanna & Trimble, 2006). We then used the minimum and maximum values as ranges for a combined (left and right) ROI box mask using the MarsBar toolbox (http://marsbar.sourceforge.net/).

Striatum. From the AAL template on the WFU Pickatlas we also extracted a mask of the striatum, combining globus pallidus, putamen and caudate.

Fusiform face area (FFA). The FFA ROI was functionally defined based on the peak coordinates from the face viewing task (face contrasted against baseline), constrained within an 8mm sphere surrounding the FFA ROI coordinates reported by Kanwisher (2010: left [-40 -50 -18] and right [42 -52 -20]). ROI masks were created on Marsbar.

Results

Attentional capture by external visual distractors

Behavioural

The behavioural results closely replicated the pattern seen in previous uses of our external distraction task (e.g., Forster & Lavie, 2016): Within subjects' ANOVAs on mean RT to correct responses showed a significant main effect of distractor type, $F(3,21) = 18.59$, $p<.001$. Planned contrasts confirmed significant distractor interference, in terms of a significant slowing of RTs, in the presence of an incongruent distractor (*M*=801.4, *SD*=187.3) versus a congruent distractor (*M*=691.4, *SD*=137.5), *t*(23)=6.38, *p*<.001, and in the presence of an irrelevant distractor (*M*=752.4, *SD*=156.3) vs the absence of any distractor (*M*=675.9, *SD*=120.3), *t*(23)=6.06, *p*<.001. A similar analysis on accuracy rates showed the same pattern as RTs: A significant main effect of distractor type was found, *F*(3,21) = 28.09, *p*<.001. Planned pairwise comparisons also showed a significant difference between the incongruent distractor (*M*=0.71, *SD*=0.14) and congruent distractor conditions (*M*=0.88, *SD*=0.11), *t*(23)=-8.31, *p*<.001, and between the presence of an irrelevant distractor (*M*=0.79, *SD*=0.14) and absence of distractor (*M*=0.85, *SD*=0.1), *t*(23)=-3.68, *p*=.001.

fMRI

As predicted, attentional capture by external distractors versus no distractor showed activations on lateral posterior parietal (LPP) regions, using the ROI mask combining the superior and the inferior parietal lobules (SPL and IPL, respectively). Activations were bilateral at cluster level, see Table 1 for coordinates. An ROI mask for further analyses was created from the active clusters derived from this. See Figure 4a.

Attentional capture by salient spontaneous thoughts

Behavioural

Performance on the SART was similar to other studies using this task (e.g., McVay and Kane, 2009; Robertson et al, 1997; Smallwood et al, 2005), with a mean commission error rate of 56% (*SD*=22) and an omission rate of 7% (*SD*=10). As in prior work, non-target RTs were shorter four trials preceding target commission errors (*M*=326.16, *SD*=50.54) than prior to correct target responses (*M*=402.7, *SD*=89.15), *t*(22)= -7.82, *p*<.001.

Among those participants experiencing one or more involuntary thoughts at some point during the internal distraction task, these were experienced during between 3%-90% of task blocks (probe caught; *M* = 33.63%, *SD* = 6.96%). Only 14/24 subjects reported thoughts about the target characters (Ms Scarlet and Mrs Peacock) in the period immediately prior to the probe: Among those subjects reporting thoughts about the target characters in the period immediately prior to the probe, these were reported at 3.33-30% of probes (*M* = 6.5%, *SD* = 9.03). The mean level of off-task reports in the period prior to probes (including both involuntary thoughts about the characters and general mind wandering) was 29.42% (*SD* =27.80%) across all subjects, which compares to 43% off-task reports observed in a prior fMRI study involving the SART (Christoff et al, 2009).

fMRI

Reactivation of perceptual processing as a marker of involuntary thoughts. We first tested whether reactivations of perceptual processing in FFA, associated with thoughts about the target characters (Miss Scarlett and Mrs Peacock), could be used as objective markers for involuntary thoughts. Our univariate analysis revealed that the two seconds immediately preceding involuntary thoughts about the target characters (versus on-task) were associated with activation of right fusiform face area (FFA) at group level, small volume corrected (see Table 1 for peak coordinates and T-scores, and figure 2a and 2b for group and single-subject maps). Subject-specific FFA ROI analysis using the masks obtained from the face viewing task similarly showed that the mean beta-weights within FFA was significantly higher for involuntary thoughts about the characters (*M*=0.85, *SD*=0.77) versus on-task reports (*M*=0.21, *SD*=0.12), $t(13) = 2.98$, $p < .01$ (See Figure 2c). For this analysis we used the FFA ROI mask from the side of the brain in which they showed the strongest FFA.

Our RSA analysis further revealed that the multivoxel perceptual reactivation in FFA by involuntary thoughts could be seen not only in the period immediately prior to thought probes, but across the whole blocks of the internal distraction task: As can be seen in Figure 3a and 3b, the volume by volume multivoxel pattern of FFA activation during blocks in which participants reported having experienced an involuntary thought about a particular character showed greater mean similarity to the perceptual template for that character (the multivoxel pattern of FFA activation during viewing of the character), compared to blocks in which no thoughts about that character were reported: For Miss Scarlett, $t(18) = -5.4$, $p < .001$, for Mrs Peacock, $t(15) = -4.63$, $p < .001$. Blocks in which participants reported an involuntary thought about a particular character also showed a higher number of reactivation events (volumes with similarity above baseline), at the threshold of 2>z-scores from baseline noise: For Miss Scarlett, $t(18) = -6.72$, $p < .00$; for Mrs Peacock $t(15) = -4.44$, $p < .001$, see Figures 3c & 3d. Furthermore, the magnitude of reactivation events (i.e. the peak reactivation per block) was greater in blocks in which participants reported having a thought about a particular character compared to those in which no such thoughts were reported: For Miss Scarlett template, $t(18) = -4.86$, $p < .001$ [Scarlett reports $M = 4.63$, $SD = 1.87$, On-task $M = 3.61$, $SD = 1.47$], for Mrs Peacock template, $t(15) = -4.36$, $p = .001$ [Peacock reports $M = 5.54$, $SD = 3.11$, On-task $M= 4.22$, $SD = 3.57$], see Figure S2 in Supplemental Materials. As can be seen in Figures 3 and S2, the above effects were observed, in terms of a numerical trend on individual level, in the majority of participants.

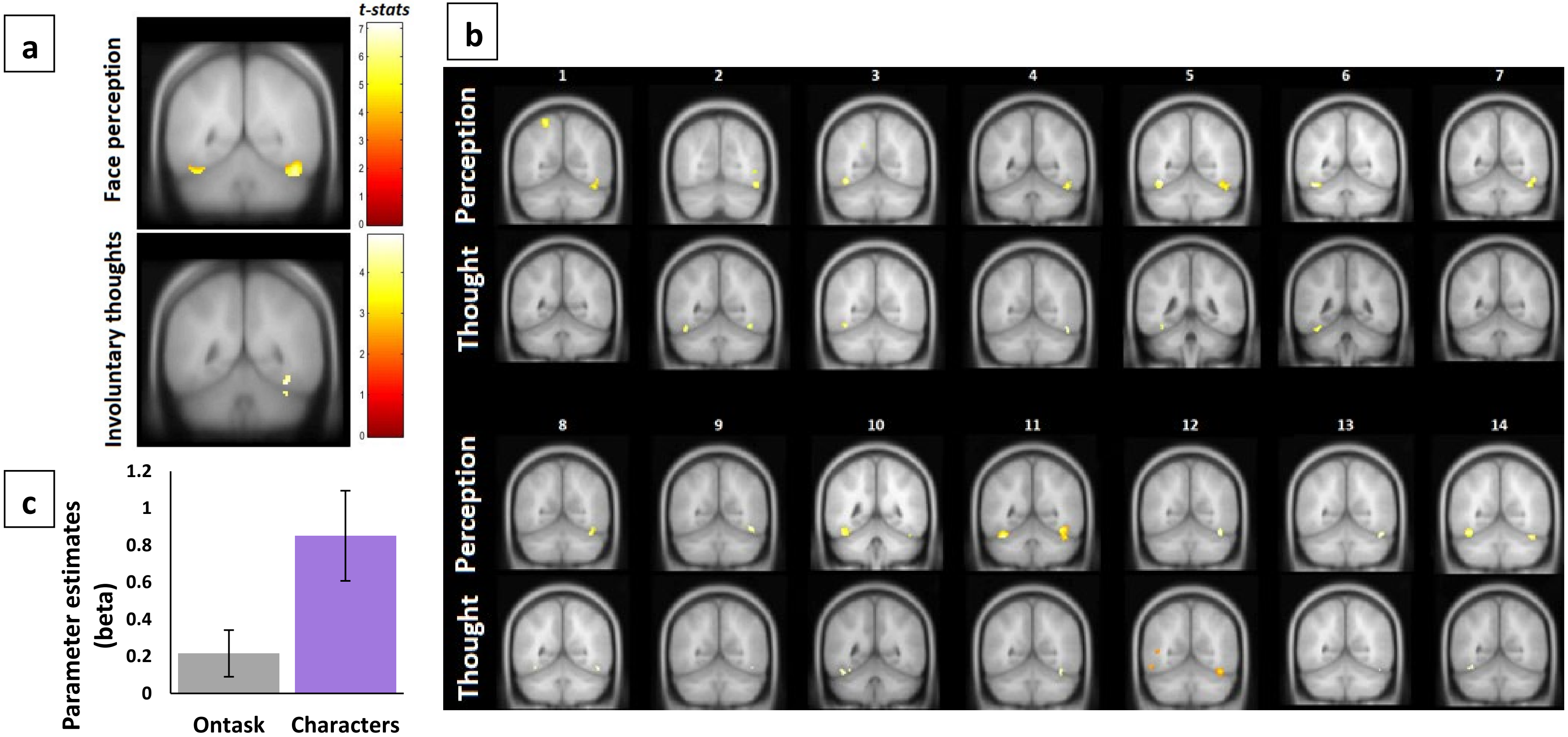

Figure 2. **Group level (a) and single subject level (b) activation of the fusiform face area (FFA) in response to face viewing (rows labelled 'Perception') and spontaneous involuntary thoughts about the characters (rows labelled 'thoughts'). (c) Mean Cross-ROI beta estimates for reports of face intrusions versus being on-task, using subject-specific FFA ROI extracted from the face viewing task. Error bars represent standard error of the mean.**

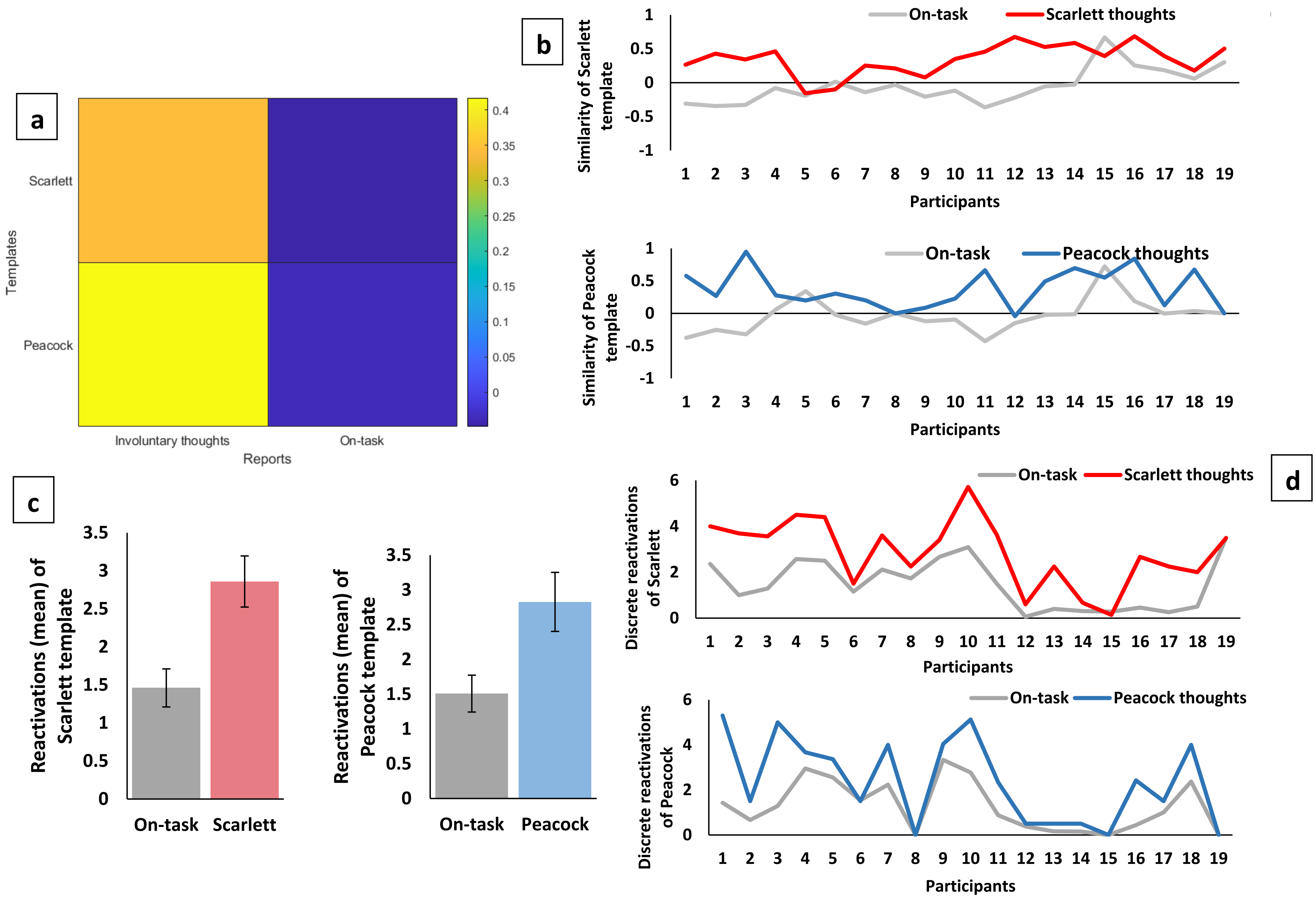
a
Scarlett
Peacock
Templates
Involuntary thoughts
On-task
Reports
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
b
On-task
Scarlett thoughts
Similarity of Scarlett template
Participants
On-task
Peacock thoughts
Similarity of Peacock template
Participants
c
Reactivations (mean) of Scarlett template
On-task
Scarlett
Reactivations (mean) of Peacock template
On-task
Peacock
d
On-task
Scarlett thoughts
Discrete reactivations of Scarlett
Participants
On-task
Peacock thoughts
Discrete reactivations of Peacock
Participants

Figure 3. **(a) Similarity matrix of multivoxel FFA response between character templates (from face viewing) and internal distraction blocks during which participants reported irrelevant thoughts of corresponding character versus on-task focus. (b) Similarity between template and reports across subjects, for Scarlett and Peacock templates. (c) Mean of discrete reactivation events for each template. (d)Discrete reactivation events across subjects. Error bars represent standard errors.**

The parietal priority map for internal distraction

We next tested our hypotheses regarding involvement of our medial and lateral parietal ROIs in allocating attentional priority to internal stimuli, as well as involvement of reward network regions. A PPI analysis from univariate model using FFA as seed was first conducted to examine regions showing connectivity with the perceptual reactivation events, in the period immediately prior to probes at which thoughts about the characters were reported. As can be seen in Figure 4a, the cluster of LPP activations from the external distraction revealed significant activation in the internal distraction connectivity in both LPP regions of interests (IPL and SPL), that are common to the external distraction task. A small volume correction, constrained within the precuneus ROI mask previously defined (see Definition of ROIs) also revealed a bilateral anterior precuneus that appears more specific to internal distraction (Figure 4b, left). Similarly, when constraining within the striatum ROI mask, this analysis also showed predicted activations, specifically in the globus pallidus (See Figure 4b, right). Several other activations were significant at whole brain level, including: the left angular gyrus, the right occipital face area (OFA), and the left posterior superior temporal gyrus (see Table 1 for peak coordinates and t-scores).

An additional analysis was conducted, using a novel 'probe-free' approach to identify periods of internal distraction. Here, discrete reactivations from the RSA were used to identify timings of potential involuntary thoughts, allowing us to explore the rest of the brain during the reactivations. This analysis concurred with our univariate analysis in revealing activity in left precuneus (see Figure 4c, left). There was also significant striatal activation in the putamen (Figure 4c, right). Significant whole brain activations are shown in Table 1.

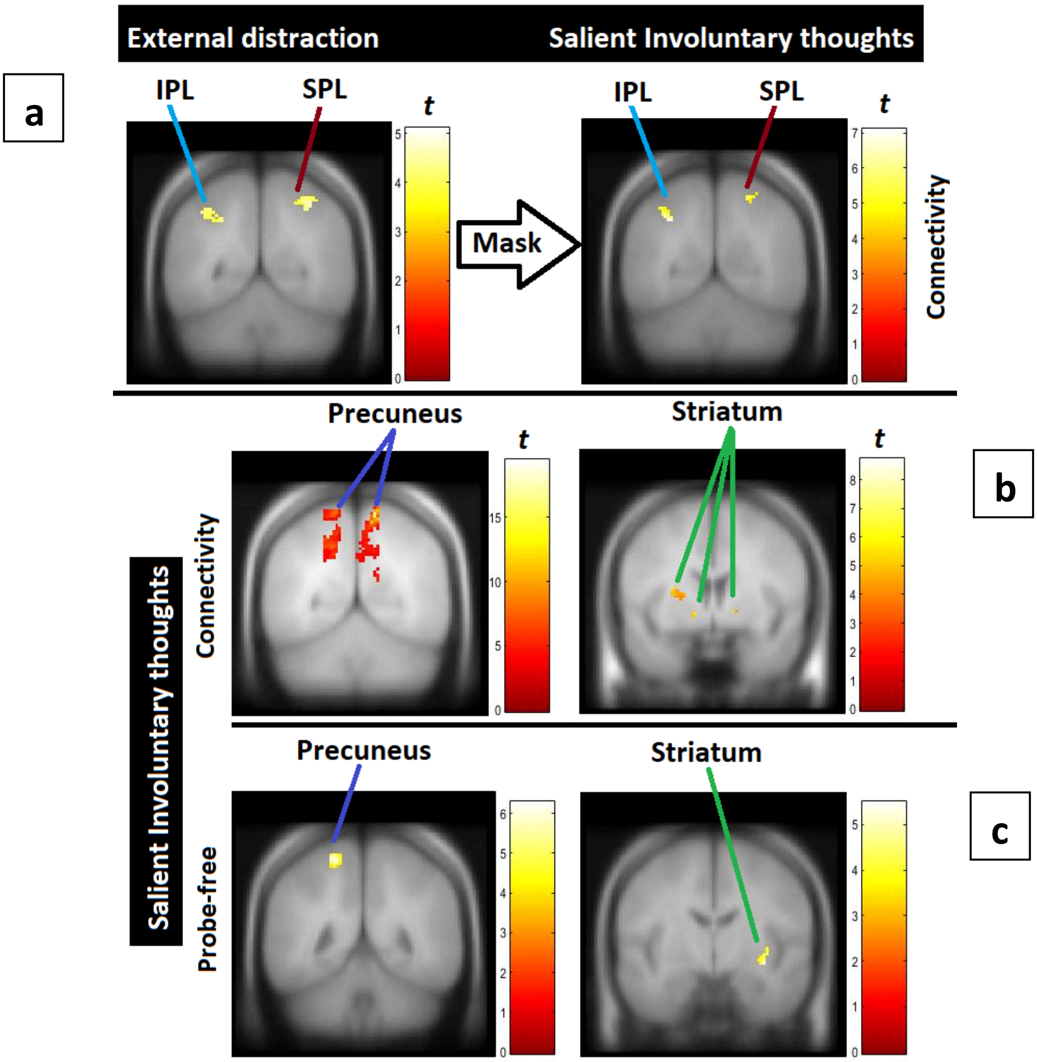

Figure 4. **(a) Comparison of LPP activation in the external task and from PPI analysis of the internal distraction task (FFA as seed), small volume corrected and constrained within the clusters from external task. (b) Precuneus and striatum activations from PPI analysis of internal distraction task, small volume corrected within respective pre-defined masks. (c) Activations of precuneus and striatum from probe-free analysis of face reactivations (internal distraction task). Threshold of maps: *p*<.001, k=5.**

Brain regions (AAL labelling)	Peak coordinates XYZ			T-scores (df)	SVC/Whole brain	Neurosynth associated terms
External Distraction Task. Distractors > No Distractor						
Right SPL	32	-62	50	*	SVC	Intraparietal sulcus, Superior parietal, Working memory, Posterior
Left IPL	-40	-50	42	*	SVC	Inferior parietal, Posterior parietal, Working memory, Intraparietal
Right FFA	36	-58	-16	9.45 (19)	Whole brain	FFA, Fusiform, Faces, Vision, Occipitotemporal
Internal Distraction Task. Characters > On-Task						
Right FFA	36	-50	-18	4.89 (13)	SVC	Fusiform, Face, FFA, Ventral vision, Face recognition
Internal Distraction Task. PPI Univariate Contrast (FFA Seed)						
Left IPL	-32	-60	40	7.07 (13)	SVC	Working memory, Intraparietal sulcus, Retrieval, Memory
Right SPL	22	-62	58	5.69 (13)	SVC	Superior parietal, Posterior parietal, Intraparietal sulcus, Visual
Left Precuneus	-20	-48	66	9.06 (13)	SVC	Superior parietal, Motor imagery, Imagery, Sensorymotor network
Right Precuneus	12	-58	66	19.37 (13)	SVC	Superior parietal, Imagery, Orienting, Spatial, Imagined, Personal
Left Globus Pallidus	-12	0	-2	8.69 (13)	SVC	Ventral striatum, Globus pallidus, Reward, Incentive delay
Right Globus Pallidus	12	6	-4	7.32 (13)	SVC	Reward, Striatum, Monetary, Anticipation, Incentive delay
Inferior frontal gyrus	-50	42	6	20.32 (13)	Whole brain	Inferior frontal, Lateral medial, Words, Semantic, Frontal gyrus

Left angular gyrus	-52	-66	32	13.58 (13)	Whole brain	Default, Default mode, DMN, Angular gyrus, Autobiographical
Left angular gyrus	-40	-62	36	12.09 (13)	Whole brain	Angular gyrus, Memory test, Default mode, Inferior parietal
Occipital face area	30	-78	-14	11.03 (13)	Whole brain	Visual, Occipital, Faces, Extrastriate, Inferior occipital, Face FFA
Internal Distraction Task. RSA Probe-Free Contrast						
Left Precuneus	-20	-48	62	6.26 (22)	SVC	Superior parietal, anterior superior, Motor imagery, Imagery, Shifts
Putamen	34	-8	-8	5.47 (22)	SVC	Amygdala, Putamen, Punishment, Caudate, Conditioned
Right temporal pole	52	4	-42	11.39 (22)	Whole brain	[no information]
Orbitofrontal /insula	26	20	-14	6.71 (22)	Whole brain	Orbitofrontal cortex, Insula, Reward, Ventromedial, Inhibition
Right sup. temporal	50	-42	2	6.61 (22)	Whole brain	Temporal sulcus, Facial expressions, STS, faces, Perception, voices

All values p<.05 (FWE corrected) and Bonferroni corr for SVC. *cluster level.

