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*Moving forward in the neurocognitive study of mind-wandering:
tracking the onset and time-course of mind-wandering*

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Abstract

In the present work, we focused on mind-wandering (MW). MW is a multidimensional mental state that absorbs parts of our waking life and can be defined as a shift of attention away from a current activity towards internal thoughts unrelated to the ongoing activity. Although neurocognitive studies on MW have increased substantially over the last years, there are still a number of overlooked questions. In particular, a number of researchers have indicated a need for investigations of the dynamics of this process. To this end, it would be especially important to focus on the two basic elements of MW experiences, specifically, the moment of the onset of MW episodes (i.e., when the flow of thoughts starts) and the maintenance of these episodes over time (i.e., what happens during the continuation of the flow). In our studies, we focused on identifying the ignition moment (i.e., the onset) of MW experiences, as well as investigating its dynamics over time. Here we report three empirical studies employing a vigilance task that allowed elicitation and analysis of MW episodes in the laboratory. Pupillometry was also employed both in the second and third study to assess the association between physiological and self-report measures.

The three studies used different versions of the vigilance task, in which participants were asked to detect infrequent target stimuli among a number of non-target stimuli and were eventually exposed to task-irrelevant verbal cues that could potentially act as triggers for MW episodes. MW was collected by using either a self-caught procedure (first and third studies) or a probe-caught procedure (second study).

Specifically, the first study was carried out for investigating the cue-dependent nature of MW and verifying whether MW episodes could be linked to preceding triggers. Thus, in a between-subject design, we studied the causal role of meaningful

external cues (i.e., verbal cues) in triggering MW experiences. We found that the exposure to the external cues increased the amount of MW and biased its temporal focus towards the past compared with a condition of no exposure to the cues.

The second study was developed on the basis of the first one, with the main aim of associating a physiological measure (i.e., pupil diameter) to the onset and maintenance of MW experiences. The main finding was obtained by tracking pupil size over 6 seconds after MW triggers and non-triggers: we found a significantly larger pupil dilation following cues reported as triggers of the MW episodes compared to non-trigger cues. This suggested that the onset of MW and its unfolding over time were accompanied by a physiological marker (i.e., a pupil dilation).

The third study was conducted with the main aim of replicating the results of the second study by using a different thought-sampling method, and extend them further. In particular, we used a self-caught procedure instead of a probe-caught procedure in order to track the pupil diameter following triggers of aware MW. We also examined whether and how the pupil dilation associated with MW was modulated by the emotional valence of MW. The main findings showed a significant increase in pupil diameter following triggers of aware MW compared to non-triggers, and this dilation appeared not to be modulated by the emotional content of MW.

Collectively, these studies provided several contributions to neurocognitive research on MW. First, they demonstrated that the onset of MW episodes could be identified in the laboratory, since MW episodes were linked to external, meaningful and task-irrelevant stimuli. Second, they showed that a physiological index (i.e., pupil dilation) was associated with the onset of MW and accompanied its unfolding over time. Third, the use of the vigilance task with verbal cues and the self-caught procedure

allowed us to also explore the latency of MW episodes (i.e., the time for the formation of thought and being aware of it).

In the general discussion, we report some implications of these findings for further investigations in MW research.

Chapter 1

General introduction

While attending a lecture, reading a book, or driving the car, there might be moments when our attention drifts away from the primary task towards internal thoughts, such as memories or prospective thoughts, whose content is unrelated to the ongoing task. Finding ourselves disengaging from a current activity and thinking about different thoughts unrelated to the ongoing activity is a common experience in our daily life. Often this attentional disengagement is also costly because it could be associated with worse performance or mistakes in the ongoing task. This cognitive phenomenon, referred to as mind-wandering (hereafter MW), is the focus of the present work. Specifically, our work aimed to address, in a series of studies, a key challenge still facing research on this topic, that is the question of the dynamics of MW, “*when*” the mind starts wandering (the onset of MW) and “*how*” MW unfolds over time (the maintenance of MW).

In this introduction, we will briefly review the state-of-the-art of the research in this field, and we will focus on both conceptual (i.e., definition, functional mechanisms) and methodological issues (i.e., measurement). We will also briefly mention the costs and benefits of MW across different contexts. In the last section, we will introduce the aims of our multi-experiment study and provide an overview of the experiments.