Table 1. **Peak coordinates in MNI space and related T-scores for ROI and whole brain analyses, for the external distraction task (simple univariate model), and the internal distraction task (simple univariate, connectivity and probe-free analyses), with associated terms on Neurosynth database (https://neurosynth.org/).**

Discussion

The present research establishes two key findings. We first demonstrated that spontaneously arising thoughts can elicit reliable stimulus-specific patterns of neural activity, in the form of perceptual reactivations, identifiable with both univariate and multivariate fMRI (via a simple general linear model and using representational similarity analyses, respectively). This finding extends previous work showing cortical overlaps between sensory perception and voluntary mental imagery of equivalent stimuli (e.g., Mechelli et al., 2004; O'Craven & Kanwisher, 2000; Naseralis et al., 2015; Pearson et al., 2015; Radoslaw, Heinzle & Haynes, 2012; Dijkstra, Bosch & Gerven, 2019; Robinson et al., 2020). For the first time, our findings suggest that even involuntary spontaneous thoughts can show reactivations akin to perception. The methodological implications of this finding reach beyond the study of involuntary thoughts to include other types of spontaneous cognition, such as involuntary episodic memory and intrusive thoughts, for example in the study of addiction and cravings, or trauma-related intrusions.

This finding also has particular utility for the study of mind wandering. In mind wandering research, a very common methodological approach is using experience sampling via thought probes, often through what has been called a probe-caught technique, in which subjects are periodically interrupted to report on the occurrence and contents of their mind wandering (e.g., Smallwood and Schooler, 2006, 2015). This method is relevant for gathering a first-person account of mind wandering, even regarding mental events for which the person did not have meta-awareness (Baird et al., 2013; Schooler et al., 2011), but some important limitations include the common biases accompany subjective reports, e.g., demand characteristics, satisficing, social desirability, and acquiescence (Weinstein, 2018), and gathering enough mind wandering events for the required analyses (Seli et al., 2013). This is of particular relevance when using neuroscience methods that depend on the onset of reports as events of interest.

Furthermore, as mind wandering rates have been suggested to typically decrease when probe frequency is increased (e.g., Schubert, Frischkorn, & Rummel, 2019; Seli et al., 2013), collecting sufficient involuntary mind wandering reports during an fMRI study would require a lengthy and hence expensive data collection session, during which only limited time periods could be analysed (although, for recent alternative resting state approaches to studying the content of unconstrained spontaneous thought see Karapanagiotidis et al., 2020, 2017; Medea et al., 2018; Chou et al., 2017; Wang et al., 2018). In the case of our study, across the 24 subjects that we tested we only found on average 29% of spontaneous thoughts (including both specific intrusions and general mind wandering) to the probe-caught question "What were you thinking just now", with 8 of subjects not reporting a single off-task thought in the period prior to probes. This rate compares to for example, the 43% incidence that Christoff and colleagues (2009) reported across 15 subjects in a probe-caught mind wandering study. Our novel technique of using the discrete reactivation events rather than probes to identify the occurrence of thoughts has the advantage of making use of the entire task block rather than only the periods immediately prior to probes. Secondly, using a neural marker associated with a specific thought allows greater sensitivity to study upregulation of thought-specific processing, which can be seen in our PPI connectivity analysis. This meant that the thoughts can be tracked with such sensitivity that it can be seen on a single subject level, using a 1.5T fMRI scanner. An important question for future research will be whether such results are limited to thoughts about categories such as faces or places that have a strong neural marker. While this appears likely to be the case for the univariate analyses, given that multivariate approaches have already been used to decode a wider range of voluntary mental imagery (e.g., Pearson, 2014; Naseralis et al., 2011; Reddy, Tsuchiya, & Serre, 2010; Boccia et al., 2017), this approach appears to have promising potential for studying many different forms of mental imagery (particularly when combined with a more powerful fMRI scanner). Further investigations from here can also help clarify whether these two methods, probe and probe-free, could be picking up distinct thoughts, occurring in slightly distinct periods of time.

Our second key finding was our demonstration of overlapping lateral posterior parietal activation in association with involuntary yet salient spontaneous thoughts, and the presentation of salient yet irrelevant external distractors. This extends prior work implicating overlapping regions of posterior parietal cortex in the voluntary orienting of attention to both external sensory stimuli and representations in working memory (Gazzaley & Nobre, 2012; Lepsien et al., 2005). However, the nature of our task, involving the 'white bear' thought suppression paradigm, meant that the thoughts about the suppressed characters in our internal distraction task were, by a strongly emphasised suppression instruction, involuntary. Similarly, participants were strongly instructed to try to ignore the cartoon image distractors during the external distraction task. Hence, the overlapping lateral posterior parietal activation seen in our study appears to reflect involuntary attentional capture, by both internally generated and external sensory representations. A question arising from our finding is the extent to which the act of noticing that we are mind wandering, i.e., the meta-awareness derived from the probing, could be behind the attentional capture (attention to awareness), instead of the contents of a specific intrusive thought. Even though a tentative answer to this question could potentially be drawn from the critical involvement of the lateral prefrontal cortex in meta-awareness of internal processes (Fleming and Dolan, 2012; Fox & Christoff, 2015), and not posterior sites (Axelrod, Zhiu, & Qiu, 2018) as it is the case on salient spontaneous thoughts, and a way of methodologically tackling this issue could be by modelling the brain activity seconds prior to the onset of the probe question, as it was the case in our research, therefore avoiding the periods of brain activity driven by meta-awareness. This methodological approach has been used in neuroimaging research of mind wandering (e.g., Christoff et al., 2009) and also helps tackle the possibility that the activity attributed to the mind wandering state, in this case inferior parietal activation, could be attributed to mnemonic processes triggered by the thought probes. But the fact that we found lateral posterior parietal activations only in the PPI analysis (2 seconds prior to reports) and not in the probe-free, means that we cannot discard the possibility that the activations could in fact be due to attention to awareness, which entails further research investigation.

Our findings are also broadly compatible with proposals of common posterior parietal involvement in both top-down and bottom-up attention to episodic memory (e.g., Ciaramelli, Grady & Moscovitch, 2008). However, the ‘Attention to Memory’ model argues that the parietal lobe is involved in top-down attention to episodic memory, while the bottom-up attention to episodic memory is confined to IPS: This conflicts with our results, in which the SPL area, including IPS, to be active during bottom-up attentional capture by involuntary thoughts. An interesting question is hence whether our paradigm might be applied to test the Attention to Memory model more directly, using reactivations of episodic memories as markers for their involuntary retrieval.

It is interesting to note that the lateral posterior parietal activation was seen in our study only during the period immediately prior to thought probes, and not in the ‘probe free’ analysis which considered the time periods surrounding reactivations irrespective of subjective reports. On the other hand, both the univariate (PPI) and multivariate approaches implicated a more medial parietal region (precuneus) that appeared specific to internal attentional capture, as well as regions of the reward network, and those involved in face or facial expression processing (OFA and STS). An interesting direction for further research would be to examine the role of meta-cognition in the lateral versus medial posterior parietal recruitment during involuntary reactivation – for example, one possibility might be that the lateral regions are recruited only in cases with high levels of meta-awareness.

Our findings of striatal activation in association with internal distraction by a reward associated face build on a large body work implicating the important role of reward in assigning salience, and hence involuntary attention, to particular stimuli (Anderson, Laurent & Yantis, 2014; Anderson, 2016; 2019). To date, the work on attentional capture by reward has considered only external stimuli, yet our data suggests that common mechanisms may be involved in attentional capture by reward-associated mental representations. Indeed, our activations in striatum and IPS parallel those previously observed in an fMRI study of external attentional capture by stimuli that had been subjected to the same reward-training procedure used here (Anderson, Laurent & Yantis, 2014). As such, our findings have the important implication that knowledge gained from the extensive literature on external attentional biases in relation to reward related stimulus categories (e.g., in relation to food among disinhibited eaters or those with a high BMI, Hendrikse et al., 2015; or in relation to addiction related stimuli among addicts, Field & Cox, 2008; Field et al., 2016) may also be informative regarding internal attentional capture by these same stimulus categories (e.g. those associated with food or addiction related cravings).

Besides not being able to completely discard whether the lateral parietal activations are due to attention to awareness as explained before, other limitations of this research are discussed here. The first limitation of the methodological approach used relates to only having a small number of probes reporting intrusive thoughts. Our behavioural pilot had suggested intrusive thoughts in 25% of probes, which was not the case here. Using a thought suppression paradigm was helpful in ensuring that the thoughts were intrusive, but perhaps not in increasing the amount reports (which could be tested as a future direction). Only 14 participants (out of 24) reporting intrusive thoughts in the period immediately before the probes led us to abandon an original aim of assessing the differences between high and low value behaviourally, however, having had 19 participants reporting those thoughts in a non-specified time within the block led us to capitalise into a probe-free method.

In summary, our findings present several key advances in the study of spontaneous involuntary thoughts. Firstly, we demonstrate that even fleeting and involuntary thoughts are associated with reactivation of sensory representations, common to external perception. Second, we demonstrate that that these reactivations can be used as a sensitive means for objectively studying the occurrence of spontaneous and involuntary thoughts. Finally, we reveal common involvement of lateral parietal regions in involuntary attentional capture by (or internal distraction by) both salient task-irrelevant thoughts and salient task-irrelevant external distractors. Our findings hence have both methodological and theoretical implications across a range of fields involving involuntary spontaneous cognition, including the study of phenomena such as mind wandering, involuntary autobiographical memory, and in the contexts of clinical disorders such as anxiety disorders, addiction, and Attention Deficit Hyperactivity Disorder.

Acknowledgments

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Supplemental Materials

Method

Value-training procedure

This task was closely based on the value training task used by Anderson (2011). During approximately 30 minutes, participants were trained to associate pictures of the faces of two characters from Cluedo board game, Ms Scarlett and Mrs Peacock, with high or low monetary rewards. As shown in Figure S1, in a circular search array of six different Cluedo characters, participants searched for the faces of either Ms Scarlett of Mrs Peacock as targets, one of each appearing in a counterbalanced order in each trial. The remaining five nontargets in the trials consisted of faces of other characters.

Participants were required to respond to the orientation of a black line over the target faces, either horizontal or vertical, while the nontargets presented black diagonal lines. When correctly responding to the target face participants would win either a high (3p) or low (0.5p) reward, with an immediate feedback display informing of the amount earned both in the prior trial and in total. One target face was designed to be associated with a higher probability of the high reward and the other with a higher probability of the low reward. The monetary value (high/low) of the face and the orientation of the black bar for each face were also counterbalanced between participants. Participants were informed that they would receive the monetary amounts earned in this procedure (range 0.5p - £5) in addition to the study payment, but at the end they were all compensated with an additional of £5 regardless of the earned amount.

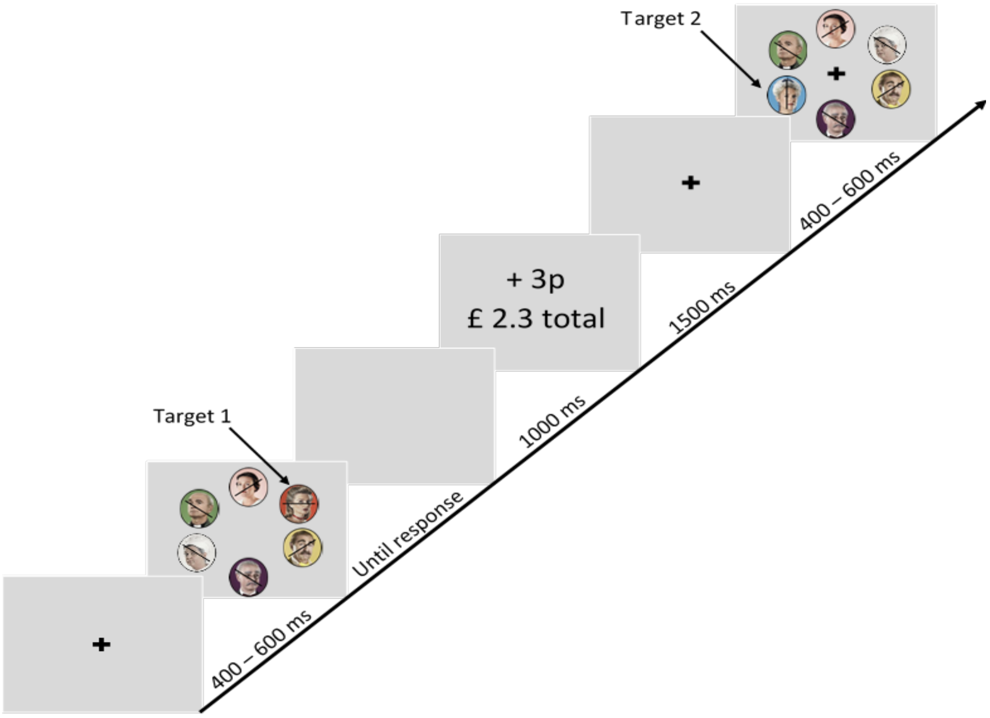


Figure S1. **Value-training procedure adapted from Anderson (2011), with Ms. Scarlett and Mrs. Peacock as targets.**

Results

Attentional capture by external visual distractors

Behavioural performance across distractor conditions:

Distractor condition						
	Incongruent	Congruent	*I-C*	Irrelevant	No distractor	*Irr-NoD*
RT (ms)	801.4 (38.2)	691.4 (28.1)	110	752.4 (31.9)	675.9 (24.6)	76
Accuracy rate (%)	71.4	87.9	5.8	79.8	85.6	16.4

Table S1. **Mean RTs (S.E. in parentheses) and % accuracy rates per distractor condition. I-C means incongruent minus congruent (response competition cost); Irr-NoD stands for irrelevant minus no distractor conditions (irrelevant distractor cost).**

Results

Magnitude of perceptual reactivations

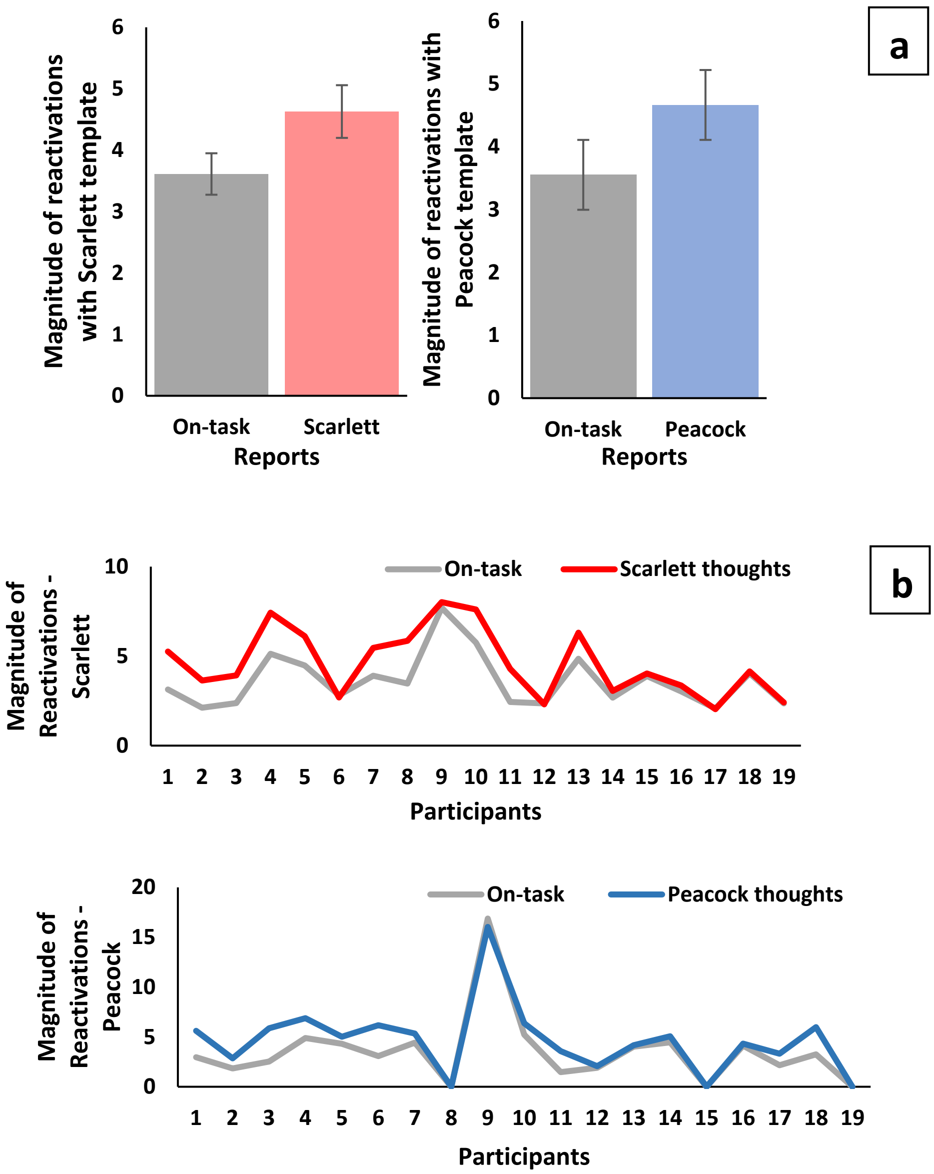


Figure S2. **(a) Mean magnitude of reactivation events for each template. (b) Magnitude of reactivation events across subjects. Error bars represent standard errors.**

Instructions

Value training task

"TASK: You will see six images of Cluedo characters arranged to form a circle. One of the characters will be either Miss Scarlet or Mrs Peacock. This is your target. Each object will have a white line over it. Your task is to identify the orientation of the line over your target. Press 0 for horizontal and 2 for vertical. You only have a short time to respond so you need to be fast - be ready with your fingers on the keys!

During the main task you will win money (0.5p or 3p) for every correct response. You will see how much you win after each trial, as well as your running total.

Press spacebar to start some practice trials (you will not win money during these)."

Face viewing/imagining

"During this part of the experiment you will be asked to think about characters that you see onscreen. You will see a picture of a character, followed by a blank screen for 8 seconds. Please think about each person until you see an instruction to rest. Try to hold an image of that character as vividly as you can in your mind's eye for the full 8 seconds, until you see the word 'rest'. When you see the word 'rest' you can relax until you see the next picture.

Repeat this each time you see a picture of a character."

Internal distraction task

"Now you are going to practice a number task that you will be doing in the scanner. You will see some numbers appear. The task is simple: press the left button for every digit you see, except for 3. When you see a 3 you should withhold your response."

“When you do the task in the scanner you will be asked to suppress any thoughts about Miss Scarlet and Mrs Peacock at the same time. You will be intermittently prompted to report your thoughts - you will be asked 'What were you thinking just now". Onscreen instructions will tell you how to respond.

Press spacebar when you are ready to begin practice.”

Probe 1: “What were you thinking just now?

Press the left button (index finger) if you were thinking about the task

Press the second left button (middle finger) if you were thinking about Miss Scarlet

Press the third left button (ring finger) if you were thinking about Mrs Peacock

Press the right button (little finger) if you were thinking about something else (neither the task nor the target)”

Probe 2: “Did you think about the suppressed characters AT ANY POINT during the last block?

Press the left button if you thought of both characters

Press the second left button if you thought about Miss Scarlet at any point

Press the third left (ring finger) button if you thought about Mrs Peacock at any point

Press the right button (little finger) if you didn't think about either of them at any point”

External distraction task

“Press the left button (under your index finger) if you see the name of a comic superhero

Press the second button (under middle finger) if you see the name of a Disney cartoon.

Respond as fast as you can while also being accurate.

Respond only to the words - IGNORE THE PICTURES!

If you do not ignore the picture it may slow you down or even make you respond incorrectly!

Before each display there will be a dot at the centre of the screen - please look straight at this dot.

If you respond incorrectly, or fail to respond, an '!' will briefly appear

Press the left button to start."

Within blocks: "Remember press left button for comic superhero and middle button for Disney cartoon. Remember to respond only to words, keep ignoring any pictures! Respond as fast and as accurately as you can!"

Pre-scan session script

PART 1: ***Pre-scan Session***
<u>Preparation</u>

Hi! Thanks for coming today. [CONSENT/SCREENING/QUs - TIME ALLOCATED: ABOUT 10 MIN]

Have you already read the consent forms and filled in the fmri and health screening forms? Great **–** Did you have any questions about the consent form? *(check signed)* I'll tell you a little more about the tasks today in a moment.
go over fmri/medical screening forms with volunteer and reiterate:
As the email explained, we use the health questionnaire and MRI screening questionnaire to make sure you are safe to participate in an fMRI experiment ***Check forms – be careful to check all metal related questions/query as necessary***

If consent, mri screening and health screening (including drug screening) is ok then proceed:

The specific experiment we are inviting you to take part in looks at the brain regions involved in paying attention to the external world and our own thoughts. In order to study this, you are first going to be asked to do a task here, outside of the scanner. In the fMRI session you will then be asked to perform three tasks – a short 'thinking' task, a thought suppression task and another short attention task. Including set up and getting a detailed structural image of your brain the whole scan session will take about 1 hours.

Does that sound okay? Do you have any questions? – *(answer if so)* Great

<u>Pre-task and</u> <u>Task Training (evaluation room) -</u>TIME ALLOCATED 40 mins
-- Experimenter – *Now the subject has finished the consent form packet* – Great. Now we're gonna practice the task you will be doing inside the scanner.

Pre-scan tasks can be run in E-Prime on the PC immediately opposite you and next to left wall as you enter the evaluation room.

Username: [redacted]
Password: [redacted]

Prescanner task:

Participant completes PreScanWinningTask (approx. 20-30 mins) - Scarlett is red, Peacock is blue

Practice tasks:
First show the participant 'ThinkRun', make sure they understand that they are meant to maintain a strong mental image of each image they see until they see the word rest. (approx. 2 mins)

Next, do SARTpractice – make sure they understand the number task, and how to respond to probes (approx. 2 mins).

Finally, practice SuperHeroCartoonPractice – make sure the participant understands that they should respond as fast as they can while being accurate. Make sure they know they will see images in the scanner as well as the words, but that they should only respond to the words. (approx. 5 mins)

Movement

--Experimenter – Okay so let's go over the issues regarding movement in the scanner – did you get a chance to read this over ***(give them movement sheet and talk it through with them)***

After go over sheet -

To recap, the main concern is movement of your head and back, coughing/ uncrossing your legs etc (because that'll move your upper body a lot).

--Experimenter – Do you have any questions?

PART 2: *Scan Session*

At the beginning of the session:

1. Turn on intercom and check in with participant (say hello, check they are comfortable etc).
2. During the structural scans blank the screen with the button to the right of the stim PC.
3. Open notepad and ask them to press buttons 1,2,3,4 to check response box is set up correctly (you can do this after localizer while radiographer is setting up the slice positioning).

REMEMBER: fill in the log sheet during the scan – record things such as participant feedback, problems with the task etc.

IMPORTANT: After each scan ends, complete the following steps in this order:

1. Wait for scan to stop (you can hear sound will have stopped)
2. Turn intercom on
3. Turn off scanner synchronization on the white box
4. Turn on blank screen if you are going to set something up or do a structural scan
5. Explain next steps to pp

The four EPI runs should accompany the following tasks
ThinkRun
SARTRun1 (pp number = 10**3**, scan session 1)
SARTRun2 (pp number = 10**3** , scan session 2)
SARTRun3 (pp number = 10**3** , scan session 3)
SuperHeroCartoonScan

IMPORTANT: **Before** each EPI scan starts, complete the following steps in this order:

1. Turn off screen blank if necessary
2. Start program and make sure the participant remembers instructions (move through slides by pressing "1" not spacebar)

3. Move on task to show the 'waiting for scanner' screen (if this is done after the scan starts, the task timing will be recorded incorrectly and the data will be worthless so ask to restart the scan if that happens).
4. Set up the scanner synchronization on the white box – should say "running session" and then counts from 0 when scanning starts, task should start after around 6 scans
5. Turn off intercom

Post scan session

Payment Form.
Ask volunteer to fill out the payment form and go through brainshare consent and information sheet if not done already.