1.1 Mind-wandering: definition

With the term mind-wandering (MW) we refer to the “*shift of attention away from a primary task toward internal information*” (Smallwood & Schooler, 2006, p. 946). Since the earlier studies in cognitive science (e.g., Antrobus, 1968; Klinger & Cox, 1987-88; Singer, 1966) to the most recent and systematic ones (see Smallwood & Schooler, 2015 for a review), the research focusing on this phenomenon has been framed into various constructs, and different terminologies have been used (Callard, Smallwood, Golchert, & Margulies, 2013), such as task-unrelated imagery (Giambra, 1995), daydreaming (Mar, Mason, & Litvack, 2012; Singer, 1966), stimulus-independent thought (Antrobus, Singer, & Greenberg, 1966; Mason et al., 2007; Teasdale, Proctor, Lloyd, & Baddeley, 1993), task-unrelated thought (Smallwood et al., 2004; Smallwood, Baracaia, Lowe, & Obonsawin, 2003), self-generated thought (e.g., Smallwood, 2013) or, more generally, off-task states (Franklin, Broadway, Mrazek, Smallwood, & Schooler, 2013; Mittner et al., 2014). All of these lines of research addressed a certain mental state in which thoughts are unrelated to the external environment and the current situation, and these terms have been somewhat interchangeably used (Christoff, Irving, Fox, Spreng, & Andrews-Hanna, 2016; but see Seli et al., 2018 for a discussion on differences among these constructs).

The term MW, which has rapidly become the most used in the field, was finally chosen with the specific intent to make this experience familiar to lay people and elevate the status of this research (Smallwood & Schooler, 2006, 2015). However, conceptual confusion about the term MW, due to an attempt to capture the rich variety of this experience, has been also observed (see Seli et al., 2018). Here we adopt the term MW (unless differently specified because of the reference to other studies) and

define it as the experience of attentional shifting from an ongoing task and the external environment towards task-unrelated thoughts.

Thus, on the basis of this definition, MW should be considered as a different experience compared with task-related thoughts or external distractions. This distinction is clearly reported by Smallwood and Schooler (2015) and represented in Figure 1.1.

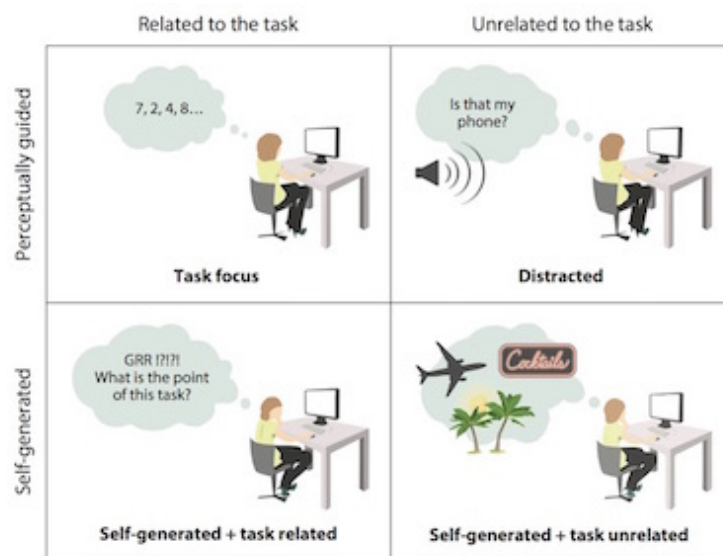


Figure 1.1. A schematic of different attentional states based on the relationship between the dimensions of task-relatedness (columns) and reliance on external information (rows) (from Smallwood & Schooler, 2015).