Notes:
-button box: 1=index finger 2=middle finger 3=ring finger 4=little finger
-you can see what button pp's are pressing from looking at the silver box next to the white box
-dont need to press white box for localizer or structural scan because it doesn't sync with the task
-all files (i.e. tasks, images etc) need to be in same folder or it won't work

Overall scan session:

Positioning is straight – whole brain. Inner mid-brain and parietal + frontal + occipital are most important

Localizer (18seconds)
Thinking task
STARTRun1
STARTRun2
StartRun3
Cartoon/superhero task
Structural scan – 6 minutes
Data – folder ppcode after each file

Brief note on tasks:

ThinkRun

This is when they see the picture of the cartoon, have to hold the image for 8s and then relax and repeat. Short task.

SARTRun1 (pp number = 10**3**, scan session 1)
SARTRun2 (pp number = 10**3** , scan session 2)
SARTRun3 (pp number = 10**3** , scan session 3)

These are all the same, they see numbers come up on the screen, they press “1” for every number that comes up APART from if they see the number 3

SuperHeroCartoonScan

Is it a superhero or cartoon. Only look at the works not the pictures

1=superhero
2=cartoon

CHAPTER III

Study 2: Establishing psychophysiological markers of strategic and affective thoughts

Abstract

Mind wandering has been shown to serve important functions such as planning for the future, decision making, and strategic problem solving relating to our current concerns. However, such 'strategic' modes of mind wandering can also take negative forms in terms of worry or ruminations. The goals of the present research were to characterise the phenomenology of strategic (i.e., goal directed) forms of spontaneous mind wandering, in relation to emotional valence as well as other dimensions (plausibility, mental time travel), and to facilitate future research in this area by establishing objective electrophysiological markers for strategic and affective dimensions of thought. To address our first goal, two large online studies (total N = 605) employed intermittent probes during an audio lecture at which participants rated and reported their thought contents. Across studies, thirty-eight % of thoughts were rated as moderately or highly strategic. These 'strategic thoughts' were more likely to be future-oriented, and highly plausible, than those rated as less strategic. The strategic dimension of thought was not consistently linked to thought valence, however the level of strategy combined with valence of thoughts predicted negative affect (although this latter result was found in only one of the two samples). We then asked 30 participants to perform a series of thought exercises designed to simulate mind wandering, varying in strategic content and emotional valence, while EEG and facial EMG data was recorded. More strategic thought and negative valence (unpleasantness) were reflected in increased frontal beta and activity of the corrugator supercilii muscle, respectively. Our findings hence provide the foundation for future research testing the ability of these objective electrophysiological markers to index strategic and affective dimensions of spontaneous thought contents.

Establishing psychophysiological markers of strategic and affective future thinking

Our minds are restless and dynamic by nature, privately flying between processing of our external environment, and a range of internally generated thoughts, memories, and feelings. This is usually called mind-wandering or daydreaming (e.g., Stawarczyk et al., 2011; Klinger, 1990; Singer,1975). Mind-wandering is a covert ubiquitous phenomenon that is said to occupy up to 50% of our waking thoughts (Killingsworth and Gilbert, 2010), in which our minds are in things other than the task that we are currently engaged in (Stawarczyk et al., 2011; Kane et al.,2007; Klinger, 1990; Christoff, 2011). The ubiquitous nature of mind wandering makes it difficult for an external observer to access the contents of a person's thoughts unless they are willing to report them. For example, while observers such as teachers might detect that a child's attention is not on their intended task, they could not know whether this is due to attention being instead engaged in constructive future planning, rumination, worry, relaxed daydreaming, or 'mind blanking'.

Previous research has highlighted that mind wandering can serve important functions such as future planning, decision making, and strategic problem solving relating to our current concerns (McVay & Kane, 2013). However, such 'strategic forms of mind wandering can also take negatively valenced forms. For example, a previous study of mind-wandering using fMRI found that individuals more prone to worry – a negatively valanced class of strategic thought – show increased frontal-default network connectivity during sustained attention, suggesting a redirection of frontal resources for mind wandering (Forster et al., 2015). This parallels with mind wandering findings of activations in frontal regions implicated in executive control (Christoff et al., 2019; Stawarczyk & D'Argembeau, 2015). The goals of the present research were to characterise the phenomenology of strategic forms of spontaneous mind wandering, in relation to both emotional valence and mental time travel, and to facilitate future research in this area by establishing objective electrophysiological markers for strategic and affective dimensions of thought.

Techniques such as fMRI and EEG have substantially advanced the understanding of mind-wandering, from its disruptive effects on external processing (Baird et al., 2014; Braboszcz & Delorme, 2011) to patterns of neural activity characteristic of general off-task thought (for example within the default-mode network; Christoff et al., 2009). EEG research offers some advantages over fMRI research as a tool for 'mind-reading'. Its superior temporal resolution potentially allows for a more fine-tuned measurement of fluctuations in thoughts. It is also substantially cheaper and more portable than fMRI, the latter has already allowed for the study of mind wandering during real world settings, such as during a live lecture (Dhindsa et al., 2019). The portability of EEG and greater resilience to participant movement (relative to fMRI) is also advantageous for expanding the field of mind wandering beyond neurotypical adults to include developing and clinical populations.

Because of the aforementioned benefits, there is a growing number of EEG studies on mind wandering in the last decades (e.g., Arnau et al., 2019; Boudewyn & Carter, 2018; Bozhilova et al., 2020; Braboszcz & Delorme, 2011; Broadway et al., 2015; Compton et al., 2019; Jin et al., 2019; Martel et al., 2019; van Son et al., 2019; Villena-González et al., 2016; Hawley et al., 2021; Jin, Borst, & van Vugt, 2020; Gouraud, Delorme, & Berberian, 2021; Tasika et al., 2020), however, with an overwhelming focus on establishing the markers of general mind-wandering or on differentiating on- versus off-task periods, rather than assessing the contents of thoughts. For instance, increased EEG spectral activity in the alpha band (8-12 Hz) has long been established as a marker of internally directed versus external attention (Cole & Ray, 1995; Cooper et al., 2003; Benedek et al., 2014; Godwin et al., 2016). Early ERP components have also been studied. Baird et al. (2014), for example, found that participants showed reduced P1 component when they were mind wandering as opposed to focusing on the task, during a visual search task. Jin et al. (2019) used machine learning for real-time trackability of the state of mind wandering versus being on-task. They were able to distinguish between on-task and off-task with 50 to 85% of accuracy, using previously established EEG markers of mind wandering: ERP components (P1, N1, P3) and power at the parieto-occipital alpha. Those results have been of utmost importance to objectively index and track the occurrence of MW and its costs to external attention. However, less is known about EEG markers of the specific contents of thoughts. This is the goal of the present study.

As mentioned previously, the gap on EEG studies investigating the neural signature of contents of thoughts corresponds with the initial focus of both neurocognitive and self-report measures of mind-wandering, which have been on indexing the occurrence of episodes, i.e., whether a person was on or off-task. Recently, however, there is growing interest on the phenomenological aspects of the wandering mind. Smallwood and Andrews-Hanna (2013), for example, suggest that the contents of mind wandering are what determine their impact on a person's life, and that contents of thoughts are particularly relevant for interventions in clinical contexts, in mental health, and wellbeing. In general, research that goes beyond attention orientation (being on or off-task) to delve into the contents of mind wandering have been showing a complex and wide range of thoughts (Wang et al., 2018), which could usually fall into some repeated phenomenological dimensions, such as, temporal orientation – past, present and future – (Baird et al., 2011), temporal distance (Spronken et al., 2016), the level of intentionality of thoughts – deliberate or spontaneous – (Seli, Risko and Smilek, 2016), goal-directedness (Baird et al., 2011; Smallwood & Schooler, 2006), emotional valence (Banks et al., 2016; Poerio, Totterdell, & Miles, 2013), self- or other-centredness (Jazaieri et al., 2016; Poerio et al., 2015), among others.

According to Smallwood and Andrews-Hanna (2013), the temporal orientation of thoughts, and the functional characteristics, for example, goal-directedness and relevance for future planning, are important aspects when considering the beneficial impacts, but some characteristics of thoughts, e.g., pervasiveness and repetitiveness, usually present in rumination and worries (Ottaviani et al., 2015; van Vugt & van der Velde, 2018; Baars, 2010), can be maladaptive and impair mental health, for example in terms of depression and anxiety, or more broadly psychological distress and unhappiness. Research has shown that both rumination and worries are two classes of repetitive and uncontrolled thoughts that correlate with anxiety and depression symptomatology, and with maintenance of symptoms (e.g., Segerstrom et al., 2000; McEvoy et al., 2013; Calmes & Roberts, 2007; Hughes, Alloy, & Cogswell, 2008), besides being associated, among other psychological wellbeing problems, to alcohol abuse (Ciesla et al., 2011) and sleep disturbance (Pillai & Drake, 2015).

Pervasive and repetitive thoughts like worries and ruminations could be considered a negatively valenced type of strategic thinking (e.g., Krys, 2020; Krys, Otte, & Knipfer, 2020; Geider & Kwon, 2010; Watkins, 2008). Specifically, while a person could be engaged in pleasant and very adaptive strategic thinking like creative problem solving or constructive planning, they could also be drawn to an unpleasant and cyclic pattern of rethinking steps and 'what ifs' that would engage similar cognitive resources, but that are no longer useful for solving the problem, and could potentially hinder their emotional state. Furthermore, these unpleasant strategic thoughts could also involve similar neural markers, specifically frontal recruitment, which might make them overlooked as different categories of strategic thoughts, but with very distinct impacts on mental health. This intersection has not yet been studied in the context of strategic mind wandering thoughts, but there is evidence that worries, for example, impose cognitive load and impair cognitive performance (Eysenck et al., 2007). It has been suggested that rumination impairs executive functions, functions that when adaptive promote goal-driven thoughts and behaviour (Ramponi et al., 2004; Friedman & Miyake, 2017). On the other hand, rumination has also been considered as a constrained and special type of mind wandering, through maladaptive use of the executive functions (van Vugt & van der Velde, 2018). The work of Ottaviani and colleagues (2015) have also suggested that rumination and worries are uncontrolled and involuntary forms of mind wandering in which thoughts are perseverative and which negatively impacts cognitive performance. Therefore, in this paper, we focus on the intersection between strategic and unpleasant thoughts, partly by conducting a large sample experience sampling study to test the extent to which strategic thoughts span the emotional spectrum, and how this drives negative affect. We are aware that ruminations, and repetitive thoughts in general, are not always maladaptive. For example, Watkins (2008) explains that repetitive thoughts, such as worries and ruminations, can take both constructive and unconstructive impacts, and that only the latter are related to anxiety, depression and psychosomatic problems, whereas constructive repetitive thoughts can be adaptative to action and future planning, and even trauma recovery. Here we shed more light on the unconstructive quality of repetitive thoughts.

One key function of mind wandering that has been highlighted is what we will term ‘strategic thoughts’, i.e., goal-directed thoughts (e.g., Smallwood & Schooler, 2006; Baird, Smallwood, & Schooler, 2011), possibly for facilitating autobiographical planning of personally relevant goals (Baird et al., 2011; Stawarczyk et al., 2011; D'Argembeau et al., 2011) or related to our current concerns (e.g., Klinger, 2004; McVay & Kane, 2013). The current concerns framework is an explanation to mind wandering drawn from Klinger’s current concern hypothesis (e.g., 2004), and later developed by McVay and Kane (2010), suggesting that currently relevant future plans are both mentally and subjectively valued as being more important than the immediate external demands, leading a person to mind wandering. This seems aligned with the famous quote by William James (1980): “My thinking is first and last and always for the sake of my doing”, displaying a functional practicality to thinking. Klinger (2013) suggests that when progress is likely, a goal captures attention and the person responds with practical mental actions to fulfil it, and when progress seems averse, the person's attention is still captured by the contents of the goal, but they tend to engage in a more passive daydreaming. In terms of temporal orientation, the future has been shown to be the most natural habitat of strategic mind wandering (e.g., Baird et al., 2011; Stawarczyk et al., 2011; Jordão et al., 2019), but this seems inconlusive as, for example, Cole and Kvavilashvili (2019) did not find differences in the temporal orientation between temporal orientation and effortful thinking requiring more executive resources.

Cole and Kvavilashvili (2019) discuss the importance of distinguishing different types of thoughts, in particular between planning and passive imagination. Various theorists all argue for the differentiation between passive fantasy and what we call 'strategic thinking'. For example, Stawarczyk, Cassol and D'Argembeau (2013) found that within-subjects' episodes of MW differed in what they called level of structuration, which they defined as more structured thoughts, such as those involving reasoning and argumentation. Mind wandering studies using fMRI have shown the recruitment of an executive frontal set of regions, the dorsal attention network (DAN), besides the already established default network (DMN), only just to a lesser extent than when focusing on-task (Christoff et al., 2016). Christoff and colleagues (2009; 2016) thus support that both the DMN and the DAN activate during mind wandering. The pre-frontal cortex (PFC) has been established as an area of activation for goal directed thoughts, in particular the lateral prefrontal cortex (lateral PFC), a prominent area in the DAN (Christoff et al., 2011). Therefore, both the DMN and the DAN being found active during mind wandering suggest some complexity of the associations between mind wandering and executive functions (Jin et al., 2019) and could point to a dynamic nature in the contents of thoughts. Differences in the level of strategy of mind wandering thoughts have also been found in studies of individual differences of mental capacity. For example, (Robison & Unsworth, 2017) found that subjects with higher working memory capacity (WMC) tend to have more strategic thoughts. This suggests that a more strategic type of thinking could be more resource demanding than a passive fantasy. Using fMRI, there seems to be correlates to ‘strategic thought’ in terms of the regions involved in executive functioning (Smallwood et al., 2012), but it has not been established with EEG. However, a way to investigate the neural differences between strategic and fantasy thoughts could be through the EEG beta frequency band (13-25 HZ), which has been recurrently associated to frontal executive functions. Ray and Cole (1985; 1995) found that increased EEG activity in the beta band over frontal sites was an indicator of cognitive effort. Others have also associated frontal beta with cognitive processes (e.g., Macaulay & Edmonds, 2004; Kiroy et al, 1996; Markand, 1990). Frontal and parietal beta has also been associated to perceived mental effort during attention tasks, as compared to a resting task (Howells et al., 2010). It has also been linked to motor action planning (Behmer & Fournier, 2014), and central site beta has been shown to be involved in the preparation and execution of complex movements (Zaepffel et al, 2013). This establishes beta as a possible marker for strategic thinking versus passive imagination.

Forster et al. (2015) have specifically linked executive recruitment and frontal-default connectivity during sustained attention to mind-wandering, anxiety, and worry. Affective valence of thoughts seems to be an important component of mind-wandering for its associations with mood and negative affect (e.g., Banks et al., 2016; Cole et al., 2016; Smallwood et al., 2009; Ruby et al., 2013; (e.g., Banks et al., 2016; Cole et al., 2016; Smallwood et al., 2009; Ruby et al., 2013). The goal of the present study was hence to establish objective signatures of strategic thoughts, including their emotional valence. Whilst the strategic aspect of thoughts could potentially be investigated using frontal beta, in terms of predicting their emotional valence one potential index could be accompanying movements of *Zygomaticus major* (smile muscle) and the *Corrugator supercilii* (frown muscle) through facial electromyography (EMG). Facial EMG has been established to be sensitive to index emotional reaction to external stimuli (De Wied et al., 2009; van Boxel, 2010; Golland et al., 2018). To our knowledge it has not yet been explored whether these could also index the emotional valence of thoughts, but they have been shown to indicate responses on affective valence even without the subject's awareness (e.g., Golland et al., 2018).

The research study is composed of two experiments in which we seek to characterise the phenomenology and establish the electrophysiological correlates of strategic thoughts. In Experiment 1 (versions 1a and 1b), carried out online, we investigate the phenomenological correlates of strategic spontaneous thoughts during an audio lecture with intermittent thought probes in which participants rated and reported their focus and the contents of their thoughts in the dimensions of level of strategy, temporal orientation, valence, and plausibility. In this manner we examined both the co-occurrence of valanced and strategic dimensions of thought, and the relationship of these dimensions to current negative affect: Here we were interested, in particular, in whether the combination of strategic and negatively valanced thoughts were associated with negative affect (reflecting Forster et al.'s, 2015, findings of stronger executive recruitment for highly anxious individuals). In Experiment 1b subjects were also invited to freely describe their thoughts. In Experiment 2, conducted in laboratory, to identify the electrophysiological markers of affective valence and level of strategy in different types of instructed thoughts, participants were asked to perform a series of thought exercises designed to simulate mind wandering, varying in strategic content and emotional valence, while EEG and facial EMG data was recorded. We anticipated an increase in frontal beta amplitude, for the more strategic thoughts as compared to passive imagination, reflecting recruitment of executive functions and exertion of mental effort. And we expected that the *Corrugator* vs *Zygomaticus* muscles would indicate unpleasant versus pleasant thoughts, respectively.

Experiment 1a and 1b

Method

This experiment sought to characterise the phenomenology of strategic forms of spontaneous mind wandering, in relation to both emotional valence and mental time travel, as well as the relationship of strategic and negatively valenced thoughts to negative affect. For this, we collected two large samples of experience sampling data. Experiments 1a and 1b were identical, with the exception of the addition of an open-ended question in Experiment 1b, which allowed further examination of the specific contents of pleasant and unpleasant strategic thoughts. In this manner we were also able to test for replication of any phenomenological patterns across both datasets.

Participants

This experiment was approved by the University of Sussex Science & Technology Cross-Schools Research Ethics Committee. All subjects were right-handed, with normal or corrected to normal hearing and vision, and fluent in English. Student samples (Experiments 1a and 1b) were recruited through the University of Sussex's participant pool, receiving course credits for their participation, and a general population sample (Experiment 1b) was recruited via Prolific (https://www.prolific.co/), receiving an hourly payment for their participation. The stopping rule was based on recruiting approximately 300 participants, age range 18-35 years. Power analysis conducted using G*Power software (Faul et al., 2007) revealed that this sample size would have 99% power to detect between subjects' correlations of $r > .24$ (alpha = .05, two tailed). $N = 302$ students (88% females, age $M = 19.74$, $SD = 1.76$) were initially recruited for version 1a, and $N = 303$ subjects were recruited for version 1b (77% females, age $M = 22.38$, $SD = 4.64$), of which a sub-sample of 113 were recruited from the general population and 190 from the student pool.

Procedure

This study was programmed and presented using Inquisit 5 (Millisecond Software; http://millisecond.com/) and completed online. Subjects were required to have a computer or tablet with an up-to-date browser, stable internet connection, good speakers, and Inquisit Player 5 installed. Prior to tasks, subjects were asked to read the study information onscreen and consent by pressing the relevant button. Subjects were then asked to complete the Depression, Anxiety and Stress Scale-21 (DASS-21; Lovibond and Lovibond, 1995) to assess their emotional state (state affect). The DASS is a public domain questionnaire, for self-administration, that covers most of the DSM 5 criteria for mood and anxiety disorders. The version used in this research is the short one with 21 items, 7 per subscale, and which are half of the original scale, with 42 items, 14 per subscale. The three subscales of the DASS, both original and short versions, are Depression, Anxiety and Stress (Lovibond and Lovibond, 1995). The Depression subscale measures "dysphoria, hopelessness, devaluation of life, self-deprecation, lack of interest or involvement, anhedonia, and inertia" (Bados, Solanas, & Andres, 2005, p. 679) as well as lack of energy (Oei et al., 2014). The Anxiety subscale measures "somatic and subjective symptoms of fear, and assesses autonomic arousal, skeletal musculature effects, situational anxiety, and subjective experience of anxious affect" (Bados, Solanas, & Andres, 2005, p. 679). Lastly, the Stress subscale assesses irritability, impatience, agitation, nervous arousal, and difficulty relaxing (Oei et al., 2014; Bados, Solanas, & Andres, 2005). The rating scale of the DASS-21 ranges from 0 (Did not apply to me at all) to 3 (Applied to me very much or most of the time). When applied to UK population, even this short version of the scale has been found to have good construct validity, both for each subscale independently as well as to measure negative affect in general (psychological distress), with reliabilities of ".88 for Depression,.82 for Anxiety,.90 for Stress, and .93 for the Total scale" (Henry & Crawford, 2011, p. 236).

Following completion of the DASS-21, subjects were asked to listen to a 30min audio recording of a university lecture on English Literature, collected from the University of Oxford podcasts archive. Thought probes interrupted the lecture at six time points, at the end of each block. Blocks had lengths varying from 2 minutes and 33 seconds to 7 minutes and 41 seconds (*M* = 5'12 minutes). At each thought probe, a series of questions were displayed to assess participants thoughts, with responses recorded via 5-point Likert scales. Probes surveyed subjects' attention focus (whether subjects were on or off task) and thought contents (in the dimensions of temporal orientation, level of strategy, level of plausibility, and valence). The probe questions were: "Where was your mind focused just before this screen?", [*1="Completely on the lecture"; 2="Somewhat on the lecture"; 3="Neither on or off the lecture"; 4="Somewhat off the lecture"; 5="Completely off the lecture"*]; "Was your mind more on the past or on the future?", [*1="Completely on the past"; 2="Somewhat on the past"; 3="Atemporal or in the here-and-now"; 4="Somewhat on the future"; 5="Completely on the future"*]; (3) "How strategic was your thinking (i.e. involving some planning or analysis), as opposed to contemplative (i.e. passive imagination)?", [*1="Completely strategic"; 2="Somewhat strategic"; 3="Neither"; 4="Somewhat contemplative"; 5="Completely contemplative"*]; (4) "To what extend was your thinking plausible or likely to happen?", [*1="Completely likely to happen"; 2="It could happen/Somewhat plausible"; 3="Neither"; 4="Not so likely to happen"; 5="Completely unrealistic or unplausible"*]; and (5) "To what extent was your mind on something pleasant or unpleasant?", [*1="Very unpleasant"; 2="Somewhat unpleasant"; 3="Neither"; 4="Somewhat pleasant"; 5="Very pleasant"*]. In Experiment 1b, there was also an open-ended question asking participants to briefly describe what they were thinking about. See Supplemental for verbatim of instructions and probe options. Thoughts with a score of 1 and 2 in the Likert scale to the question of "How strategic was your thinking (i.e. involving some planning or analysis), as opposed to contemplative (i.e.

passive imagination)?" were categorised as low strategy, and thoughts with a score of 3 to 5 were categorised as hight strategy.

Results

Intra-individual variation in strategic thoughts

Across both versions of the experiment, 37.8% (*SD* = 24.8%) of thoughts were rated as moderately or highly strategic, 35.7% (*SD* = 23.2%) in Experiment 1a and 39.9% (*SD* = 26.0%) in Experiment 1b. We first compared the valence, temporal orientation, and plausibility ratings on a within-subject basis among those subjects who had reported of both high and low strategy thoughts ($N = 85$ for Experiment 1a, and $N = 117$ for Experiment 1b). Both Experiments 1a and 1b were consistent in showing a slight prospective bias (more future thoughts) for high strategy versus low strategy: For Experiment 1a, $M = -.78$, $SD = 1.11$, $t(84) = -6.47$, $p < .001$; replicated in Experiment 1b, $M = -.83$, $SD = 1.08$, $t(113) = -8.2$, $p < .001$. Both experiments also found increased plausibility ratings in the high strategy condition versus low strategy: For Experiment 1a, $M = -.82$, $SD = 1.12$, $t(81) = -6.66$, $p < .001$, replicated in 1b, $M = -.78$, $SD = 1.42$, $t(102) = -5.54$, $p < .001$.

With respect to our key question of the valence of strategic thoughts, this varied only in Experiment 1a, in which high strategy thoughts ($M = 3.04$, $SD = .30$) were less pleasant than low strategy thoughts ($M = 3.26$, $SD = .71$), $t(84) = 2.89$, $p =.005$), see Figure 1. For Experiment 1b, no difference in valence was observed between high strategy ($M = 2.93$, $SD = .85$) and low strategy thoughts ($M = 2.83$, $SD = .83$), $t(116) = 1.04$, $p = .30$).

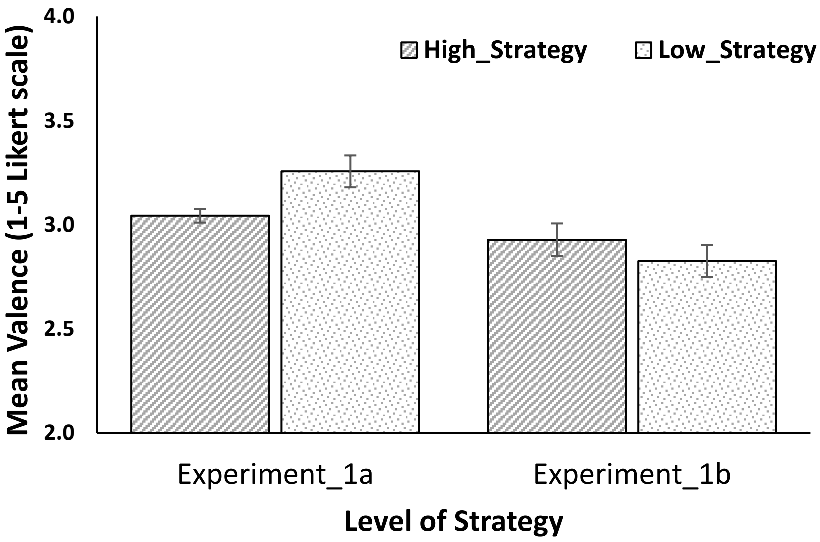


Figure 1. **Mean valence of thoughts by level of strategy per version of Experiment 1, +/- SEM.**

Inter-individual propensity to strategic and affective thoughts and negative affect

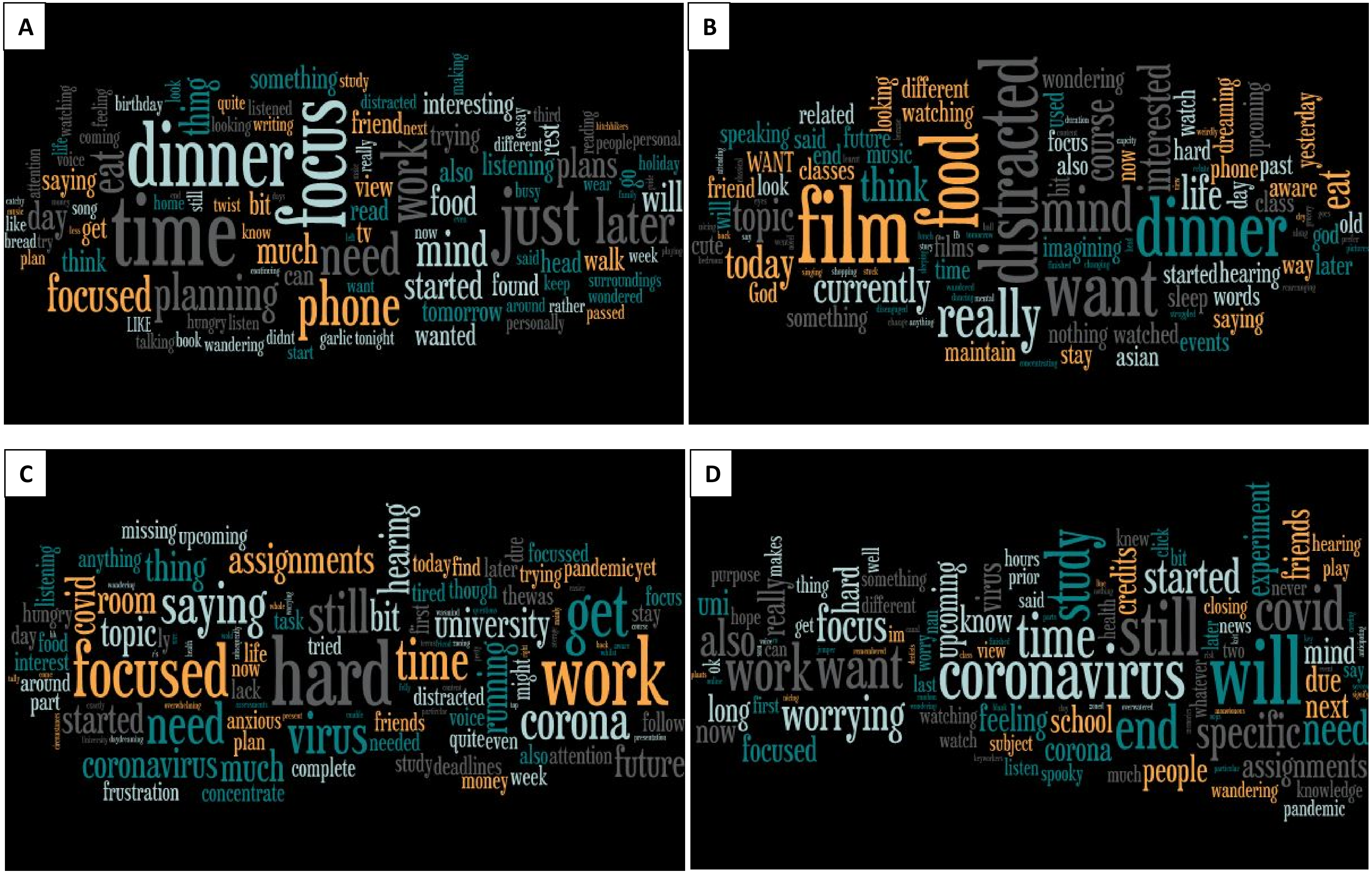
Between subject's Pearson's correlation analyses showed patterns largely mirroring the within subject findings, in terms of individuals reporting higher levels of strategic thought also reporting a stronger prospective bias (for Experiment 1a $r(292) = .20$, p = .001, for Experiment 1b $r(301) = .33$, $p < .001$) and a tendency to greater plausibility (for Experiment 1a $r(291) = .40$, $p < .001$), for Experiment 1b $r(300) = .38$, $p < .001$). Level of strategy did not correlate with valence in either experiment, $p > .17$ and $p > .27$, respectively.

We next examined the ability of our key variables of strategy and valence to predict negative affect, as measured by the total score in the DASS. In terms of the correlations, negative affect was predicted by thought valence (for Experiment 1a $r(294) = -.26$, $p < .001$, for Experiment 1b $r(302) = -.37$, $p < .001$), but no relationship was observed between the strategic dimension of thought and negative affect, $p > .06$ and $p > .67$, for Experiments 1a and 1b, respectively. Our prediction of a joint role of strategy and valence in predicting negative affect was supported by the data in Experiment 1a: Results of the multiple linear regression indicated that there was a joint significant effect of valence and level of strategy in negative affect, $F(2, 289)$, $p < .001$, $R^2 = .076$. The individual predictors indicated that valence, $t = -4.53$, $p < .001$, and level of strategy, $t = 2.13$, $p = .03$, were significant predictors of the model, but this was not replicated in Experiment 1b, where negative affect was predicted by valence alone.

Content analysis

In Experiment 1B, an exploratory analysis of the contents of thoughts reported in the open-ended question summarises the most salient words in four dimensions according to combinations of level of strategy and valence, distributed in a word-cloud. The word-cloud was created using the software Pro Word Cloud version 1.0.0.3 (Orpheus Technology, Ltd). Word-cloud were restricted to a maximum of 110 words and obtained by automatically excluding common words and prepositions in the English language, such as '*by*', '*the*', and '*and*', and by excluding the following repeating words which were specific to the task or the probes: '*lecture*', '*lecturer*', '*Dickens*', '*thinking*', '*going*', '*don't*', '*boring*', '*bored*', '*I'm*', '*thoughts'*, '*many*', '*things*', '*mostly*', '*point*', '*Oliver*', '*Twist*'. Further excluded words were: '*getting*', '*whether*', and '*just*'. See word-clouds in Figure 2 for the frequency distribution of words across dimensions.

As can be seen in Figure 2, a clearer separation between the high and low strategic dimensions can be seen for pleasant thoughts, with words such as '*planning'*, '*focus'*, '*plans',* for pleasant high strategy, versus words such as '*imagining'*, '*dreaming'*, '*god'*, '*distracted'*, for pleasant low strategy. In the case of the unpleasant thoughts, both high and low strategy thoughts include social and academic topics as well as mentions of the COVID-19 pandemic (this dataset was collected between February-April 2020), with the strategic thoughts also including financial topics. Interestingly, food-related thoughts are found in all quadrants, which is in line with previous research on the prevalence of food-related thoughts during mind wandering similar to cravings (May et al., 2010) .


A
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long
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Figure 2. **Word-clouds from contents analysis of descriptions of thoughts during mind wandering. A-Moderate to high strategy, pleasant. B-Low strategy, pleasant. C-Moderate to high strategy, unpleasant. D-Low strategy, unpleasant.**

Experiment 2

Methods and materials

Participants

Thirty-five subjects initially took part on this study. Subjects were all right-handed, fluent English speakers, recruited from the University of Sussex's Participant Pool. Most subjects were undergraduates or master students. Each subject received £6 per hour as compensation for their participation. Participants had normal or corrected-to-normal vision and hearing. Any clinical or neurological conditions, as well as skin problems or injuries on the head or neck were taken as exclusion criteria. The study was approved by the University of Sussex Sciences & Technology Cross-Schools Research Ethics Committee. During preprocessing and analysis, the full data from five subjects were rejected due to excessive muscular and ocular artifacts. Thus, here we report the results of the remaining subjects (N = 30, 22 females, age range 19-31, M = 22.67). Because of a recording problem, for the facial EMG we could only retain for analysis the data from 17 subjects over *Corrugator supercilii*, and 8 subjects over *Zygomaticus major*. Our power analysis showed that our sample of N = 30 for EEG gives us a 80% power for dz > .54, two tailed, and the EMG sample N = 17, for *Corrugator* muscle, gave us 80% power to detect dz > .73.

Rating of scenarios

The scenarios used in this experiment were devised by the three researchers to reflect naturalistic thought topics, varying in the level of both strategy and valence – see Table 1 for examples. To minimise variation in dimensions we were not studying, all scenarios had a future temporal orientation.

Participants. This pilot experiment was approved by the University of Sussex Science & Technology Cross-Schools Research Ethics Committee. *N*=22 subjects were recruited via Prolific (https://www.prolific.co/), receiving a payment of £6 per hour (63% females, age M = 26.35). All subjects had normal or corrected to normal hearing and vision, and fluent in English.

Procedure. During this online pilot experiment, participants were shown scenarios on their computer screens which they were instructed to think of, holding each of them in their mind's eye during 30s. After thinking of a single scenario, they were asked to rate them according to what was their experience of them in different dimensions (level of strategy: "How STRATEGIC (involving planning) was your experience?"; pleasantness: "How was the emotional valence of this scenario for you (i.e., neg/pos feeling)?"; plausibility: "How PLAUSIBLE (likely to happen) was the scenario for you?"; vividness: "How VIVID was it for you?"). Rating were taken on a sliding scale varying from 'Not at all' to 'Extremely', and corresponding to ranges from 0 to 100, except for the pleasantness dimension, that ranged from -50 to 50, corresponding to negative-positive. See Table 1 for examples of scenarios according to conditions. See Supplemental Materials for instructions.

	Examples of scenarios	
	High strategy	**Low strategy**
Pleasant	Plan how you would spend your money if you won the lottery.	Imagine you are meeting a famous person and they are impressed by you.
Unpleasant	Plan the logistics of an event you are dreading, e.g., how you will get there, what you need to prepare beforehand, etc.	Imagine being asked a question in a seminar which you do not know the answer to.

Table 1. **Example of scenarios options according to conditions. Except for the external attention condition, each of the other conditions had twelve scenarios, distributed in terms of level of plausibility, strategy, and valence.**

Results and discussion. As analysis, we looked at differences between ratings of planning (high strategy) versus imagining (low strategy), and positive (pleasant) versus negative (unpleasant) for the four dimensions. See Table 2 for mean rating results. Results confirmed that the scenarios varied as intended: scenarios in the high strategy condition were rated as significantly more strategic than scenarios in the low strategy condition, with 21/22 raters showing this effect. Pleasant and unpleasant scenarios also differed as intended for all 22 raters (see Supplement for variation across subjects). Unexpectedly, a small but significant difference was observed between the valence of the high versus low strategy scenarios, with scenarios in the low strategy condition being rated on average as slightly more pleasant than those in the high strategy condition although in both cases the average ratings were close to the midpoint of 0. On the other hand, there was no significant difference between pleasant and unpleasant thoughts neither in terms of strategy nor vividness. There were also a small but significant between-condition difference in vividness and plausibility of the key conditions. See Table 2.

	Mean (SD)			
	Strategy (0-100)	Valence (-50 - +50)	Plausibility (0-100)	Vividness (0-100)
HS	67.2 (8.8)	1.0 (6.3)	62.7 (9.2)	66.2 (10.0)
	**	*	**	*
LS	36.7 (16.8)	6.6 (6.4)	50.5 (7.6)	71.3 (7.8)
Po	53.0 (11.8)	29.0 (7.4)	52.8 (9.3)	70.8 (10.4)
	n.s.	**	*	n.s.
Ne	50.9 (9.7)	-21.3 (10.4)	60.4 (8.9)	66.8 (8.0)

*** p<.05, ** p<.001, n.s. = non-significant; HS – High Strategy; LS – Low Strategy; Po – Positive; Ne - Negative**

Table 2. **Mean rating for high versus low strategy and pleasant versus unpleasant scenarios.**

Stimuli and procedure

Stimuli were presented in black on a computer screen with a white background. Participants completed one session of a guided future thinking task comprising of different scenarios that they were required to think about, while EEG data were acquired. See Figure 3A for exact instruction verbatim.

There were 108 trials, divided into 12 blocks of approximately five minutes (nine trials per block). Each nine-trial block was followed by a rest period controlled by the participant. The trial sequence can be seen in Figure 3B. In each trial, text giving an instruction first appeared onscreen for 5s, followed by a 30 second thinking period. On 88.9% of trials there was a scenario was displayed about which participants were asked to think as vividly as possible (see verbatim of instruction in Figure 3A), during the 30 second period. The word cues '*Planning*' – for high strategy – or '*Imagining*' – for low strategy – were presented on top of the scenario.

An example of a scenario verbatim was as follows: '*IMAGINING: Imagine a social event that you have already arranged and are looking forward to attend*', for low strategy, and '*PLANNING: Plan the logistics of a social event you are excited about, e.g. how you will travel there, or for a dinner party what you would cook and when to do the shopping*', for high strategy. On the remaining 11.1% of trials, instead of having a scenario, the onscreen instruction would simply ask participants to pay attention to the flashing crosses on-screen (external attention condition), with the instruction worded as follows: '*Now, please, pay full attention to the crosses on screen*'. See Supplemental Materials for full scenarios across conditions (strategy, valence and plausibility).

To maintain fixation, participants were asked to fixate throughout the thinking period on a flashing black fixation cross (font size of 22), monitoring for occasions in which the cross would increase in size (to font size 36, 3/9 trials per block, randomly selected). The cross was displayed in the middle of the screen for 250ms, appearing with a jittered interval that would range between 300-700ms (mean=500ms). Following the thinking period, a probe would be displayed asking whether the participant noticed the bigger cross during the previous trial. They were asked to press 1 for "*Yes*" or 2 for "*No*", on the keyboard. After this, they were instructed to initiate to the next trial by pressing 0, see Figure 2 for trial example.

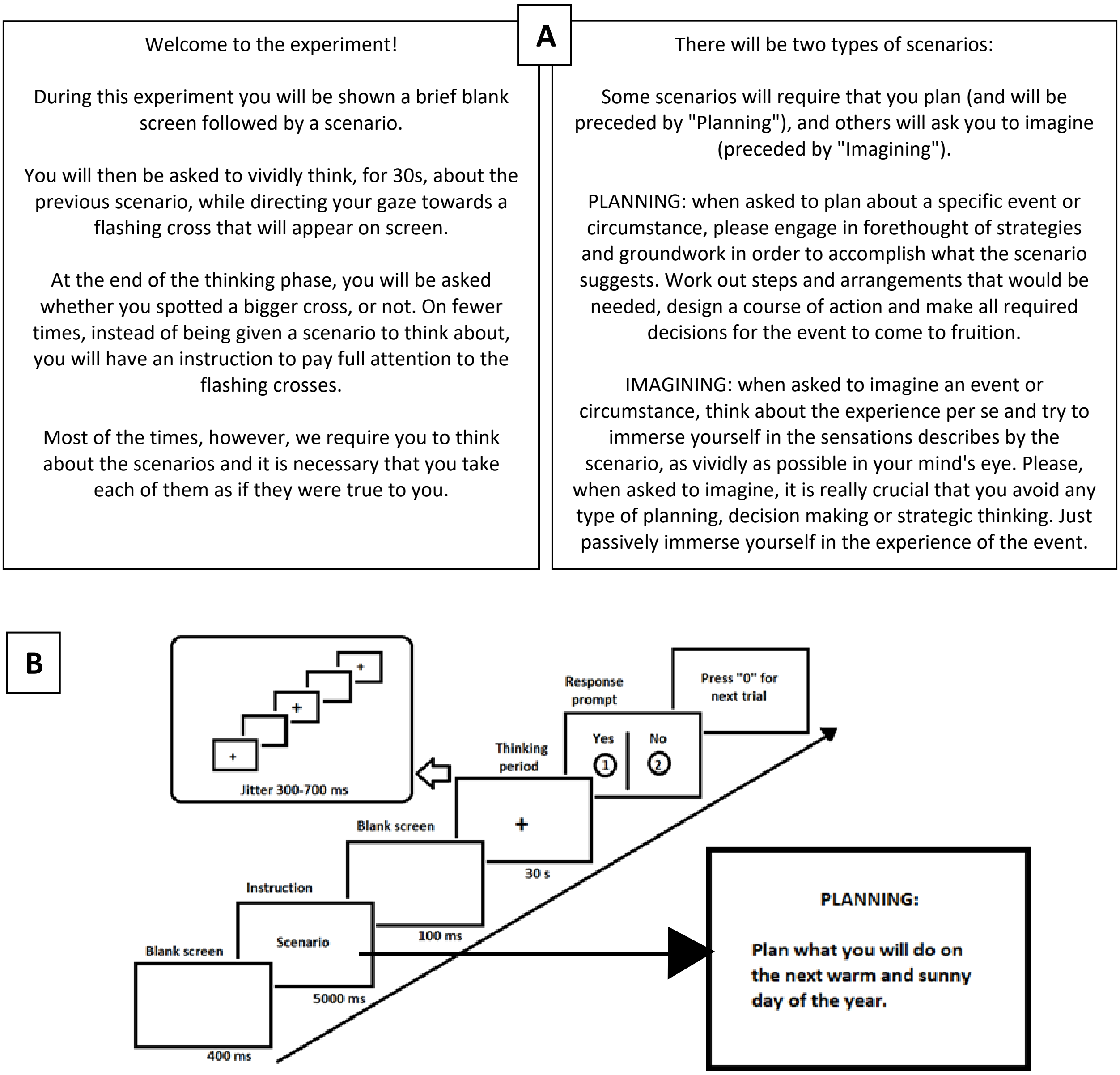


Figure 3. **A – Verbatim of instructions. B – Schematic of the trial sequence with example of scenario.**

Psychophysiological signal

Recording. EEG and facial EMG data were simultaneously collected using ASALab's Ant-Neuro system, with a sampling rate of 1000Hz and using a 64 high speed channel amplifier. EEG data were recorded from 64 channels, with mastoid electrodes (M1 and M2), on each side, recorded as reference. EEG electrode impedances were kept below 5kΩ. Facial muscle activity was bipolarly recorded over the *Zygomaticus major* and the *Corrugator supercilii* muscles using two pairs of Ag/AgCl surface electrodes, both placed on the left sides of the face following the placement guidelines from Fridlund and Cacioppo (1986). The distance within each pair of electrodes was kept around 0.5cm, to avoid crosstalk. The electrode sites were cleaned with isopropyl alcohol pads, and gently abraded using NuPrep skin gel preceding electrode placement, for better impedance (i.e., below 20kΩ; Golland et al., 2018).

Preprocessing. Raw EEG and facial EMG data processing and analyses were performed offline using a combination of the EEGLAB toolbox (Delorme & Makeig, 2004) and custom scripts on MATLAB (The MathWorks, Inc.). For EEG data, slow drift and very slow and high frequencies were filtered using a 0.05 highpass and a 40Hz lowpass filters. We then downsampled the data from 1000Hz to 250Hz and re-referenced to the average of linked mastoids. We visually inspected the data and manually rejected channels containing non-stereotyped artifacts (a maximum of 4 per subject) followed up by an automatic channel rejection using two EEGLAB functions for cleaning line noise at 50Hz and artifacts such as channels with flatlines, rapid burst and slow drifts. We kept the default parameters. Stereotyped artifacts, such as blinks, saccadic eye movements and muscle noise were pruned using Adaptive Mixture Independent Component's Analysis (AMICA; Palmer, 2012). For each subject, we chose the baseline period to be the 400ms interval prior to the onset of the scenario, and the time of interest was a 5s period after the offset of a short blank screen following the scenario (6-11s from the start of trial). We considered that subjects would engage deeper with the task in these first five seconds, as it was the case in previous mind wandering EEG studies (Compton et al., 2019; van Son et al, 2019). This decision was made after data collection and prior to analyses, informed by literature review of common practices in similar studies (Compton et al., 2019; van Son et al, 2019).

The processing of facial EMG data followed the guidelines outlined by van Boxtel (2010). We applied a notch filter at 50 Hz to remove line noise, and a bandpass filter at 20-500Hz as the frequency range of interest, especially to account for low frequency artifacts such as eye blinks and movements, activity from nearby muscles, and motion potentials. Following common practice for facial EMG (e.g., van Boxtel, 2010; Hart et al, 2018; Sato et al., 2020; Li et al., 2020), the signal was full wave rectified by pulling its absolute number on Matlab. We also segmented the data into epochs analogue to EEG, i.e., starting from 400ms pre-scenario until 11s, with time of interest 6-11s. The baseline period was the 400ms interval preceding the scenario and were used to normalise the data for group comparisons. We rejected the noisy artifacts manually by visual inspection. Flat channels were rejected, as well as those with rapid high-amplitude bursts.

Analyses. For EEG, power spectra were computed using Fast Fourier Transform (FFT) during the 5s period of interest, to investigate the event related spectral perturbations (ERSP) induced by the planning condition versus the imagining condition, in the beta band (13-25Hz), averaging across frontal electrodes: FP1, FPz, FP2, AF3, AF4, AF7, AF8, Fz, F1-F8 (see Figure 4 for topographical distributions). For replication purposes, we also investigated ERSP differences between the internal conditions and external attention, in the alpha band (8-12Hz), averaging across posterior electrodes: Pz, P1-P6, POz, PO3, PO4, PO5, PO6, Oz, O1, O2 (see Figure 3). The division of electrodes per region (frontal and posterior) followed that of previous mind wandering work (van Son et al., 2019).