Smallwood and Schooler (2015) compared different attentional states that might be experienced during a task, that is (i) on-task (OT): the participant is fully focused on the task and the contents of thoughts are only those that arise from task-related sensory input (top left panel); (ii) external distractions (ED): the attention is focused on other external stimuli, unrelated to the ongoing task (e.g., noise in the room, temperature) (top right panel); (iii) task-related interferences (TRI): the attention is

distracted by interfering thoughts related to the appraisal of the current task, including evaluations about the task or about task performance (e.g., “What is the point of this task?!”); in this situation the contents of thoughts are related to the ongoing task but self-generated (i.e., unguided by sensory input) (bottom-left panel); (iv) mind wandering (MW): attention is drifted away from the ongoing task and external environment toward internal contents unrelated to the task; the contents are unrelated to the task and self-generated (i.e., unguided by sensory input) (bottom right panel).

Recently, an additional off-task attentional state has been proposed to be distinct from MW, that is mind-blanking (MB; Ward & Wegner, 2013). Mind-blanking is defined as a state in which there are no inputs at all into conscious awareness, that is our attention is directed neither towards perceptual stimuli nor toward stimuli decoupled from the current situation.

In the following, a brief description of task-related interferences (TRI), external distractions (ED) and mind-blanking (MB) is presented, in order to explain further the distinction between MW and these other attentional states.

Task-related interferences (TRI)

These thoughts are formed by contents somehow related to the task that people are currently performing and they include thoughts related to features of the task (e.g., *I was wondering about the colour of the words in this book which I am reading*) or to the own performance (e.g., *I was thinking that I cannot remember what I have just read*) (e.g., Smallwood, Baracaia, et al., 2003). Evidence has been reported that MW and TRI behave differently during a task (e.g., Smallwood, Obonsawin, & Reid, 2003; Stawarczyk, Majerus, Maj, Van der Linden, & D’Argembeau, 2011) and they also differ at the physiological level (Unsworth & Robison, 2016). For example, in the

laboratory study by Stawarczyk, Majerus, Maj, et al. (2011), participants were asked to perform the Sustained Attention to Response Task (SART) while being intermittently interrupted by probes asking them to report about their current attentional state. The comparison between MW and TRI revealed that, although both attentional states were associated with decreased performance in blocks in which they were reported (decreased accuracy to the target and increased variability in RTs), the frequency of TRI was not influenced by the time on task and block duration, whereas the frequency of MW increased with both variables. Moreover, the number of TRI were not related to global performance at the task. In a few studies on the relations among adult aging, MW and TRI, older adults reported more TRI and less MW than did younger adults (McVay, Meier, Touron, & Kane, 2013; Zavagnin, Borella, & De Beni, 2014).

Globally, these results highlight the importance of distinguishing between the two different attentional states.

External distractions (ED)

External distractions include thoughts about both exteroceptive stimuli (e.g., “I was thinking about the twitter of the birds”) and interoceptive stimuli (e.g., “I was thinking that I am hungry”). These thoughts are unrelated to the task at hand but they are clearly related to the external environment or the personal current situation. MW, on the contrary, is unrelated both to the task at hand and to the current situation.

Indeed, as we will specifically discuss in Study 1 (see Chapter 2), MW might also be triggered by an external stimulus. However, the difference between ED and MW triggered by an external stimulus is that MW might start from an external stimulus but, afterwards, thoughts move away, drifting to other information (e.g., “While I was

listening to the birds, a memory from my childhood holidays spent in the countryside suddenly popped in my mind”) (see also Plimpton, Patel, & Kvavilashvili, 2015, for a discussion on this topic).

Studies that directly compared ED and MW (self-generated) have shown differences between the two attentional states, at both behavioural (e.g., Stawarczyk, Majerus, Catale, & D’Argembeau, 2014) and physiological level (Unsworth & Robison, 2016). For example, in a recent study on young adults and adolescents, Stawarczyk et al. (2014) found that adolescents experienced more frequent ED, but not more MW, than young adults during the Sustained Attention to Response Task (SART). Moreover, in young adults, after taking into account an attentional composite score (i.e., the combination of four measures of attentional abilities), only MW, but not ED, remained an independent predictor of task accuracy. These results show that MW cannot be entirely reduced to failures in the ability to maintain one's attention focused on task, and suggest that EDs rather than MW are due to attentional control failures.

Mind-blanking (MB)

To describe the experience of this state, we could say that our mind is nowhere and lacks any contents (e.g., *“My mind was blank. I realized this when I was just staring blankly at a sentence and not reading it. I think I only stared at the sentence for a few seconds before I snapped out of it”*, Ward & Wegner, 2013, p. 6).