In the case of facial EMG, average activities were calculated for baseline and for time of interest using the rectified amplitudes. The mean activity during baseline was then subtracted from time of interest to compute reactivity scores in each epoch. An average of all epoch windows was then computed first at subject and then at group levels, with the normalized data These analyses steps followed previous work (Hart et al, 2018; Sato et al., 2020; Li et al., 2020). Statistical analyses were conducted on the calculated average of the normalised mean values per condition, and to investigate de amplitude differences between pleasant and unpleasant scenarios over both the *Corrugator* and the *Zygomaticus* muscles.

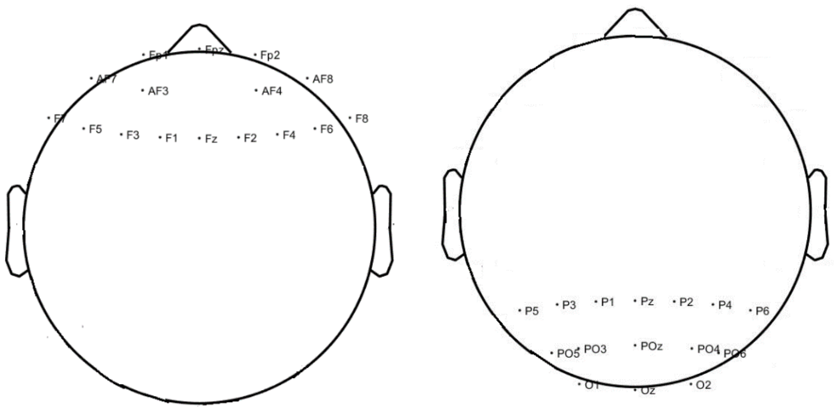


Figure 4. **Topographical distribution of electrodes of interest. On the left, over frontal sites, on the right, over posterior sites, including parietal and occipital.**

Results

Event Related Spectral Perturbation

As predicted, the frontal beta spectral power was significantly higher when subjects were engaged in high strategy (*M* = 0.87, *SD* = 0.57) versus low strategy (*M* = 0.37, *SD* = 0.57), $t(29)=3.38$, $p=0.002$, during the first 5s interval after scenario offset (see Figure 5A for topographical distribution maps, and 5B for difference maps). As can be seen in Figure 5C, this pattern was observed on an individual level in the majority of subjects 21/30.

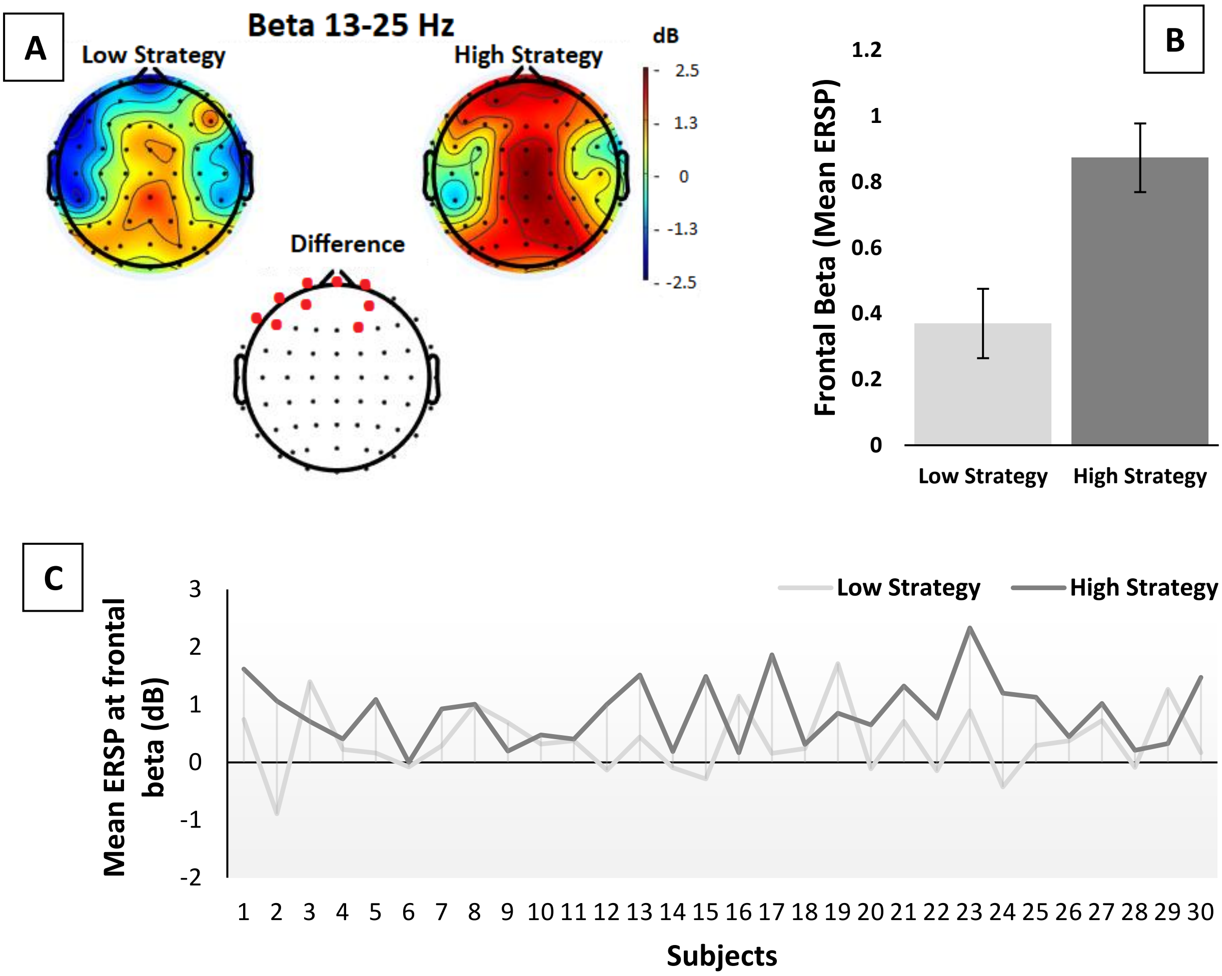


Figure 5. **A-Event-related spectral perturbation (ERSP) topographical plots and difference significance plot at *p*<.001 between high strategy and low strategy conditions, throughout time of interest. B & C – Mean event related spectral perturbation of frontal beta at group level (B) and subject by subject numerical pattern (C).**

For replication purposes, we also investigated posterior alpha ERSPs between internal and external conditions. As can be seen in Figure 6, Internal attention, when subjects were engaged in future thinking, had significantly higher power (M = 0.35, SD = 0.81) than when subjects were attending to the external stimuli (M = -0.31, SD = 0.37), $t(29)$ = -4.26, p<.001. Thus, we replicated previous studies of alpha ERSP as a measure of internal attention versus external.

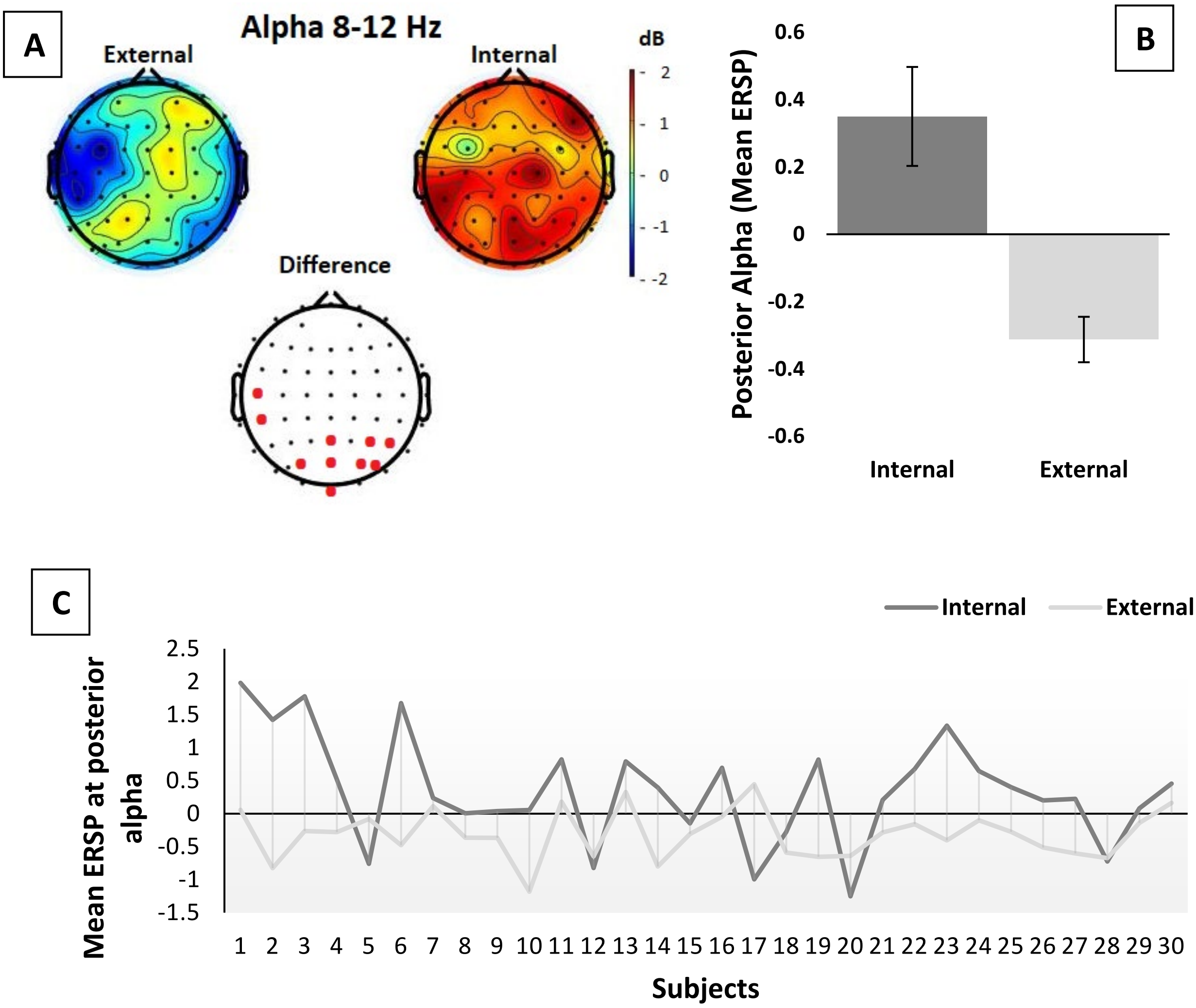


Figure 6. **A-Event-related spectral perturbation (ERSP) topographical plots and difference significance plot at *p*<.001 between external and internal attention, throughout time of interest. B & C – Mean event related spectral perturbation of posterior alpha at group level (B) and subject by subject numerical pattern (C).**

Facial EMG amplitude

The mean amplitude over the *Corrugator supercilii* (frowning muscle) was higher for unpleasant future thinking (M = 1.3, SD = 3.71) than for when subjects were thinking about pleasant future episodes (M = -3.4, SD = 3.0), $t(16)$= -3.53, p<0.003 (see Figure 7). This result was very consistent across 15/17 subjects (Figure 7A), suggesting that the frowning muscle could be a reliable objective measure of emotional valence during episodic prospection.

The analysis of the *Zygomaticus major* (the smiling muscle) was severely underpowered (N=8) due to artifacts and technical issues in the recording. Nevertheless, as can be seen in Figure 7B, the numerical trend was in line with the expected difference between pleasant and unpleasant future thoughts, with 6/8 participants showing greater amplitude during pleasant thoughts (M = 0.83, SD = 0.25) than unpleasant thoughts (M = 0.27, SD = 0.57), although non-significant, $t(7)=2.32$, $p=0.054$.

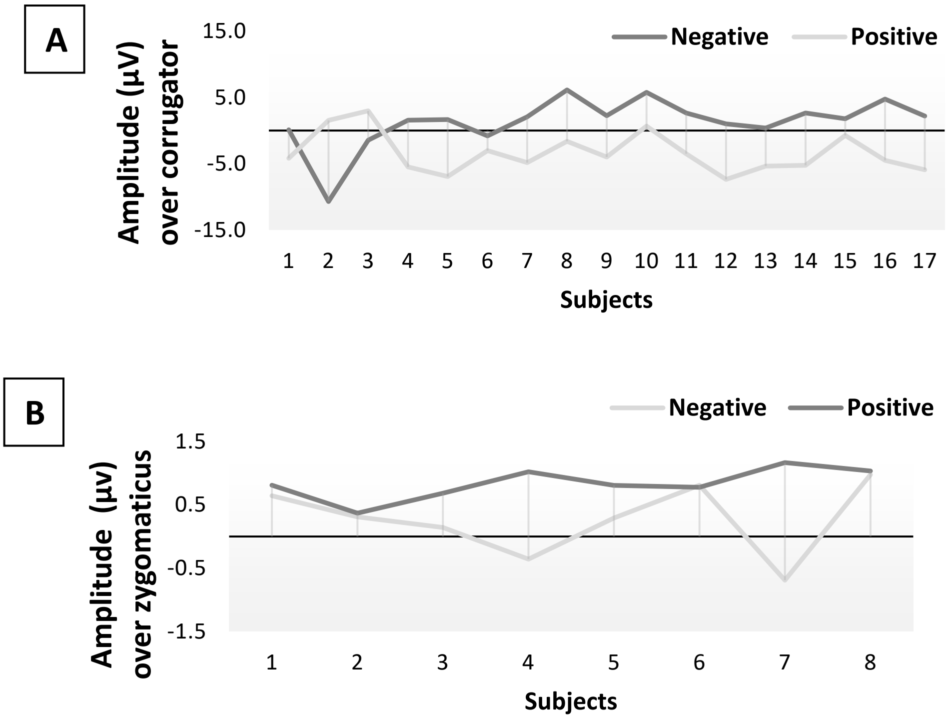


Figure 7. **A-Electromyographic amplitude across subjects, over Corrugator muscle, for pleasant and unpleasant thoughts. Unpleasant thoughts showing a higher trend across participants, except for one subject. B-Trend of electromyographic amplitude across subjects, over Zygomaticus muscle, for pleasant and unpleasant thoughts.**

General Discussion

The present study sought to characterise the phenomenology of strategic forms of spontaneous mind wandering, in relation to both emotional valence and mental time travel, and to facilitate future research in this area by establishing objective electrophysiological markers for strategic and affective dimensions of thought. Across two experiments, a behavioural and a an electrophysiological, we came to two respective main findings. Firstly, in our behavioural experiment we show that strategic thoughts represent approximately 36% of mind wandering thoughts and can be both pleasant and unpleasant. We also replicate previous finding confirming a prospective bias to strategic thoughts (Ruby et al., 2013; Smallwood & Andrews-Hanna, 2013; Kane et al., 2017). This prospective bias in strategic thoughts has been shown to point to constructive functions of mind wandering, such as future planning and goal-directed thought to facilitate action (e.g., Baird et al., 2011; Kane & McVay, 2012), however, when taking negative forms, this could be linked to perseverative and repetitive forms of thinking, such as rumination and worries (Ottaviani et al., 2015; van Vugt & van der Velde, 2018). In keeping with this suggestion, negative affect was driven by unpleasant strategic thoughts in Experiment 1a, although this was not replicated in Experiment 1b.

Secondly, using electrophysiology (EEG and facial EMG), we established the intended objective markers of strategic and unpleasant thought dimensions that can be used to further investigation in this field. With respect to our objective markers, frontal beta event related spectral perturbation (ERSP) can be used to distinguish between strategic future thoughts and passive imagination, in line with previous research showing frontal beta associated to mental effort and motor planning (e.g., Macaulay & Edmons, 2004; Howells et al., 2010; Behmer & Fournier, 2014), but in this case we establish these markers specifically associated with strategic thoughts designed to simulate those experienced during mind wandering. We also show that facial muscles, specifically *Corrugator Supercilli* can be used to index between negative and positive thoughts, with the muscle being particularly sensitive to negative thinking. In this respect our study extends previous applications of facial EMG for inferring emotional valence of external stimuli (e.g., van Boxel, 2010; Golland et al., 2010), applying it to the novel domain of affective thoughts. Besides this, and even though we have a small sample size, there seems to be a trend in the *Zygomaticus Major* muscle, for being more sensitive to positive thinking.

Our results suggest that facial EMG markers could be combined with measures of ERSP in frontal beta and parieto-occipital alpha as an index of internally directed attention (Cole & Ray, 1995; Godwin et al., 2016), but now with discrimination by level of strategy and valence of thoughts. As we used a guided-thought paradigm, an important next step is to test, using a thought-probing approach, whether these same EEG signatures can be observed in relation to thoughts that arise spontaneously. If so, this could be used for objectively studying spontaneous mind wandering, in particular in situations when we cannot rely on subjective reports, such as in developmental and clinical contexts. Nevertheless, even though this paradigm does not explore the spontaneous side of mind wandering, it is a more controlled way for indexing neural correlates of future thoughts, with a potential to serve as the bedrock to posterior indexing, tracking and prediction of spontaneous thoughts, not only the occurrence, but also the contents.

It is important to note that the EEG correlates were seen across the majority of subjects, but some subjects experienced the reverse pattern, suggesting that this measure might yet not be suitable for 'mind-reading' on an individual level, but might nevertheless be useful in triangulation with subjective reports (Smallwood & Schooler, 2015). For future research directions, perhaps multivariate EEG might be a possible avenue for more fine-tuned individual level mind-reading of contents of thoughts.

Returning to our behavioural findings, it is important to note that our Experiments 1a and 1b were inconsistent with regards to both the difference in negative valence between low and high strategic thoughts, and the joint prediction of negative affect by valence and strategy. These differences might simply reflect unreliability of the findings, and hence these effects should be interpreted with caution. However, it also appears relevant to note the potential difference that that Experiment 1b data collection took place during the unique time period of the first months of the COVID-19 pandemic (February to April 2020). In fact, an observation of saliency of participants thoughts, as mentioned in an open-ended question, point to a qualitative similarity between high and low strategy negative thoughts, in terms of frequency of mentions related to the pandemic. The impact of the pandemic on mind wandering occurrence and contents is more directly explored in Chapter 4. Another unexpected finding was how prevalent thoughts about food were linked to both positive and negative-valenced thoughts. And explanation of this could be that people tend to think about food in a similar manner as other cravings (May et al., 2010), and this was highlighted as an impact of stress during the COVID-19 pandemic (Shen et al., 2020; Rodgers et al., 2020). Still regarding our behavioural experiments (1a and 1b), it is important to note that other statistical methods, such as multi-level methods, could be more powerful to explore this data without reducing the sample size or transforming a continuous variable into categorical. Regarding the contents of thoughts, further analysis is needed (e.g., content analysis) to separate different forms of thoughts that were going on besides mind wandering and spontaneous thoughts.

In summary, our findings highlight the importance of considering the intersection of valence and strategy of thought in the impact on wellbeing and provide the foundation for future research testing the ability of these objective electrophysiological markers to index strategic and affective dimensions of spontaneous thought contents.

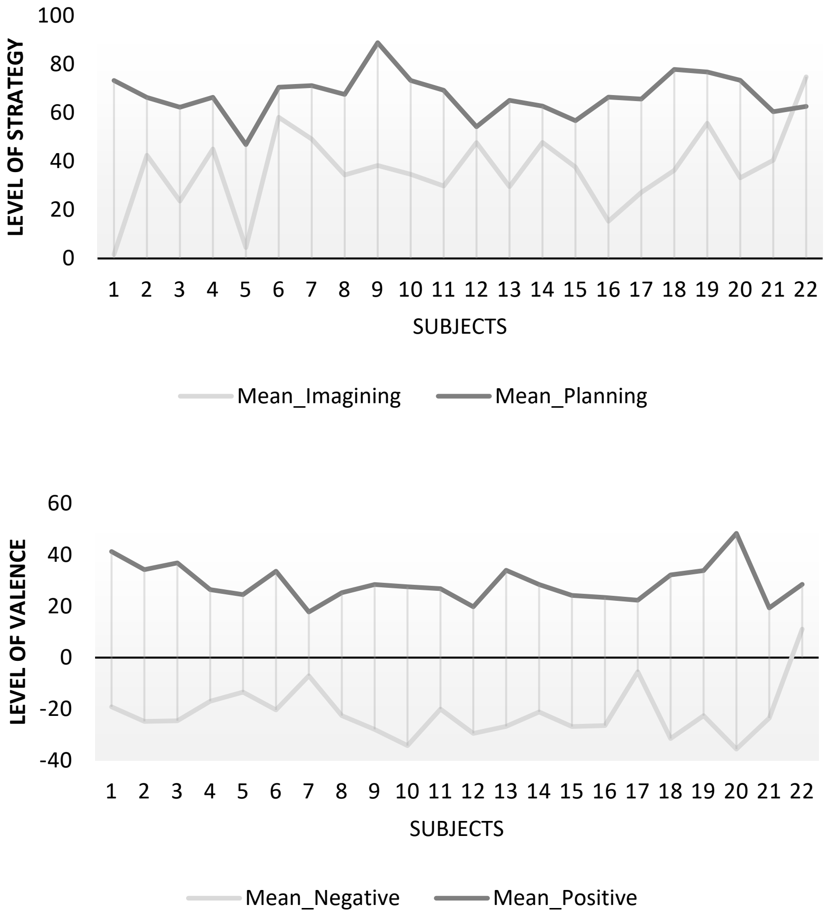
Acknowledgements

We thank Aleksandra Korbacz for her help with data collection.

Supplemental Materials

Experiment 2

Scenario ratings - Pilot



Suplemental Figure 1. **Scenario ratings for strategy, valence, and plausibility across subjects.**

Scenario Instructions - Pilot

WELCOME TO THE EXPERIMENT!

During this experiment you will be shown some scenarios. The task is to vividly think of each scenario, holding it in your mind's eye. You will be given 15 seconds for that, please use all of this time. It is important that you think of each scenario vividly, for the entire time in which "Thinking of scenario" is onscreen.

Right after thinking of each single scenario, you will be asked to rate them according to your personal experience of them, in different dimensions. This will repeat after each scenario, with some instructions.

Press "Continue" for more instructions.

There will be two types of scenarios:

Some will require that you PLAN (and will be preceded by "Planning"), and others will ask you to IMAGINE (preceded by "Imagining").

PLANNING: when asked to plan about a specific event or circumstance, please engage in forethought of strategies and groundwork in order to accomplish what the scenario suggests. Work out steps and arrangements that would be needed, design a course of action and make all required decisions for the event to come to fruition.

IMAGINING: when asked to imagine an event or circumstance, think about the experience per se and try to immerse yourself in the sensations described by the scenario, as vividly as possible in your mind's eye. Please, when asked to imagine, it is really crucial that you avoid any type of planning, decision making or strategic thinking. Just passively immerse yourself in the experience of the event.

Press "Continue" for more instructions, or "Previous" to read again.

For example:

SCENARIO: Losing your friend's dog in a park.

Imagining could be: immersing in the feelings of despair and fear and hopelessness, feeling guilty and worried, and wanting to cry.

Planning would be: setting up a course of action to find the dog (which streets to look at, involving other people, posting an add) and to inform your friend (how to call her, explain everything, etc).

VERY IMPORTANT: Please think vividly about each scenario and take each of them as if they were true to you.

WE REALLY APPRECIATE YOUR HONESTY WHEN RATING THE SCENARIOS.

The task will roughly take 25 minutes. To abort the experiment before the end, click Ctrl+Q.

If ready, press "Continue" to start with first scenario, or "Previous" to read again.

Scenarios

High strategy		
Valence	**Plausibility**	**Scenarios**
Pleasant	**High**	Plan your summer holiday. Plan the logistics of a social event you are excited about, e.g. how you will travel there, or for a dinner party what you would cook and when to do the shopping. Plan what you will do on the next warm and sunny day of the year.
	Low	Plan how you would spend your money if you won the lottery. Plan a party with no budget to which you can invite anyone. You don't have to be the host, it can be a party you plan for someone else or just one you would enjoy attending. Plan how your life would be if you suddenly woke up and could choose an entirely different life of your liking.
Unpleasant	**High**	Plan a particularly stressful problem you are going to have to deal with in the coming months, and make a plan for how to deal with it. Plan the logistics of an event you are dreading, e.g., how you will get there, what you need to prepare beforehand, etc. Plan which presents you could buy for a person you don't like buying presents for, for example because they have everything or are very picky.
	Low	Plan what you would do if you lost your wallet on the bus. Plan how you would respond if you were falsely accused of cheating in an exam or coursework. Plan what you would do if you found an inappropriate flirty message from your best friend on your partner’s phone.

Supplemental Table 1. **High strategy scenarios across valence and level of plausibility.**

Low strategy		
Valence	**Plausibility**	**Scenarios**
Pleasant	**High**	Imagine a social event that you have already arranged and are looking forward to attend.
		Imagine the next time you are seeing a person who is important to you.
		Imagine a food you bought and are looking forward to cooking or eating.
	Low	Imagine you are meeting a famous person and they are impressed by you.
		Imagine your dream house.
		Imagine winning an award.
Unpleasant	**High**	Imagine an upcoming event you are worried about.
		Imagine a chore, which you don't like, that you have to do this week.
		Imagine your next dentist appointment.
	Low	Imagine being late to an important event because you are stuck in traffic or missed the bus/train.
		Imagine being asked a question in a seminar which you don't know the answer to.
		Imagine you have to walk a long way home in the dark while it is raining.

Supplemental Table 2. **Low strategy scenarios across valence and level of plausibility.**

Psychophysiological measures across subjects

	Beta		**Alpha**		**Corrugator**		**Zygomaticus**	
	Imagining	**Planning**	**Internal**	**External**	**Negative**	**Positive**	**Negative**	**Positive**
Mean	0.36992	0.87323	0.35007	-0.3128	1.2953017	-3.389211	0.2661701	0.834673
SD	0.577215	0.57115	0.80530	0.36987	3.713279	2.987901	0.568539	0.2479406
SE	0.10539	0.10428	0.14703	0.0675	0.90060	0.72467	0.201009	0.08766
p	0.00211		0.0002		0.0028		0.054	
N	**30**	**30**	**30**	**30**	**17**	**17**	**8**	**8**
	0.744634	1.62035	1.9828	0.05734	0.1109150	-4.193781	0.643307	0.809967
	-0.89178	1.06390	1.42203	-0.8246	-10.72586	1.5415216	0.309967	0.3692048
	1.399549	0.71063	1.78032	-0.2629	-1.449813	2.9778489	0.14353	0.68433563
	0.222866	0.40692	0.51989	-0.279	1.57273	-5.49015	-0.3567	1.023365
	0.164077	1.09265	-0.7602	-0.0811	1.66286	-6.95546	0.292695	0.808903
	-0.07885	0.0032	1.67513	-0.476	-0.79691	-3.02521	0.8099607	0.778637
	0.289363	0.92748	0.23702	0.11394	2.06748	-4.83492	-0.690033	1.1673
	1.006805	1.00802	0.00615	-0.3631	6.135957	-1.63166	0.9766342	1.03567
	0.689046	0.19614	0.03975	-0.3662	2.23714	-3.98927		
	0.318137	0.47515	0.05549	-1.182	5.76825	0.67012		
	0.376128	0.40437	0.82279	0.18129	2.65303	-3.50316		
	-0.13435	1.0064	-0.8225	-0.647	1.02042	-7.38569		
	0.439358	1.5164	0.7932	0.3291	0.37925	-5.37773		
	-0.09138	0.1869	0.3964	-0.8005	2.6582	-5.2437		
	-0.28544	1.4917	-0.1463	-0.307	1.7771	-0.74103		
	1.15159	0.16739	0.6967	-0.0471	4.761	-4.51495		
	0.156773	1.86607	-0.9948	0.44584	2.188176	-5.91927		
	0.240084	0.31276	-0.2765	-0.58928				
	1.713181	0.85476	0.8202	-0.6546				
	-0.1117	0.64989	-1.2519	-0.6405				

0.711766	1.32469	0.20875	-0.2845
-0.14544	0.76465	0.67746	-0.1595
0.895237	2.3329	1.3337	-0.4035
-0.42409	1.20093	0.6462	-0.1013
0.294573	1.13092	0.40127	-0.2742
0.373566	0.44469	0.20019	-0.5121
0.726385	1.02199	0.22596	-0.6023
-0.08778	0.21093	-0.725	-0.6730
1.26706	0.32782	0.0818	-0.1401
0.168234	1.476	0.4559	0.1624

Instructions and Probe questions - Experiment 1

59% Sun 20:13

Welcome to the second part of the experiment!

PLEASE, TURN ON YOUR SPEAKERS!

You will listen to a lecture by Professor Joe Mee (University of Warwick), themed 'Dickens's Points of View'.

A few times during the lecture, you will be prompted to report about your state of mind. Click the response box that BEST represents your state.

You cannot change your answer once you clicked a response box.

Please, pay attention to the lecture SO THAT YOU COULD ANSWER TO COMPREHENSION QUESTIONS AT THE END.

The task will roughly take between 30 to 40 minutes. To abort the experiment before the end, click Ctrl+Q.

WE REALLY APPRECIATE YOUR HONESTY.

Continue

How focused on the task were you, just before this screen?

Not at all (focused)	Slightly (focused)	Moderately (focused)	Very (focused)	Extremely (focused)
1	2	3	4	5

00:05:37

Could you please describe below the thoughts you were having during the lecture and prior to this screen?
You can freely write whatever you remember.
There are no right or wrong answers. We really appreciate your honesty.

Continue

00:05:56

Was your mind more on the past or on the future?

Very much on the past	Moderately on the past	Atemporal or in the here-and-now	Moderately on the future	Very much on the future
1	2	3	4	5

00:06:08

How strategic was your thinking (ie. involving some planning or analysis), as opposed to contemplative (ie. passive imagination)?

Not at all (strategic)	Slightly (strategic)	Moderately (strategic)	Very (strategic)	Extremely (strategic)
1	2	3	4	5

00:06:15

To what extent did your thinking include hypothetical events, with a low probability of actually occurring/have occurred?

Not at all likely to happen/ have happened (completely hypothetical)	Slightly likely to happen/ have happened	Moderately likely to happen/have happened	Very likely to happen/have happened	Extremely likely to happen/ have happened
1	2	3	4	5

00:06:19

To what extent was your mind on something pleasant or unpleasant?

Very unpleasant	Moderately unpleasant	Neither unpleasant nor pleasant	Moderately pleasant	Very pleasant
1	2	3	4	5

00:06:23

CHAPTER IV

Study 3 - Pandemic brain: Task focus and affect across the COVID-19 pandemic

Abstract

We could expect the COVID-19 pandemic to have psychological impacts in people's lives. Besides some reports of mental health impairments, anecdotal reports in the media have raised the phenomenon of 'mind fog' as a state debatably brought up by the pandemic, and which is suspected to impact the ability to focus on daily tasks, such as online classes or remote meetings. However, changes in people's task focus relative to pre-pandemic levels have not yet been empirically established. The present paper presents the first evidence directly quantifying and characterising the extent and nature of the pandemic impact on task focus, by comparing two datasets measuring UK undergraduate students' ability to focus on a remote lecture, as well as the contents of their off-task thoughts. Data was gathered from February to April of 2019 (i.e., prior to the Covid-19 pandemic) and the same timeframe in 2020 (i.e., during the early months of the pandemic in the UK). Further datasets were collected at points throughout the pandemic, from both student and general population samples. Contrary to the anecdotal reports of brain fog, our data did not find a decrease in task focus during the pandemic. However, we found a pandemic-related reduction in positive thoughts mediated by negative affect, suggesting that the increase in current concerns brought by the pandemic has resulted in a decrease in positive mind wandering. Furthermore, we found task focus differences between students and general population in the pandemic, with students reporting more off-task thoughts. This could have consequences in task performance, and should be accounted for, especially in educational settings, and during an era of remote learning.

Study 3 - Pandemic brain: Task focus and affect across the COVID-19 pandemic

Spending large amounts of time throughout our day focusing on things other than our current tasks is a ubiquitous aspect of human life (Singer & MCraven, 1961; Kane et al., 2007; D'Mello et al, 2016; Bixler & D'Mello, 2015; Stawarczyk et al., 2012), a phenomenon usually termed as mind wandering or task-unrelated thoughts (Smallwood & Schooler, 2006; 2015). In some cases, this phenomenon might serve beneficial functions, for example, in allowing us to engage in a constructive thought (such as creativity, problem solving, prospective planning, e.g., Moneyham & Schooler, 2013), or simply alleviating us from boredom into a more enjoyable thought when we are caught on traffic or at a doctor's waiting room (Pachai et al., 2016). In some cases, this also offers benefits to our mood and state affect (Franklin et al., 2013). However, a large amount of literature has highlighted that off-task thought, like other forms of distraction, substantially disrupts a wide range of daily life tasks, from driving (Baldwin et al., 2017; Yanko & Spalek, 2013), to reading (Feng, D'Mello & Graesser, 2013; Unsworth & McMillan, 2013; McVay & Kane, 2012; Schooler et al., 2004), performance during work (Dane, 2018) or in lectures (Farley, Risko & Kingstone, 2013; Pachai et al., 2016; Szpunar et al., 2013; Wammes et al., 2016), and can also impact wellbeing (Yamaoka & Yukawa, 2020). Current concerns in a person's life have long been held as playing an important role in driving thoughts away from tasks (Antrobus, Singer, & Greenberg, 1966; Klinger, 2009; McVay & Kane, 2013). This leads to the question of how mind wandering, and hence task-focus, is impacted when current concerns are suddenly and substantially increased across the population by events such as the COVID-19 global pandemic. The present study examines how both the rate and contents of mind wandering change during the early months of the covid-19 pandemic, compared to the same period in 2019.

The COVID-19 is an infectious respiratory disease that arouse in the world in December 2019 (WHO, 2020). In early 2020, the rapid spread around the world led the World Health

Organization to declare it as a pandemic. To respond to the pandemic, authorities all over the world urged to put in place measures that included travel restrictions, social distancing, and various forms of 'lockdown' (Sahu, 2020). Many institutions and organizations across the world were forced to cancel in-person contact or temporarily close altogether. Across the general population, the social, economic, and political impacts of the pandemic include loss of employment and source of income (Crayne, 2020; Kartseva & Kuznetsova, 2020), business closures (Nicola et al., 2020; Barrot, Grassi, & Sauvagnat, 2020), housing stability and housing market (Jones & Grigsby-Toussaint, 2020; Marona & Tomal, 2020; Liu & Su, 2020), changes in childcare (Sevilla & Smith, 2020; Blum & Dobrotić, 2021) alongside with remote working (Beland et al., 2020). In case of universities, activities were postponed, cancelled, or transferred to online, to protect students and staff from infection and to contain the spread (Sahu, 2020). Under these circumstances, it is likely that the level of pressing current concerns, in terms of both immediate practical problems and longer-term worries about the future, would be widely increased.

An early experimental study on the field of mind wandering (Antrobus et al., 1966) suggest that increasing current concerns can substantially increase mind wandering by approximately 25%. Their manipulation involved exposing a sample of American undergraduates to a fake news bulletin broadcasting that all unemployed young adults and university students were about to be conscripted to fight in the Vietnam war (Antrobus, Singer, & Greenberg, 1966). More recent work has provided inconsistent results, however, with stress manipulations such as the anticipation of giving a speech or placing a hand in cold water either failing to impact overall mind wandering rates at all (Banks et al., 2014; Stawarczyk, Majerus, and D'Argembeau, 2013), or doing so only among participants with negative affect (Vinski & Watter, 2013). The more modern manipulations, although effective in increasing negative affect, are for ethical reasons likely to induce less profound and personally relevant concerns than either the (fake) news of impending conscription or the direct personal disruption and threat associated with a pandemic. Hence, it appears conceivable that the impact of the COVID-19 pandemic on task focus might be more in line with the large effect revealed by Antrobus, Singer and Greenberg (1966).

Given the extensively documented disruptive effects of mind wandering on daily life tasks, as outlined above, a large pandemic increase in the overall rate of mind wandering would have profound impact across a wide range of domains, from poorer academic performance and workplace-productivity to increased risk of serious accidents. A second important area of potential impact would be on wellbeing and mental health. It is already documented that the pandemic has brought increased levels of anxiety, stress, and depression symptoms in the general population (Salari et al., 2020; Shevlin et al., 2020; Bergman et al., 2020, for review see Salari et al., 2020). In the UK, data from a longitudinal study using the General Health Questionnaire 12 (GHQ-12) found that levels of mental distress among the general non-clinical population increased from 18.9% in 2018-2019 to 27.3% during the 2020 lockdown, with a higher risk among the adults under 35 years of age (Pierce et al., 2020). Other studies agree with the higher mental impact in young adults, especially in terms of wellbeing, stress, depression, anxiety, sleep quality and loneliness (e.g., Pieh et al., 2020; Solomou & Constantinidou, 2020; Lee et al., 2020). Being a student has also been shown as a risk factor for mental health problems during the pandemic, as found in a general population systematic review conducted by Xiong et al. (2020) and reviewing literature in countries across Europe, Asia and in the US. Other studies across the world have shown heightened levels of depression and anxiety particularly among university students during the pandemic (e.g., in Bangladesh: Islam et al, 2020; France: Husky et al., 2020; China: Cao et al, 2020; Italy: Nania et al., 2020; USA: Son et al., 2020). As such, unlike the virus itself, which disproportionately affects older people, the impact on mental health appears greater for younger adults (for studies comparing age groups: Klaiber et al., 2021; Bruine de Bruin, 2020). An important question is hence how changes in mind wandering rates and contents might interact with these negative changes in mental health and wellbeing.

Evidence within the mind wandering literature suggests that negative affect (including anxiety, stress and depression) has a bidirectional relationship with mind wandering. On one hand, there is evidence implicating a causal role for negative affect in mind wandering: Individuals prone to negative affect are also prone to mind wandering, in particular of unpleasant content (Forster et al., 2015; Makovac et al., 2018, Ottaviani & Couyoumdjian, 2013); negative mood temporally predicts mind wandering about current concerns (Poerio, Totterdell, & Miles, 2013); and inducing negative mood has been found to increase mind wandering (Smallwood et al., 2009). As such, the pandemic-related increase in negative affect might be expected to drive increased mind wandering. On the other hand, there is also evidence suggesting that overall mind wandering can drive and maintain negative affect (Killingsworth and Gilbert, 2010; Stawarczyk, Majerus, and D'Argembeau, 2013), although other evidence suggests that mind wandering only impacts negative affect when the thought contents are negative (Poerio, Totterdell, & Miles, 2013). Hence, a key question is whether the established pandemic-related increases in negative affect – specifically, anxiety, depression, and stress – might mediate a potential increase in negative mind wandering (given the impact of the pandemic as a strong personally relevant stressor).

On the other hand, there are contexts in which mind wandering has been shown to have positive effects on mood which might serve adaptive functions during the pandemic. For example, Poerio et al. (2015) found that naturally occurring mind wandering about loved ones increased mood and feelings of connectedness, serving the means of emotional regulation. In a following study, they found that during naturally stressful times, such as the transition to university, mind wandering with a social content is related to positive affect and reduced feelings of loneliness (Poerio et al., 2016). Therefore, in the context of the social isolation experienced by many during the pandemic, mind wandering might also conceivably serve a positive function, although the interplay between these variables seem to largely depend on the content of mind wandering thoughts.

The present study is based on two datasets collected as part of a separate study (see Chapter 3), that by chance were collected during the outbreak of pandemic in the United Kingdom (February to April 2020) and the same period in the previous year, allowing us to investigate changes prior and during the early months of COVID-19 pandemic, encompassing the first lockdown in the UK. Our subjects across both 2019 and 2020 were from a university undergraduate cohort (University of Sussex), with an additional general population cohort tested in 2020. In addition to the sharp local and global rise in COVID-19 infections, events specifically impacting our University of Sussex participants during the timeframe of our 2020 dataset includes an early (February) outbreak in the immediate local area of the university, the migration of their studies to online format on the 16th of March, and the first UK lockdown from the 23rd of March. In each period, participants, aged between 18-35, answered to the Depression, Anxiety and Stress Scale (DASS) prior to listening to an audio lecture during which they were repeatedly prompted to report on the contents of their thoughts. This dataset affords the unique opportunity to examine pandemic-related changes in the frequency, contents and valence of mind wandering, and the relation of such changes to established changes in negative affect, in terms of stress, anxiety and depression. Two additional datasets were collected during the second and third UK lockdowns, to control for a minor methodological variation between the versions of the experiment used in 2019 and 2020.

Experiment 1

Methods

Participants

The data in this study was originally collected for a separate study (see Chapter 3), approved by the University of Sussex Sciences & Technology Cross-Schools Research Ethics Committee, investigating the strategic and affective correlates of mental time travel during mind wandering, in 2019 and 2020, in students and general population. The original 2019 cohort comprised of 303 undergraduate students, with data collected from early January to mid-May, whereas the 2020 comprised of students, with data collected from early February to end of April, and general population, with data collected in late March and early April 2020. For the purposes of this study and effects of comparison between the student cohorts, we only included the data from early February to end of April in both student cohorts. At the end, this study comprised of 524 subjects, divided in three cohorts (see Table 1). Subjects were all right-handed, fluent in English speakers, with normal or corrected-to-normal hearing and vision, age range 18-35 years[1]. The student samples were recruited via the University of Sussex's Participant Pool of undergraduate students and received course credits for their participation. The general population sample was recruited via Prolific (https://www.prolific.co/) and received financial compensation for their time.

[1] Exclusion criteria: Participants with missing data for a given variable were excluded from analysis concerning that variable only, therefore some variables have slightly different degrees of freedom. Exclusion of data was based on response latency. Probe responses with latency below 0.4 sec and above the upper limit of the first quartile led to exclusion of that question. More than two questions excluded led to exclusion of entire probe. All probes excluded caused exclusion of participant.

Cohort (Year)	N	% Males	% Females	Age (mean)
Student (2019)	225	11	88	19.74
Student (2020)	186	19	81	19.69
General Pop. (2020)	129	27	73	26.87

Table 1. **Demographic characteristic of all groups in Experiment 1, in terms of gender and age.**

Procedure

This was an online study programmed and presented using Inquisit (Millisecond). Subjects were required to have access to a computer with good speakers, stable internet, an up-to-date browser, and were asked to install Inquisit Player 5. Prior to the tasks, subjects read the information screen and gave their consent by pressing a relevant button. Participants were first asked to respond to the Depression, Anxiety, and Stress Scale – 21 (DASS-21; Lovibond & Lovibond, 1995), to assess their emotional state.

Participants were then asked to listen to a 30min audio recording of an English Literature university lecture, sourced from the University of Oxford podcasts repository. Thought probes interrupted the lecture at six time points throughout the 30 min period (length of blocks: 2 min 33 sec to 7 min 41 sec, mean: 5'12 min). At each thought probe, participants were presented with the following series of questions regarding their thoughts (responses were recorded via 5-point Likert scales, with the options indicated in parentheses): (1) "*Just before this screen, how focused on the task were you?*" [from "*Not at all (focused)*" to "*Extremely (focused)*"]; (2) "*Was your mind more on the past or on the future*" [from "*Very much on the past*" to "*Very much on the future*", with "*Atemporal or in the here-and-now*" as the middle point]; (3) "*How strategic was your thinking (i.e., involving some planning or analysis), as opposed to contemplative (i.e., passive imagination)?*" [from "Not at all (strategic)" to "Extremely (strategic)"]; (4) "*To what extent was your thinking plausible (i.e., concrete or likely to occur/have occurred?)*" [from "*Not at all (plausible)*" to "*Extremely (plausible)*"]; (5) "*To what extent was your mind in something pleasant or unpleasant?*" [from "*Very unpleasant*" to "*Very pleasant*"]. For both 2020 cohorts, there was also an open-ended question at the end of each thought probe: "*Could you please describe below the thoughts you were having during the lecture and prior to this screen? You can freely write whatever you remember*".

Results and discussion

Pandemic-related task-focus and negative affect in students

We first compared overall mind wandering rates among our student samples during the first months in which the pandemic and the first lockdown unfolded in the UK (February-April 2020), and during the same period in 2019. The rate of task-focus among students did not decrease during the pandemic (M = 2.21, SEM = .05, N = 185), compared to in 2019 (M = 2.18, SEM = .05, N = 226), $t(409)$ = -.45, p=.65, 95% CI [-.17, .10]. However, considering the contents of the thoughts, as can be seen in Table 2, the mean valence of off-task thoughts became significantly less positive in 2020, compared to in 2019, $t(409)$ = 2.14 p<.03. No changes in the level of strategy (p=.54) or plausibility (p=.13) were observed between the 2019 and 2020 student samples, but there was a change in the temporal orientation (p=.007).

	Mean rating of thoughts (SEM) [from 1-5]			
Cohort	**Valence**	**Time**	**Strategy**	**Plausibility**
Student (2019)	3.20 (.04)	3.07 (.03)	2.36 (.04)	2.80 (.04)
Student (2020)	3.08 (.04)	3.21 (.04)	2.31 (.05)	2.90 (.05)
General (2020)	3.13 (.06)	3.19 (.05)	2.47 (.07)	2.85 (.07)

Table 2. **Mean rating of thoughts (SEM in parentheses), on categories of valence, temporal orientation (time), strategy and plausibility, across cohorts.**

Replicating recent findings (e.g., Pieh et al., 2020; Maia & Dias, 2020; Mazza et al., 2020), state negative affect (total DASS score) was significantly increased in the student cohorts of 2020 (M = 22.51, SE = .84) compared to 2019 (M = 19.48, SE = .72), $t(439) = -2.75$, p=.006, and this was also the case for subscales of depression ($t(439) = -3.79$, p<.001) but not the case for stress ($t(439) = -2.11$, p=.04), which did not survive Bonferroni correction for multiple comparisons, nor anxiety ($t(409) = -1.74$, p=.28).

Furthermore, and as can be seen in Figure 1, the increase in negative affect partially mediated a pandemic-related decrease in pleasant thoughts: A 95% bias-corrected confidence interval based on 5,000 bootstrap samples indicated that the indirect effect (ab = -.0108; SE = .006) was entirely below zero (CI: -.0242 to -.0016). However, the pandemic caused a decrease in pleasant offtask thoughts even after considering the pandemic indirect effect through negative affect (c' = -.0643, p =.02), and (c = -.0751, p =.007). Dependent variable pleasant offtask thoughts are measured as the category of offtask thought scored as 4 and 5, and variable X coded as 0 and 1. The moderator is a continuous variable.