Authors suggested that mind-blanking might not be part of the same attentional cycling system of MW (Ward & Wegner, 2013), and that it might correspond to the short periods of microsleep that occur during monotonous and long-lasting tasks since its association with high level of sleepiness (Stawarczyk & D’Argembeau, 2016). On

the other hand, it has been found that mind-blanking is increased in both clinical and subclinical ADHD patients (Van den Driessche et al., 2017) suggesting that it could reflect deficiencies in metacognition or mixed/confused states occurring at the transition between other states, such that many short episodes of MW occur but fail to be sustained.

1.2 Costs and benefits of mind-wandering

After defining this cognitive experience, we could ask why neurocognitive research should focus on MW. Besides the importance on the theoretical level for cognitive science, its investigation is also worthy because of the several costs and benefits of MW (Mooneyham & Schooler, 2013; Smallwood & Schooler, 2015). Indeed, it has been shown that MW is costly in educational contexts and learning environment, such that students who experience more MW episodes during lectures were found to have poorer memory for the lecture material (e.g., Lindquist & McLean, 2011; Risko, Anderson, Sarwal, Engelhardt, & Kingstone, 2012; Smallwood, Fishman, & Schooler, 2007; Szpunar, Khan, & Shacter, 2013). For example, Lindquist and McLean (2011) found that participants who reported high rates of MW were also more likely to self-report that they took fewer notes, and they performed more poorly on a later exam. Moreover, Risko et al. (2012) reported that students spent a relative portion of time (around 40%) experiencing MW during lectures and, in their study, an increase in MW over the course of a video lecture was found to be negatively correlated with retention of lecture material. In a recent investigation of students' self-reports of their everyday attention failures, Unsworth, McMillan, Brewer, and Spillers

(2012) found that most self-reported attentional lapses occurred either while studying or in class, and that these lapses predicted subsequent standardized test scores.

Besides these costs in educational contexts, studies also found that MW affects encoding of perceptual information (Smallwood et al., 2003), distorts interval timing discrimination (Terhune, Croucher, Marcusson-Clavertz, & Macdonald, 2017), or impairs face processing (Denkova, Brudner, Zayan, Dunn, & Jha, 2018). For example, Denkova et al. (2018) asked participants to perform a task in which they had to respond to upright faces (non-target stimuli) and withhold response to inverted faces (target stimuli) while being simultaneously probed about their mental experience (i.e., whether they were on-task or off-task). EEG data were also recorded throughout the task and the ERP analyses revealed an attenuated N170 (an ERP component consistently associated with face perception) response to non-target faces preceding reports of MW.

Costs of MW have been also documented in driving (Galera et al., 2012; He, Becic, Lee, & McCarley, 2011; Yanko & Spalek, 2014). For example, Yanko and Spalek's study (2014) examined the effects of MW on driving by using a driving simulator. Participants with driver's licence were seated in a simulated driving environment and were asked to follow a pace car along a route while abiding by all traffic laws. At randomly times throughout the session, participants were probed by an auditory prompt and should indicate whether they were on-task or mind wandering. Results from two experiments showed that MW reports, compared to on-task reports, were associated with longer response times to sudden events, higher velocity, and shorter headway distance. The authors suggested that their results differentiate MW from dual-tasking (e.g., talking on a cell phone while driving). Indeed, they reported that dual-tasking has been found to promote longer headway distance (e.g., Strayer &

Drews, 2004) and slower velocity (e.g., Chiang, Brooks, & Weir, 2004), whereas in their study, MW was associated with shorter headway distance and higher velocity.

In addition, Smallwood, Mrazek, and Schooler (2011) reported that the experience of MW may also have costs in medical contexts. Given that some aspects of a medical professional's work (i.e., fatigue, low mood, highly practiced task) facilitate the tendency to mind wander, this mental experience is likely to occur frequently in medical contexts, and these authors suggested that *"it has the potential to interfere with the information-gathering process upon which medical decisions are based"* (p. 1078).