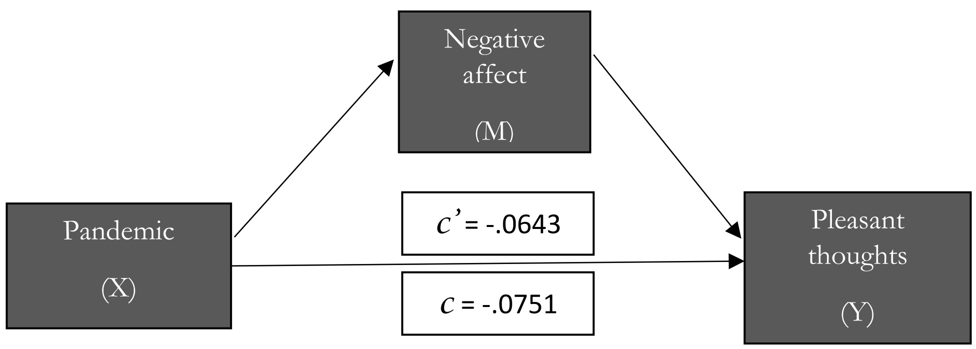


Figure 1. **Negative affect (total DASS score) partially mediated the relationship between the pandemic and pleasant off-task thoughts negatively. Notes: a is effect of pandemic on the DASS score; b is effect of DASS score on pleasant thoughts; c' is direct effect of pandemic in pleasant thoughts; c is total effect of pandemic in pleasant offtask thoughts.**

Mind wandering thoughts specifically about the pandemic in students

We next examined the extent to which COVID-19 related topics emerged in the contents of mind wandering, within the pandemic student sample. Participants' descriptions of their thought contents were searched for the following pandemic-related keywords: *coronavirus, corona, covid, virus, covid-19, pandemic, lockdown, and quarantine*. During the pandemic, on average .55% (*SD* = 1.15) of thoughts directly referenced the pandemic (see Table 3 for examples). Indeed, most students (78.5%) did not mention a single thought about the pandemic. Among the 21.5% of participants who did mention thoughts of the pandemic such thoughts tended to reoccur across multiple probes (*M* = 42.5%, *SD* = 17.28, range 16.7% – 83.3%).

	Examples of thoughts
COVID-19	"Thought of *covid* news, I have to stop reading news."
	"Remembering time before coronavirus, being surprised that 5 minutes had passed"
	"Tired of lockdown"
	"There is a pandemic around and I am doing this boring task"
Social	"Thinking about a friend going through a hard time"
	"Thinking about when my friend was coming back from her lecture"
	"Coronavirus is spooky hope my nan is okay"

"I was thinking about the *wearabouts* of my flatmates…"

***Table 3*. Examples of specific reported mentions of COVID-19 and other people, from the open question.**

Furthermore, as can be seen in Figure 2, the percentage of students explicitly referencing the pandemic in their thoughts increased as the pandemic unfolded, with a significant difference among participants tested pre- versus post-lockdown, X^2 (1, N = 186) = 6.506, p=.011. Surprisingly, however, we found no evidence for any correlation between specific COVID-19 mentions and negative affect, r (185) = -.094, p = .202.

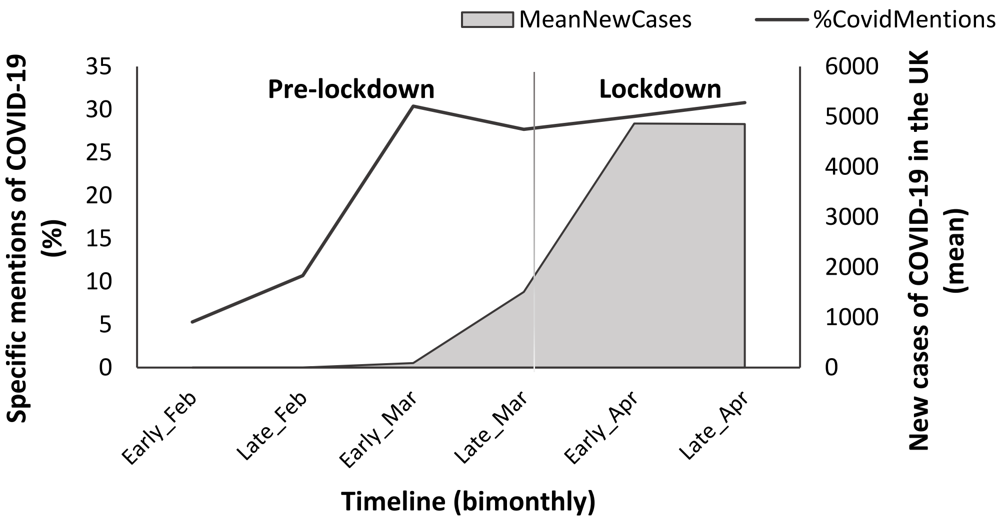


***Figure 2.* Timeline of percentages of COVID-19 mentions in the 2020 student cohort, and number of new cases of COVID-19 in the UK, during the pandemic, from early February to late April. Early dates go from the 1st to 15th of each month, late from the 16th until the end of the month.**

Social mind wandering pre and post lockdown in students

Finally, we examined the degree of social mind wandering before and during lockdown by searching participants' thought reports for the following keywords: f*riend, relative, people,* *husband, wife, brother, sister, sibling, parent, father, mother, mom, mum, dad, nan, nanny, grandma, granny, grandmother, grandfather, grandpa, granddad, grandparent, mate, housemate, flatmate, mate, colleague, co-worker, cousin, uncle, nephew, children, child, niece, aunt, aunty, partner, fiancé, girlfriend, boyfriend, son, daughter, stepmom, stepmum, stepmother, stepdad, stepfather*. The percentage of students reporting social mind wandering was similar pre ($M = 24.1$, $SE = 1.95$) and post lockdown ($M = 31.6$, $SE = 3.58$), $t\ (46) = -1.98$, $p = 0.5$, See Table 3 for examples of thoughts. There was no relationship between social mind wandering and negative affect either across the 2020 student sample, $r\ (185) = -.025$, $p = .74$.

Comparison of student and general population lockdown sample

A comparison of our general population sample, with the subset of the student sample collected over the same time period (i.e. during the first lockdown) found significant differences in both task focus and negative affect, with the student sample reporting less task focus ($M = 2.21$, $SE = .05$), than the general population ($M = 2.93$, $SE = .72$), $t(302) = -8.35$, $p < .001$; and the students reporting more negative affect ($M = 22.5$, $SE = .84$), than the general population ($M = 19.4$, $SE = 1.01$), $t(330) = 2.31$, $p = .02$, and this difference was even more pronounced in the anxiety subscale, $t(330) = 3.06$, $p = .002$. On the other hand, the proportion of thoughts directly referencing the pandemic was markedly higher among the general population versus the student sample (general population $M = 6.95\%$, $SE = 1.46$, student population $M = .55\%$, $SE = .08$), $t(116) = 4.22$, $p <.001$, even though there was no difference in the proportion of participants mentioning the pandemic during this time period (22.1% of general population compared to 27.7% of students, $X^2 <1$). There were no differences between the two samples in the valence of thoughts, $p = .50$, or the level or prevalence of social thoughts, $t <1$, $X^2 <1$.

Experiment 2

The data for this experiment was pre-registered and collected with the purpose of replicating the findings of Experiment 1, that initially suggested a decrease in task focus during the pandemic and controlling for a methodological variation. Our first experiment was originally collected for a separate study which did not involve comparison across the 2019 and 2020 cohorts, and hence included a minor methodological variation between these datasets in terms of the addition of the open-ended question to the thought probes in 2020. The purpose of Experiment 2 was hence to rule out any alternative account by which this methodological variation could explain the findings of Experiment 1, in particular, the increased rates of mind wandering – for example, one might imagine that writing about their thoughts could prompt participants to have further thoughts on that topic. To this end, we tested a further sample of participants, recruitment across both student samples and the general population, on both variants of the task (i.e., with and without the open-ended question). Given that this data was collected between November 2020 and March 2021, which coincided with the second and third UK lockdowns, a secondary aim was to examine how rates and contents of mind wandering have changed since the first months of the pandemic (around the first UK lockdown), as compared to the second and third UK lockdowns, respectively. However, those effects turned out to be incorrect due to a data processing error. This study was originally pre-registered on Open Science Framework https://osf.io/vg86y/[2], deviations from the pre-registration are related to the main effects that were to be replicated, namely, the comparison between the two versions of the experiment in terms of task focus and valence. No deviations were made in terms of data treatment and preprocessing.

[2] During embargo, it can be viewed using this link: https://osf.io/vg86y/?view_only=7b42625c2c2e4eefb89f7e95a89d6330. Complete file also on Appendix.

Methods

Participants

This study was approved by the University of Sussex Sciences & Technology Cross-Schools Research Ethics Committee. A power analysis using the software program G*Power (Faul et al., 2007) was conducted based on Experiment 1 (means and SD's) and showed that a sample size of at least 310 participants would have had >99% power to detect any effect of the methodological variation on overall task focus, based on the effect size of .73 found in Experiment 1's comparison of the 2019 and 2020 student cohorts (alpha = .05). This sample size would also allow to obtain power >.8 for all other planned analyses, as follows: (1) percentage of neutral mind wandering (MWneutral %): Power = .80, effect size = 0.32; (2) percentage of unpleasant mind wandering (MWneg %): Power = .96, effect size = 0.42; (3) mean valence: Power >.99, effect size = 0.61. Our pre-registered stopping rule was based on reaching a sample of 350 to allow for possible exclusions. Following pre-registered exclusions, our final sample included 344 subjects was recruited from a combination of the University of Sussex's Participant Pool of students, receiving course credits for their participation, and from the general population via Prolific (https://www.prolific.co/), receiving financial compensation (see Table 1 for demographics, broken down by the time of data collection). Subjects were all right-handed, fluent English speakers, with normal or corrected-to-normal hearing and vision, age range 18-35 years.

Cohort (Year)	N	% Females	Age (mean)
Student (Lockdown 2)	122	53	24
Student (Lockdown 3)	103	56	23
General Pop. (Lockdown 3)	119	51	26

Table 4. **Demographic characteristic of participants in Experiment 2**

Procedure

All stimuli and procedure were identical to Experiment 1, with the exception that we ran both versions of Experiment 1 at the same time, with random assignment of subjects, with half of the participants doing version A (i.e. the 2019 version, with no open-ended question following the thought probes), and half doing version B (i.e. the 2020 version, with an open ended question following the thought probes).

Results and discussion

Mind wandering across the pandemic among students and general population

We explored how task focus and valence of thoughts changed across the course of the pandemic, comparing data collected in the time periods surrounding the first (spring 2020), second (autumn 2020) and third (winter 2021) UK lockdowns in the student sample, and between the first and third lockdown in the general population samples (the general population sample was not tested during the second lockdown). One-way ANOVA tests of both the student and the general population showed significant changes in overall task focus across the three lockdown periods using version B[3] of the task. For students, $F(2,296) = 6.061$, p=.003, and for general population, $F(1,188) = 5.103$, p=.025. In both cases, this reflected a significant increase in task focus between the third lockdown and all other time periods (i.e., third UK lockdown versus both the first, p <.001, and second lockdowns, p = .04, for student[4]; and third UK lockdown versus the first lockdown for general population, p = .005. Within the student population, the levels of task focus did not differ between the first and second lockdown, p = .255.

[3] Only version B was used to compare across lockdowns because it is the version used during the first lockdown. In parallel, version A was used to compare between pre- and post-pandemic, because it was the version used during the period pre pandemic.
[4] LSD Post-hoc test

Within the student population only, using one-way ANOVAs we did not observe any significant change in the mean valence of thoughts, but F <1, with a numerical trend for thoughts to become more positive from lockdown 1 (M = 3.08, SE = .04), to lockdown 2 (M = 3.17, SE = .06), to lockdown 3 (M = 3.23, SE = .07). In the general population, changes in valence of thoughts between lockdown 1 (M = 3.13, SE = .05), and lockdown 3 (M = 3.33, SE = .07), were observed, $F(1, 188) = 6.175$, $p = .01$.

It is also notable that a One-way Anova of the reports of negative affect did not show significant changes in either the student or general population sample over the course of the pandemic, for students $F(2, 3017) = 2.334$, $p = .099$, for general population F <1, using version B of the experiment.

Among those participants who reported the open-ended question, the mean number of specific mentions of pandemic related topics decreased in the general population between the first and third lockdown $F(1,230)=13.632$, $p<.001$, but no change in pandemic mentions was found in the student sample, F <1. Both samples however, showed a sharp decrease in the percentage of participants experiencing at least one thought about the pandemic: For students, such thoughts were experienced by 21% of the sample during lockdown 1, but only 1.6% and 2% in lockdowns 2 and 3 respectively, X^2 (2, N = 183) = 22.680, p = .001. For the general population, pandemic thoughts were experienced by 22.1% of participants in the first lockdown, but only 4.3% in the third lockdown, X^2 (1, N = 113) = 10.613, p = .001. Neither sample reported any change in the mean level of thoughts involving social content (defined as in Experiment 1), for students F <1, for general population F (1,181) = 1.715, p = .192; nor in the percentage of participants reporting these thoughts, $X^2 < 1$.

Using version A, differences were found in negative affect between pre-pandemic (M = 19.48, SE = .07) and post-pandemic (M = 23.28, SE = 1.12), $t(351) = -2.94$, p = .003, being more evident for the depression ($p<.001$) and stress subscales ($p=.02$), and non-significant for the anxiety ($p=.24$). No significant differences between pre and post pandemic using version A of the experiment were found for task focus ($p=.28$) nor valence ($p=.30$).

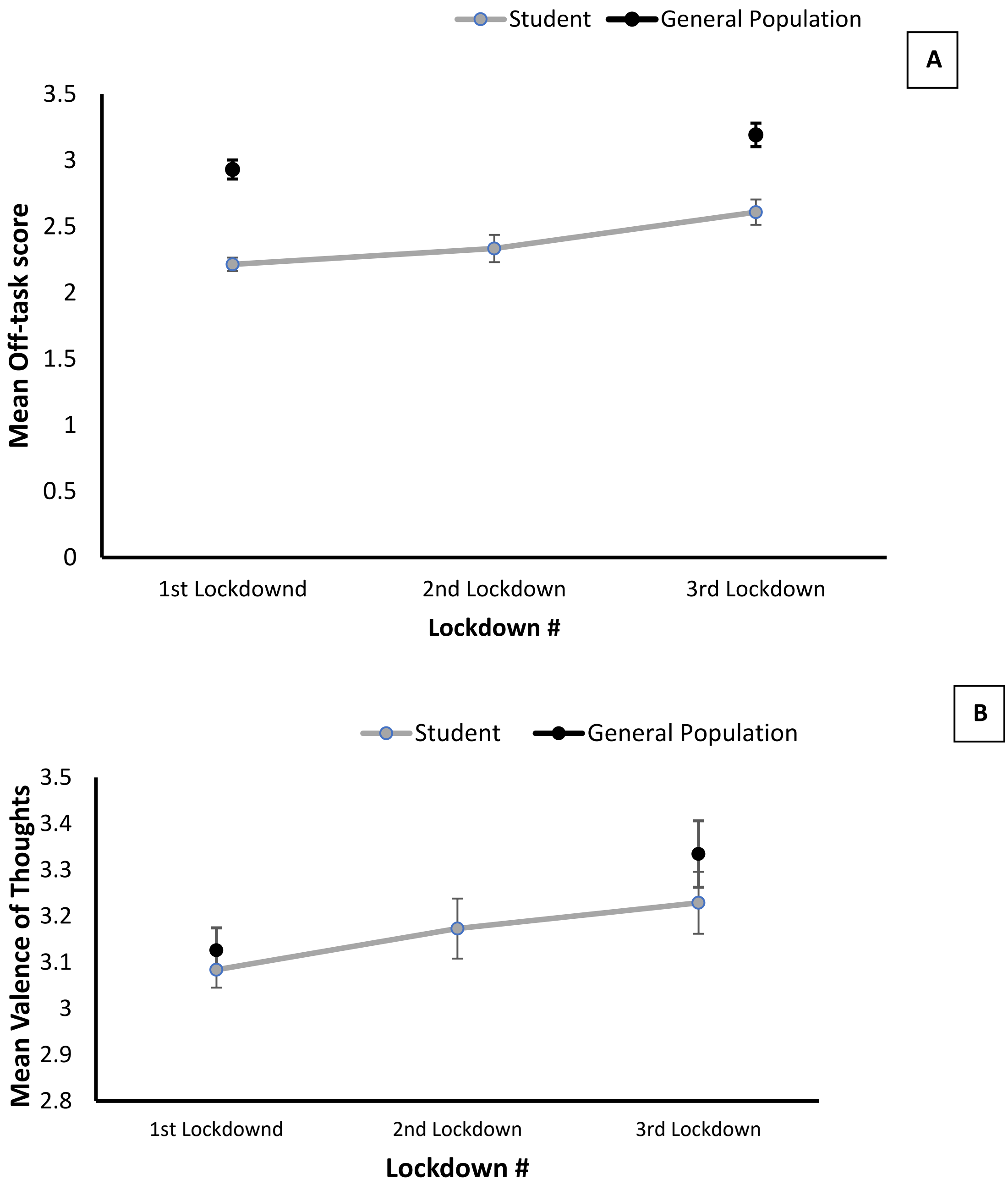


Figure 3. **Changes of off-task focus (A) and valence of thoughts (B) over the course of the pandemic, using version B of experiment, +/- SEM.**

General discussion

This study reports, to our knowledge, the first examination of task-focus and mind wandering levels during the COVID-19 pandemic, relative to a pre-pandemic baseline. Several findings arose from this study, however, to our surprise and contrary to anecdotal accountas of brain fog, we did not find an increase of off-task thoughts from before to during the pandemic. We found, however, a pandemic-related reduction in positive thoughts mediated by negative affect. This effect is in line with prior work using an experimental manipulation of strong, personally relevant, current concerns (Antrobus et al, 1966): Our results hence suggest that the substantial and widescale increase in current concerns brought by the pandemic has resulted in a decrease in positive mind wandering. Notably, the we found task focus differences between students and general population in the pandemic, with students reporting more offtask thoughts.

Given the established disruptive impact of mind wandering on a wide range of daily life tasks, in contexts from driving to education to the workplace, this implies a pandemic-related impairment in all these tasks for students. Given our use of a student sample, listening to an online lecture, our findings have particular relevance for the field of higher education. A particularity of this pandemic is that even though institutions such as universities have interrupted face-to-face activities, students are still required to engage in online academic activities. Previous research suggests that these changes in delivery may themselves reduce task focus – for example students' engagement have been found to decrease during distance learning activities, such as in online video-lectures, compared to in person teaching (Timmons, 2020; Guo, Kim, & Rubin, 2014; Kim et al., 2014), and mind wandering rates have also been shown to be increased (Wammes & Smilek, 2017; Risko et al., 2012; Szpunar et al., 2013; Kane et al., 2017). Given the established disruptive effects of mind wandering on academic activities such as lecture and reading comprehension (Wammes & Smilek, 2017; Smallwood, Fishman, & Schooler, 2007; Risko et al., 2011; Delgado & Salmerón, 2021), such effects should be considered by universities and examination boards.

Our findings also are in line with prior work finding cognitive disruption, in terms of poorer performance on a sustained attention task, before versus after an earthquake in Christchurch, New Zealand (Helton and Head, 2012). The authors interpret their findings as reflecting an impact on mood and thoughts' occurrence. Our findings, by measuring the contents of thoughts as well as negative affect, can more directly address the relationship between mood, thoughts, and task focus. Our second key finding suggests that the pandemic-associated increase in negative affect (established previously and replicated in our sample) partially mediated the effects of the pandemic in students' unpleasant mind wandering but did not play any role in boosting neutrally valanced mind wandering (which accounted for the majority of mind wandering). On one hand, this is a meaningful finding because university students are already a vulnerable population for mental health problems such as depression and anxiety (Storrie et al., 2010; Ibrahim et al., 2013; Räsänen et al., 2016; Bruffaerts et al., 2018), during the COVID-19 pandemic being a young adults and a student have consistently been considered as a risk factor for mental health (e.g., Pierce et al., 2020; Pieh et al., 2020; Solomou & Constantinidou, 2020; Lee et al., 2020), and life stressors have the potential to impact affect and mind wandering rates, which in turn can impair academic performance. On the other hand, the fact that negative affect only partially mediated this relationship leaves room for further exploration. A compelling possibility could be borrowed from studies showing mind wandering, in particular with a social content, as serving an emotional regulation function, during stressful times (e.g., Poerio et al., 2016), however, this does not explain why specifically unpleasant and neutral mind wandering increased, instead of pleasant. Overall, we show that negative affect plays a role in the decrease of positive off-task thought, yet other factors as, perhaps, a widescale increase in salient and personally relevant 'current concerns' (e.g., Klinger, 2009) could also be in the picture. Our third finding demonstrates that, despite the decrease in pleasant thoughts, these were primarily on topics not directly related to the pandemic. However, there was an escalation in thoughts about the covid pandemic, from 5% in February to 30% around March-April, which coincided with the onset of the first UK lockdown (on the 23rd of March) and which were hand in hand with the increase of infection cases in the UK.

In summary, the present study presents the first evidence quantifying and characterising the impact of the COVID-19 pandemic on task-focus and mind wandering. Our findings suggest an impactful influence of the pandemic on mind wandering, which could have consequences in task performance, and should be accounted for, especially in educational settings, and during an era of remote learning.

CHAPTER V

General discussion

With this thesis, my general purpose was to contribute to the toolkit of objective measures for spontaneous thoughts, with an emphasis in the methods for studying the contents of thoughts. For this, I resorted to neuroimaging and electrophysiology methods, such as fMRI (Chapter 2) and a combination of EEG and facial EMG (Chapter 3). My second purpose with this thesis to use the developed measures to investigate questions regarding certain types of thought contents, with a particular emphasis on: executive and affective thoughts, as well as intrusive and involuntary types of thoughts, and those with personal or motivational relevance. This goes in line with accounts that, beyond asserting the importance of investigating mind wandering and spontaneous thoughts, due to its ubiquity and impacts on people's lives (Smallwood & Schooler, 2015), emphasise the heterogeneous nature of this phenomenon (Wang et al., 2018; Irving & Thompson, 2018) and express the priority that should be given to investigating the contents of thoughts, especially when accounting for impacts on mental health and wellbeing, and when proposing impactful interventions (Smallwood & Andrews-Hanna, 2013). In line with this, I finally sought to characterise the phenomenology of the types of thoughts aforementioned and look into their relationship with state mental health variables (Chapters 3 & 4).

In the introductory chapter I establish that, despite the ongoing discussions regarding what scientifically constitutes mind wandering and spontaneous thoughts and their boundaries and overlapping concepts (Christoff, 2012; Metzinger, 2013; Seli et al., 2018a, 2018b), for the sake of this thesis, my working definition of the phenomenon under investigation is off-task and stimulus-independent thoughts, without excluding involuntary thoughts, personally-relevant thoughts, nor perseverative and repetitive thoughts. In this thesis, I termed all of this as within the umbrella of 'spontaneous thoughts.' In the introduction I explained that this working definition does not fully parallel with accounts of mind wandering and spontaneous thoughts as being specifically unconstrained and unguided (i.e., 'Dynamic Framework', Christoff et al., 2016; 2018). Even though their definition is plausible and relevant to the field, and supported by research, including neuroimaging studies (e.g., Kucyi, 2018), it suggests that mind wandering only represents a very narrow subset of thoughts. My working concept more broadly encompasses classes of thoughts that have been shown to be an important component of mind wandering phenomenon (e.g., Seli et al., 2018a, 2018b; Maillet & Shacter, 2016; Ottaviani et al., 2015; Klingler, 2009; Baird, Smallwood & Schooler, 2011; Baars, 2010; Berntsen, 2019) and related to the many widely documented mind wandering negative impacts (Smallwood, 2011; Beck, Laude & Bohnert, 1974; Ottaviani & Beck, 1987; Shrimpton, 2017), and that would otherwise have been neglected. Such classes of thoughts include ruminations, intrusions, and worries, which are linked to anxiety and depression, among other negative affect and mental health problems, besides impairing a broad range of daily activities. Their associations to mental health problems and detriments in performance are part of the rationale that in the introduction I presented for studying mind wandering at all, and the contents of thoughts in particular. I also reviewed the available methods for studying mind wandering and spontaneous thoughts, emphasising the gap on objective methods for studying the contents of thoughts, which I aimed to address throughout the thesis. Below I discuss each of our findings, their implications, and propose future directions.

My first empirical study (Chapter 2) reports an fMRI study with two findings. First, my colleagues and I developed a method to 'see' the occurrence of a specific spontaneous thought, tracked in the brain, using perceptual reactivations. This demonstrated that spontaneous and involuntary thoughts can elicit reliable stimulus-specific patterns of neural activity, and we can identify this with both univariate and multivariate fMRI. This extend previous research on perceptual reactivations of mental imagery (e.g., Mechelli et al., 2004; O'Craven & Kanwisher, 2000; Naseralis et al., 2015; Pearson et al., 2015; Radoslaw, Heinzle & Haynes, 2012; Dijkstra, Bosch & Gerven, 2019; Robinson et al., 2020) because in our paradigm the thoughts are not guided, are spontaneous and intrusive by nature (subjects were insistently required to suppress those thoughts). Thus, to our knowledge, this is the first study that shows perceptual reactivation of spontaneous thoughts. Here we sought to explore similarities between external and internal types of distraction, in terms of bottom-up attentional capture, drawing mainly on literature and well-established findings from external attention (e.g., Itti & Koch, 2001; Ptak, 2012; de Fockert et al., 2004). Our second key finding shows that salient involuntary spontaneous thoughts, activate lateral posterior parietal areas, similar to irrelevant salient external distractors, thus we demonstrate brain parallels between attentional capture by external stimuli and attentional capture by thoughts. Previous work had shown an overlap for voluntary orienting of attention, which we now demonstrate to occur to involuntary thoughts. This has some methodological and mental health implications discussed below.

On Chapter 3, I report two experiments on the executive and affective dimensions of thoughts. Experiment 1a and 1b present a phenomenological characterization of executive and affective spontaneous thoughts, in terms of temporal orientation, valence and plausibility of thoughts and in their relationship with negative affect. We found that executive thoughts account for approximately 36% of mind wandering thoughts and that vary in valence, in terms of pleasant and unpleasantness, as predicted. As a replication of previous work, we found executive thoughts to be more future-oriented (Ruby et al., 2013; Smallwood & Andrews-Hanna, 2013; Kane et al., 2017), in line with accounts of mind wandering as functional for future planning and goal-directed thought to facilitate action (e.g., Baird et al., 2011; Kane & McVay, 2012). However, it is important to consider when this tendency also takes negative or unpleasant forms, as this could be a key to better understand perseverative and repetitive forms of thinking, such as rumination and worries (Ottaviani et al., 2015; van Vugt & van der Velde, 2018), which would have mental health implications, see relevant section below.

This behavioural study was followed by an electrophysiology research to establish the EEG and facial EMG correlates of executive and affective thoughts, respectively, through a guided-thought paradigm. The intended objective markers were established, we can use frontal beta event related spectral perturbation (ERSP) to tell apart executive thoughts from passive imagination. This was expected as it parallels finds showing that frontal beta is associated to mental effort and motor planning (e.g., Macaulay & Edmons, 2004; Howells et al., 2010; Behmer & Fournier, 2014), but our novel contribution is to establish these markers specifically for executive thoughts that simulate mind wandering, therefore it contributes to advancing research on spontaneous thoughts. In terms of facial muscles, we demonstrate that specifically the *Corrugator Supercilli* can be used to index between negative and positive thoughts, thus, both the affective and the executive dimensions of spontaneous thoughts can be investigated from now on.

Chapter 4 is my final empirical chapter, in which I report changes in task focus and and contents of mind wandering during the unexpected COVID-19 pandemic, which can conceivably be seen as a personally relevant and strong category of thoughts, which would be in line with mind wandering theories of current concerns (e.g., Klinger, 2009; McVay & Kane, 2013, Antrobus et al., 1966). Because of the unexpected nature of the pandemic, this was not a study that I could initially have planned to include in the thesis, but a unique opportunity was presented as the behavioural data presented in Chapter 3 was collected during parallel timeframes in 2019 and in 2020, the latter coinciding with the initial months of the COVID-19 pandemic and the first lockdown in the UK. We found associations between the pandemic and decrease of pleasant mind wandering, mediated by negative affect. This parallels to prior work using an experimental manipulation of strong, personally relevant, current concerns (Antrobus et al, 1966), except that in this case the pandemic served as a 'natural laboratory'.

Implications

One of the first and most obvious implication of this thesis, as a whole, relates to the further understanding the contents of specific thoughts, for research purposes, and also to contribute with objective measures. However, I will be more specific below, on proposing some methodologic and theoretical contributions, as well as those relating to mental health and education.

Methodological implications

First, the work presented in this thesis points to less reliance on thought probes for the study of mind wandering. Thought sampling or thought probes are a common methodological approach in the study of mind wandering, whether probe-caught or self-caught variants of techniques (see Chapter 1). In the probe-caught variant subjects are periodically interrupted to report on the occurrence and contents of their mind wandering (e.g., Smallwood and Schooler, 2006, 2015). However, subjects not always are able to provide accurate accounts of their thoughts, and a probe-free method could be the answer (Smallwood et al., 2021). In Chapter 2 I propose a method of tracking thoughts that does not depend on a person reporting on their thoughts.

The results on Chapter 3 also offer the methodological possibility of using facial EMG markers (specifically the *Corrugator Supercilii* muscle) combined with measures of EEG time-frequency or spectral perturbation, in frontal beta and parieto-occipital alpha, to detect the presence of spontaneous executive and affective thoughts. As I used a guided thought paradigm, for better experimental control, it remains to be tested whether these methods can be applied to spontaneous thoughts. If so, specific spontaneous thoughts such as worries can be further investigated using this new method.

Theoretical implications

Some of the theoretical implications of this work is related to accounts of common mechanisms of internal and external distraction, showing that individuals prone to mind wandering also show increased distraction from irrelevant external stimuli (e.g., Forster and Lavie, 2009; 2013; 2016; Morris et al., 2020). This work helps answer the question of what those common mechanisms are that would make a person more likely to distraction by both their own thoughts and the environment. Models of selective attention argue about the existence of both top down and bottom-up mechanisms playing a role in distraction, and previous research has shown some top-down commonalities in terms of voluntary attention allocation (e.g., Christoff et al., 2016), those mechanisms are goal-directed and can help prevent attentional capture by both external and internal distractors. However, there is still a lot to learn in terms of spontaneously arising thoughts or thoughts that have automatic constraints, as seen in the Dynamic Framework (Andrews-Hann et al., 2018), or unintentional spontaneous thoughts, as seen by Seli et al. (2018). Thus, this work sheds light into what makes a thought salient to the point of capturing our attention and configuring into a failure of the top-down mechanisms, perhaps very similar to what an external source of distraction would do, for example, perceptual salience, emotional and affective, or even regarding rewards. All of those things could potentially make a thought salient and gives way to establishing a priority map for thoughts, which we found in the common overlapping posterior parietal areas.

This research as a whole can also be expanded to contribute to the understandings of internal triggers of desire, cravings and even binge eating and food addictions, along the lines of the Elaborated Intrusion (EI) Theory (May, Kavanagh, & Andrade, 2015). Research proposing this Theory has been showing that the spontaneous, automatic, and repetitive aspect of desire-related thoughts are an important feature in food craving, but also cravings related to smoking and alcohol consumption, with desire thoughts being reported to automatically appear in a persons' mind, and with failed attempts to suppression (May et al., 2015). A powerful connection could be the through linking these theories of attentional capture and onset of spontaneous thoughts of a intrusive content with self-regulation through mindfulness and distraction as proposed by Esther Papis (e.g., van Dillen & Esther Papies, 2014). This account proposes the use of both deliberate distraction and mindfulness as strategies to reduce the negative impacts of automatic intrusive and spontaneous thoughts.

Implications for mental health and educational contexts

Related to our fMRI findings in Chapter 2 is being able to track specific involuntary and intrusive thoughts, which could be extended to the study of addiction and cravings, or trauma-related intrusions. We found striatal activation in response to attentional capture by thoughts that are associated to reward. On one hand, this finding is novel because this has only been shown when considering external reward-associated stimuli, but we see the same areas active when considering internal stimuli (for which we used a similar value-training procedure; Anderson, Laurent & Yantis, 2014). These parallels suggest that we can use finding from either external or internal to help us better understand internally directed cravings and addictions (Moss et al., 2015), including food addictions (Maya et al., 2010; Berry, Andrade, & May, 2007; Garcia et al., 2014).

As some categories of mind wandering contents have been widely associated to negative affect, with some categories of thoughts such as ruminations, intrusions and worries, being linked to depression and anxiety, the method we establish on Chapter 3 allow us to further investigate those negative categories of mind wandering in an objective manner. This is of particular importance when conducting research with clinical populations or those less able to provide accurate subjective reports of their thoughts.

Establishing objective markers is also important for school children, during educational activities. Nowadays EEG can be portable and has at least once been used to measure mind wandering in adults during a class (Dhindsa et a., 2019). If our new method can also be applied to spontaneous thoughts, we would be able to know whether a child is engaged on passive imagination or some goal-driven mind wandering, and facial EMG would help detect the valence of the thoughts. This is particularly because mind wandering has been shown to disrupt the engagement on school related activities (Wammes et al., 2019) and well as impairing performance. But it has not yet been established whether these impacts can be distinguished between executive and non-executive, pleasant and unpleasant categories of thoughts.

In Chapter 4, the implications for academic contexts are even more relevant. In many countries, the pandemic has almost resorted on remote learning activities. Remote studying has been shown to increase mind wandering as compared to in person, but our results showing reduced task-focus in students as compared to the general population are especially interesting for educational settings. Given the established disruptive effects of mind wandering on academic activities such as lecture and reading comprehension (Wammes & Smilek, 2017; Smallwood, Fishman, & Schooler, 2007; Risko et al., 2011; Delgado & Salmerón, 2021), such effects should be taken into account by universities and examination boards. Education institutions, including higher education, did not stop with the pandemic, students are still required to produce work and engage on activities, but our results show that the effects of the pandemic on task focus should be taken into account when planning academic activities, including examinations.

Future directions

There is the need to answer to some questions by further exploration of the data on this thesis. One of the question relates to the fMRI study, and is to explore why we did not see lateral parietal activation using the probe-free analysis and only the PPI. A potential reason that should be explored could be because the functional connectivity analysis focused on the 2 seconds immediately prior to subjective reports, which are ignored by the probe-free. This could indicate that the regions are actually involved in selection for awareness. For Chapter 2, it would also be interesting to explore the 'Attention to Memory' (AtoM) model (Ciaramelli, Grady & Moscovitch, 2008; Cabeza et al., 2012) and establish whether the IPS and more broadly the lateral posterior parietal regions respond to bottom-up or top-down types of thoughts, in contrast with accounts from Seghier (2013), who suggests that the LPP regions work as a hub housing different types of representations, including top-down (see also Rugg & King, 2018). Thus, our paradigm could be used to test the AtoM through the use of episodic memories and tracking their involuntary reactivations. It would also be interesting to compare the reactivations with measures of behavioural performance, especially in relationship to Value-driven Attentional Capture (Anderson et al., 2014), by distinguishing between high and low value thoughts, which could not be done here due to few reports. However, future work is important on this, especially when comparing the behavioural value data with regions of the reward network that were found active in this work. Lastly, further analysis of this data could also involve assessing the degree to which the two distraction tasks (internal and external) match in terms of difficulty. A solution could be replicating this work using matched or similar tasks for both types of distraction.

On Chapter 3 it is relevant to explore, through multivariate pattern analysis, whether we can use this method as 'mind reading' on a subject-by-subject level, or to only use it as a triangulation method alongside subjective measures. However, the major future direction from this method is the possible application to EEG.

Combined, all this work could also be used to study negative repetitive thoughts, such as rumination and intrusions (for example, in anxiety, phobia, OCD and depression, addiction, food-disorders). In phobia, for example, we could explore the role of the lateral posterior parietal regions as well as the amygdala, in a similar way to our fMRI study. The work presented here could be helpful to also associations to ADHD such as involuntary thoughts, mind-wandering and even negative affect and addictions.

Limitations

As a whole, this work offers new concrete ways to objectively investigate into the contents and occurrence of spontaneous thoughts. However, the work presented here is limited to specific categories or features of thoughts, which are just a small subset of what constitute our mental lives. We look into strategic thoughts, pleasant versus unpleasant, and those with specific brain representation (faces). However, by looking at the descriptions of subjects, it is possible to infer that much more is going on, and some of the thoughts might not be easy to capture. This is a limitation because, thus far, and using most of the methods presented here, we are only able to mind-read those thoughts that have such a specific neurocognitive and electrophysiological signature that allow us to read them. For example, in the fMRI study, could we capture anything other than faces or places, which are consistently represented in the FFA and PPA, respectively? The answer is that perhaps only with the multivariate approach, if we use a ‘viewing/visual pattern’ as template, very more unlikely with the univariate approach. And this situation remains true throughout the chapters. As if thus far we ‘mind-read’ those thought contents that want to be read.

Further, there is also the question raised and that I attempted to answer in the introduction, on whether an objective measure can really replace subjective reports. This work is limited to pointing more to the powers of triangulation, of using objective measures to corroborate thought probes.

Conclusion

To conclude, this thesis offers a number of methodological advances to the research field of spontaneous thought, from tracking ‘marker’ thoughts and seeing their spontaneous reactivation, to establishing electrophysiological markers of specific types of thoughts. I demonstrate that we can objectively study the occurrence of spontaneous and involuntary thoughts. My research also showed brain similarities in the activation of involuntary salient thoughts to their external stimuli counterpart, which has impacts across several fields, from attention to involuntary autobiographical memories, and in clinical contexts.

Furthermore, this thesis highlights the importance of considering both the level of strategy and valence when studying spontaneous thoughts, and their impact on mental health, and I presented a way of studying those categories of thoughts in an objective manner. Finally, when quantifying and characterising the impact of the COVID-19 pandemic on task-focus and mind wandering, this thesis draws attention on the detriments that a reduction of task focus could have on a wide range of daily activities, and in particular on academic contexts, and with impacts on general wellbeing of students and the world population as a whole.

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APPENDIX

Pre-registration for Experiment 2, Chapter 4

Embargoed registration until December 16, 2024

https://osf.io/vwd9g

Registration title: Mind wandering during the pandemic: Follow-up study

Contributors

Paloma Manguele and Sophie Forster

Description

Brief background: This study is being conducted as a follow up to an initial study comparing rates and content of mind wandering during February-May 2020 and during the same months in 2019. As outlined in more detail in the 'data collection procedures' section, the purpose is primarily to test the impact of a methodological difference between the probing methods used in 2019 versus 2020, i.e., the addition of an open-ended question at the end of each probe in 2020. More specifically, we will test whether any of the differences observed between 2019 and 2020 (from now on, version A and version B, specifically) can be explained by this methodological difference. A secondary aim is to examine how rates and contents of mind wandering have changed since the first months of the pandemic. Research questions: • Confirmatory: Can the introduction of an open question at the end of each thought probe account for the 2019 versus 2020 between group differences observed in the in the rate of, or valence of, mind wandering? • Exploratory: Are there changes in the rate and contents of mind wandering between the first months of the pandemic (immediately before and during the first UK lockdown) and the period during and immediately following the second lockdown? •

Exploratory: Are there changes in negative affect between the first months of the pandemic (immediately before and during the first UK lockdown) and the period during and immediately following the second lockdown?

Registration type: OSF Preregistration

Date registered: December 17, 2020

Date created: December 17, 2020

Registered from: osf.io/vg86y

Subjects

- Social and Behavioral Sciences
- Life Sciences

Tags

- COVID-19
- Mind wandering
- Negative thoughts
- Pandemic

Citation

Manguele, P., & Forster, S. (2020, December 17). Mind wandering during the pandemic: Follow-up study. Retrieved from osf.io/vwd9g

Study Information

Hypotheses

If the methodological differences between version A and version B of the study can explain our prior findings, we would expect to find the following group differences: • Increased percentage of mind wandering among participants for whom the open question was included (version B), compared to those who the version was excluded (version A). • Lower rating of valence among participants for whom the open question was included. • Increased percentage of negative valanced mind wandering among participants for whom the open question was included • Increased percentage of neutrally valanced mind wandering among participants for whom the open question was included

Design Plan

Study type

Experiment - A researcher randomly assigns treatments to study subjects, this includes field or lab experiments. This is also known as an intervention experiment and includes randomized controlled trials.

Blinding

- No blinding is involved in this study.

Is there any additional blinding in this study?

No response

Study design

This is a between-subjects design with two conditions reflecting different versions of the thought probing protocol: Version A (without open-question) and Version B (with open-question) of the probing task.

No files selected

Randomization

No response

Sampling Plan

Existing Data

Registration prior to any human observation of the data

Explanation of existing data

Data collection is in progress - we commenced data collection prior to pre-registration for practical reasons relating to the timing of the course credit scheme. Data is automatically stored on the Millisecond server (creators of Inquisit, https://www.millisecond.com/). The data collected so far has not been downloaded from the server or viewed in any way. Therefore, there are no summary statistics or patterns that have been observed yet.

Data collection procedures

• The methods replicate those of two online experiments programmed and presented using Inquisit (Millisecond). The version A of the experiment was run in 2019, prior to the COVID-19 pandemic, and the version B was run during the first lockdown in 2020. These two experiments are largely similar, based on probe responses with options on a Likert scale. The difference is that version B has an extra open-ended question on the probe response where participants report their thoughts. • The current follow-up study is set to investigate whether the differences in the MW rates could be caused by the addition of the open-ended question. Thus, we are now running both versions at the same time, with half of the participants doing version A (i.e. the 2019 version), and half doing version B (i.e. the 2020 version). • Participants are recruited from the University of Sussex Participant Pool of undergraduate students (SONA), from the School of Psychology, and receive course credits as compensation for their participation. • Inclusion criteria: participants must be between 18 and 35 years old, fluent in English, with normal or corrected-to-normal hearing and vision. Exclusion criteria: Participants will be excluded from analysis if all of their probe responses are excluded according to the criteria described in the 'Data exclusion' section. We also exclude participants who do not complete the experiment. • As in the two previous versions, subjects are required to have access to a computer with good speakers, stable internet, an up-to-date browser, and were asked to install Inquisit Player 5. Prior to the tasks, subjects read the information screen and give their consent by pressing a relevant button. • In terms of tasks, in both versions participants are first asked to respond to the Depression, Anxiety, and Stress Scale (DASS), as a measure of negative affect. Participants are then asked to listen to an audio lecture and respond to six intermittent thought probes. At each thought probe, participants are presented with series of questions rating the focus, temporal orientation, level of strategy, plausibility and valence of thoughts. In version B, there is the open-ended question added to each set of thought probes, asking the participants to briefly describe what they were thinking about.

No files selected

Sample size

Our minimum sample size target is 310 participants. We will attempt to recruit 350, to account for participant exclusions due to very short or very long response latencies across probes (see 'Data exclusion' section) or non-completion of experiment. If the exclusion leads to the sample size dropping below 310, more participants will be recruited.

Sample size rationale

We used the software program G*Power (Faul et al., 2007) to conduct a power analysis. Our minimum total sample size of 310, would have >99% power for the key comparison of group differences on overall rate of mind wandering, to detect an effect size of .73. This sample size will also allow us to obtain power >.8 for all other planned analyses, as follows: - Percentage of neutral mind wandering (MWneutral %): Power = .80, effect size = 0.32 - Percentage of negative mind wandering (MWNeg%): Power = .96, effect size = 0.42 - Mean valence: Power >.99, effect size = 0.61 For the power analyses we used two-tailed comparisons at the standard .05 alpha error probability. Effect sizes were computed from the means and SD's of the two prior experiments, for each of the planned comparisons. Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior research methods, 39(2), 175-191.

Stopping rule

During data collection, the number of participants will be checked approximately every 2-3 days and stopped once 350 participants have been recruited, to allow for possible exclusions. If after exclusions the sample size drops below 310 then additional participants will be recruited until 310 participants with usable data have completed the experiment.

Variables

Manipulated variables

Sequential alternating allocation of participants to 2 conditions of the experiment: o Version before pandemic (Version A) o Version during pandemic (Version B)

No files selected

Measured variables

The outcome variables will be: • The ratings by participants at the thought probes, regarding the focus of their attention and the valence of their thoughts. Participants will be asked: “Just before this screen, how focused on the task were you?”, responses are recorded via 5-point Likert scales, with the options ranging from “Not at all (focused)” to “Extremely (focused)” and “To what extent was your mind in something pleasant or unpleasant?”, ranging from “Very unpleasant” to “Very pleasant”. • Other variables measured at the thought probes are the mean rates of temporal orientation, strategy, plausibility, but these will be used in exploratory analyses only.

No files selected

Indices

The following additional indices will be computed from the ratings: - Overall mind wandering rate (MW%): The percentage of probes at which a participant responded with a score of 1-3 in the question “Just before this screen, how focused on the task were you?” - Percentage negative mind wandering (negativeMW%): The percentage of probes at which a participant responded with a score of 1-2 in the question “To what extent was your mind in something pleasant or unpleasant?" while also responding with a score of 1-3 to the question "Just before this screen, how focused on the task were you?" - Percentage neutral mind wandering (neutralMW%): The percentage of probes at which a participant responded with a score of 3 in the question "To what extent was your mind in something pleasant or unpleasant?" while also responding with a score of 1-3 to the question "Just before this screen, how focused on the task were you?" - Percentage positive mind wandering (positiveMW%): The percentage of probes at which a participant responded with a score of 4-5 in the question "To what extent was your mind in something pleasant or unpleasant?" while also responding with a score of 1-3 to the question "Just before this screen, how focused on the task were you?"

No files selected

Analysis Plan

Statistical models

Independent samples t-tests will be conducted for each of the primary outcome variables (as outcomes), with the grouping variables being each of the two experimental conditions (version A, version B).

No files selected

Transformations

No response

Inference criteria

Inferences for the presence of an effect will be based on null hypothesis significance testing - p-values t-tests will be interpreted as significant if they are less than .05, two-tailed.

Bayes factors will be additionally reported in order to assess the sensitivity of any null results. Bayes factors will be interpreted as providing substantial evidence for the null hypothesis if they are equal to or less than .33. They will be interpreted has providing substantial evidence for the experimental hypothesis if they are equal to or greater than 3 (cf. Dienes, 2008). The prior expected effect sizes which will be modelled as a half-normal distribution from a mean of zero, will be based on the effects observed in our previous experiment, as follows: o Difference in MW%: 15.1% o Difference in mean valence: 0.35 o Difference in NegativeMW%: 8.63% o Difference in NeutralMW%: 8.55% Confidence intervals will be interpreted as significant if zero is not between the lower and upper bound (cf. Field, 2013). Dienes, Z. (2008). Understanding psychology as a science: An introduction to scientific and statistical inference. Macmillan International Higher Education. Field, A. (2013). Discovering statistics using IBM SPSS statistics. sage.

Data exclusion

Exclusion criteria: will be based on latency times. Probe question responses with a latency of response below 0.4 seconds and above the upper limit of the first quartile of latencies* will lead to exclusion of that question. Having more than two questions excluded will lead to exclusion of the entire probe. Having all probes excluded will cause the exclusion of the participant. In addition, those participants who do not complete the experiment for any reason will also be excluded from the final sample. *Based on the first quartile of latencies across probe questions and across subjects. The open-ended question was treated separately from the closed questions.

Missing data

• Participants with missing data for any given variable will be excluded from analysis concerning that variable only.

Exploratory analysis

No response

Other

Other

No response