Despite these negative effects, MW has also benefits in several important aspects. This mental experience can have a positive role in problem-solving abilities (Ruby, Smallwood, Sackur, & Singer, 2013), autobiographical planning and maintaining of goal-directed thoughts (Mooneyham & Schooler, 2013) as well as a sense of self-identity across time (Smallwood & Andrews-Hanna, 2013), since task-unrelated thoughts are highly self-relevant and engaged in mental time travel.

A relationship has also been found between MW and reduced delay discounting (i.e., a tendency to opt for the smaller immediate reward over a larger future reward) such that the amount of MW during an undemanding task has been found to be associated with a greater resistance to the temptation of an immediate reward in favour of receiving a larger economic reward in the future (Smallwood, Ruby, & Singer, 2013).

Moreover, in the context of a creative task, performing an undemanding task (characterized by a high amount of MW) during the incubation break improved the subsequent divergent thinking (i.e., the unusual uses task) performance (Baird et al., 2012; see also Leszczynski et al., 2017, for similar positive results on compound

remote associates performance). However, the results of the studies on the association between MW and creativity are still contradictory. For example, Hao, Wu, Runco, and Pina (2015) found that MW during creative idea generation was detrimental to divergent thinking (i.e., the alternative uses task). The results of a recent study by Agnoli, Vannucci, Pelagatti, and Corazza (2018) showed that trait-level measures of spontaneous and deliberate daily MW were differently associated to the originality score in a divergent thinking task (i.e., titles task), such that deliberate MW positively predicted creative performance, whereas spontaneous MW was negatively associated with that. These authors also suggested that research on the association between MW and creative thinking should perhaps take into account the different processes involved in creative thinking as well as different dimensions of MW.

Also, the experience of MW can have positive effects in the short term, that are likely to be related to the increase in arousal levels. It has been proposed a functionality of MW for attentional-cycling and relief from boredom (Mooneyham & Schooler, 2013): MW might allow us to switch between different trains of thought to maintain goal-appropriate behaviours for various goals simultaneously. In other words, during a boring or uninteresting task, our ability to mind-wander might be adaptive because it helps us to overcome the boredom and not to abandon the activity. The preliminary study of Baird, Smallwood, and Schooler (2010) gives initial support to this suggestion. They presented participants with a tedious task to perform for 45 minutes. The comparison between pre-task and post-task assessment of mood revealed that, although the mood was worse after the task, this drop was reduced the more MW people had. Perhaps MW can make us perceive the time as going faster than the actual time, resembling what happens with the time compression phenomenon in episodic memory retrieval (Jeunehomme & D'Argembeau, 2018).

A deeper understanding of MW and its underlying processes, therefore, might ultimately help to reduce the costs and boost the benefits of this ubiquitous mental experience.

1.3 Measurement of mind-wandering

Generally, triangulation between different methods is important to allow an explanation for cognitive processes that is not tied to a specific method. Therefore, it would be the optimal strategy also in the case of MW (Smallwood & Schooler, 2015). In order to study MW experiences, researchers can possibly use self-report measures associated with behavioural as well as physiological ones in the same study. In the next sections, each of these measures will be separately described. We will specifically focus on how MW has been investigated in the laboratory, even though it is also possible to study this experience in daily-life by using mainly self-reports (e.g., Kane et al., 2007; Kane et al., 2017; Killingsworth & Gilbert, 2010; Maillet et al., 2018; Song & Wang, 2012).

1.3.1 Behavioural paradigms

Generally, MW is studied in the laboratory by asking participants to perform sustained attention tasks, that are not too demanding and are easily automatized. In some of these tasks, behavioural measures, such as amount of errors (e.g., Smallwood et al., 2004) or reaction times (e.g., Bastian & Sackur, 2013; McVay & Kane 2009, 2012), can be also extracted by analysing the task performance, and these behavioural indexes have been associated to certain attentional states (i.e., MW periods) collected with self-report measures either during or after performing the tasks. A number of

different tasks have been used across studies. In the following, we will report some examples of the most used ones.

The Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) is a task used by a high percentage of studies (e.g., Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Jackson, Weinstein, & Balota, 2013; Seli, Risko, & Smilek, 2016; Shrimpton, McGann, & Riby, 2017; Smallwood et al., 2004; Stawarczyk & D'Argembeau, 2016; Stawarczyk et al., 2014; Stawarczyk, Majerus, Maj, et al., 2011). It is a go/no-go task in which participants are required to press a button in response to frequent non-target stimuli (e.g., digits from 1 to 9, except 3) and inhibit the response to infrequent target stimuli (e.g., the digit 3) (but see also the semantic and perceptual versions of the task; e.g., McVay & Kane, 2009; Smallwood, Riby, Heim, & Davies, 2006). Given the nature of this task, it is sensitive to the tendency to automate behaviour (Smallwood & Schooler, 2006). Accuracy of response and reaction times can be recorded as measures of performance on the task and studies have found a relationship between these behavioural markers and off-task states (e.g., McVay & Kane, 2009; Smallwood et al., 2004; Stawarczyk, Majerus, Maj, et al., 2011). For example, Smallwood et al. (2004) reported that task blocks in which task-unrelated thoughts occurred were associated with faster response times to non-target stimuli than blocks in which attention was on-task.

A task which has been developed more recently is the Metronome Response Task (MRT, Seli, Cheyne, & Smilek, 2013; see also Laflamme, Seli, & Smilek, 2018, for the visual version of the MRT). This task more simply presents participants with tones interspaced by a blank interval and requires them to respond synchronously with each tone, via a key press (Seli, Cheyne, et al., 2013). Similarly to the SART, the MRT allows for measuring behavioural measures. For example, Seli, Cheyne, et al. (2013)

measured the rhythmic response times (i.e., the temporal intervals between the metronome onset and the button responses) and used the variance of these response times computed in a definite number of trials before reports of on-task and MW. They found that MW was associated with more behavioural variability than on-task reports.

A third example of laboratory task used in MW studies is the Choice Reaction Times task (CRT; e.g., Smallwood, Brown, et al., 2011). It is an undemanding task in which participants are presented with a series of stimuli (e.g., digits) and are requested to make a choice only when certain target stimuli (e.g., digits characterised by a different font colour) appear on screen. When a target stimulus appears, participants have to press a button to decide whether the current digit is even or odd. This task is used for investigating MW in the laboratory because it can likely stimulate a high percentage of MW compared to more demanding tasks (Smallwood, Brown, et al., 2011; Smallwood, Nind, & O'Connor, 2009).

Finally, reading tasks (e.g., Frank, Nara, Zavagnin, Touron, & Kane, 2015; Franklin et al., 2013; Franklin, Smallwood, & Schooler, 2011; Smallwood et al., 2009; Uzzaman & Joordens, 2011) are also used to investigate MW in the laboratory and they are especially important for examining the costs of MW associated with reading behaviour (e.g., Franklin et al., 2011; Reichle, Reineberg, & Schooler, 2010; Schooler, Reichle, & Halpern, 2004). Typically, in these task participants are asked to read some text passaged and afterwards their text comprehension is evaluated. Moreover, the experience of MW during the reading is also assessed. By using this procedure, studies have found that MW was associated with worse performance in subsequent comprehension tests (e.g., Franklin et al., 2011, 2013).

1.3.2 Self-report sampling methods

To collect self-reports about the contents of one's mind, thought-sampling methods are employed. Three types of sampling methods are commonly used: probe-caught, self-caught and retrospective method.

Probe-caught method

It is the method used by the vast majority of studies to sample MW. People are intermittently interrupted during a task and are asked (probed) about their experience immediately before the probe. Thought-probes can be presented randomly or pseudo-randomly. Rarely, they can be also presented at a particular timing based on changes in some parameters. For example, based on known associations between changes in task performance and MW states, researchers can program online the appearance of thought-probes according to the current performance of participants on the task (e.g., Franklin et al., 2011).

As for the time interval between two consecutive thought-probes, studies found that larger gaps between two consecutive probes are associated with greater reports of off-task thoughts (e.g., Seli, Carriere, Levene, & Smilek, 2013). According to Seli, Carriere, Levene, et al. (2013), this could be explained by two possibilities: probe rates might affect either the experience of MW or the likelihood of reporting MW. These authors, however, argued for the second hypothesis on the basis of their findings. In their study, they found no relationship between the mean time between thought-probes and the variance of response times in the MRT. Since previous studies have, instead, found that variance of response times index MW experiences (e.g., Seli, Cheyne, et al., 2013; see section 1.3.1 of the present chapter), the authors suggested that the probe

rates might affect the likelihood of reporting MW without modifying the actual incidence of MW (Seli, Carriere, Levene, et al., 2013).

When the probe appears, participants can be provided with different questions and different modality of response (see Weinstein, 2018). For example, some studies asked participants to simply indicate whether they were on-task or off-task (considered to reflect MW experiences) (e.g., Forster & Lavie, 2009; Foulsham, Farley, & Kingstone, 2013; Mason et al., 2007; Yanko & Spalek, 2014); others asked participants to choose an option between more precise categories about different attentional states (e.g., on-task, MW, external distraction, task-related thoughts, Stawarczyk et al., 2014; Stawarczyk, Majerus, Maj, et al., 2011) or about possible contents of thoughts (e.g., daydreams, personal worries or everyday things, Frank et al., 2015); others presented participants with a Likert Konishi scale ranging from “completely on-task” to “completely off-task” or vice versa (e.g., Christoff et al., 2009; Konishi, Brown, Battaglini, & Smallwood, 2017; Mittner et al., 2014).

However, MW episodes can be also recorded by using experimenter-classification (i.e., having participants report all of their possible thoughts verbatim and having judges classify thought-reports) instead of self-classification (i.e., having participants choose if they had MW or not) (Smallwood & Schooler, 2006). It means that open-ended questions about one’s experience can be also employed instead of requesting participants to classify their thoughts into distinct categories proposed by researchers (e.g., on-task vs. off-task). Thus, open-ended questions ask participants to describe the contents of their mind by their own words and, afterwards, these contents are classified by judges. By asking participants to describe their attentional state, it is possible not to inform them about the attentional states categories before starting a certain task. It is especially important in psychological studies where participants’

beliefs regarding the purpose of an experiment should be controlled despite the fact that the knowledge of the specific phenomenon is necessary to permit the self-report investigation (Nisbett & Wilson, 1977).

Moreover, it has been proposed that sometimes participants have difficulty classifying their mental contents into the fixed categories provided (Seli, Jonker, Cheyne, Cortes, & Smilek, 2015). It may be that, on certain occasions, it is not clear to participants whether they are completely focused on a task or not but they have not the possibility to choose an intermediate state. For example, Seli, Jonker, et al. (2015) asked participants to perform the MRT while presenting them with thought-probes asking them to indicate whether they were on-task or in a MW state (i.e., a dichotomous response). Participants were also required to indicate their confidence in the report they provided on a 5-point scale. A behavioural marker of MW (i.e., variability in participants' response times) was also computed. The findings showed that participants reported various level of confidence ratings and that the association between MW reported and responses' variability was moderated by participants' level of confidence: the higher the level of confidence reported, the stronger the association of MW and responses' variability. This suggests that, by using thought-probes with a simple dichotomous response modality, participants do not always find easy to classify their answers (but see Meier, 2018).

Finally, it has been reported (Weinstein, 2018; see also Weinstein, De Lima, & van der Zee, 2018) that differences in the specific question asked to participants at the moment of thought-probe and in the response modality may influence the actual report of the experience of MW. Thus, open-ended questions (such as "*What were you thinking just before?*") may overcome problems related to the effects that response modality or formulation of the questions ("*Were you on-task?*" vs. "*Where you off-*

task?”) may have on MW reports (Weinstein, 2018). They may be also useful for studying the heterogeneity of thought-contents (Seli et al., 2018; Smallwood & Andrews-Hanna, 2013) without providing selected categories prearranged by the researcher that force the individual to put her/his thought into one of them, losing the peculiarity of its content. Collecting and analysing large samples of open-ended reports by using text-mining techniques would contribute, for example, to revealing unknown features of MW (Seli et al., 2018).

Self-caught method

This method requires participants to self-report, by pressing a button, when they realise that their attention is disengaged from the task. In other words, they have to stop any specific task they are doing every time they catch their mind not to be on-task. Specific instructions are given to participants to inform them to stop the task for reporting MW states or off-task generally (e.g., Jackson et al., 2013; Kopp, D’Mello, & Mills, 2015; Mrazek, Smallwood, & Schooler, 2012). After participants stop the task, they may be asked to resume the ongoing task (e.g., Cunningham, Scerbo, & Freeman, 2000) or they may be required to answer few other questions about their specific mental state (e.g., Drescher, Van den Bussche, & Desender, 2018; Jackson et al., 2013). The self-caught approach is different from the previous one in the way that participants have to monitor their thoughts in order to report when their attention is not focused on task.

Retrospective method

Sampling MW retrospectively means that MW experiences are collected at the end of a task via questionnaires. On the one hand, differently from the previous

methods, this approach preserves the natural time-course of the task (Smallwood et al., 2012) and this is especially important for obtaining certain objective measures simultaneously, such as fMRI (e.g., Barron, Riby, Greer, & Smallwood, 2011). On the other hand, the retrospective measurement has several intrinsic limitations, such as the risk of forgetting some material or being confounded with individual differences (Smallwood & Schooler, 2015).

The most used retrospective questionnaire is the Thinking Component of the Dundee Stress State Questionnaire (Matthews et al., 1999). Specifically, it is composed of 16 items that allow the measurement of the frequency of both task-unrelated thoughts (8 items; e.g., *“I thought about an event in the recent past”*) and task-related interferences (8 items; e.g., *“I thought about how poorly I performed”*). Participants rate their answers on a 5-point scale (ranging from 1 = never, to 5 = very often) and subscale averages (both task-unrelated thoughts and task-related interferences) are computed. The task-unrelated thoughts scale is used as measure for MW frequency.

1.3.3 Psychophysiological measures

In addition to the measures described above, psychophysiological and neurocognitive measures have been also collected in MW investigations. Some examples are: ocular measures (such as eye-movements, blinks, pupil activity; e.g., Foulsham et al., 2013; Smallwood et al., 2012; Smilek, Carriere, & Cheyne, 2010), EEG (Barron et al., 2011; Kam et al., 2011; Smallwood, Beach, Schooler, & Handy, 2008; Xu, Friedman, & Metcalfe, 2018), fMRI (Christoff et al., 2009; Mason et al., 2007), heart-rate response and skin conductance (Ottaviani & Couyoumdjian, 2013;

Smallwood et al., 2004) or spontaneous movements and fidgeting (Carriere, Seli, & Smilek, 2013; Seli, Carriere, Thomson, et al., 2013).

For example, the combination of the eye-movements recording with self-report measures has been important in the context of reading, in that by collecting MW reports while participants read passages of text and their eye-movements were recorded, it has been found that MW reports were associated with fewer and longer fixations, and less responsive ocular activity to linguistic features (e.g., word frequency effect) (e.g., Foulsham et al., 2013; Frank et al., 2015; Reichle et al., 2010; Smilek et al., 2010). Moreover, Smilek and colleagues (2010) also found that blink rate was higher when participants were in a MW state than when they were in an on-task state.

Moreover, the coupling between self-reports and neurocognitive measures has been crucial for revealing the main brain areas associated with MW (e.g., Christoff et al., 2009; see section 1.6 of the present chapter for further discussion). Finally, the association between physiological measures with self-reports, and behavioural ones has also been significant for providing validity to the self-report procedures themselves (Smallwood & Schooler, 2006).

1.4 Contents and phenomenology of mind-wandering

Studies on MW have consistently shown that it encompasses a considerable heterogeneity of experiences (Seli et al., 2018; Smallwood & Andrews-Hanna, 2013; Wang et al., 2018) and it can vary on a number of dimensions (e.g., Seli, Ralph, Risko, et al., 2017). In this section we will focus on three main dimensions by which MW experiences can be differentiated, namely the temporal focus (i.e., whether the content

of MW is related to the past, the present or the future), the meta-awareness (i.e., whether an individual is aware or not that she/he was wandering) and the dimension of intentionality/spontaneity of thoughts (i.e., whether an individual is engaged in MW with conscious intention).

Temporal focus

MW episodes may have contents related to past episodes, present circumstances, future plans or even atemporal considerations (“timeless MW”, Jackson et al., 2013). The temporal focus of mental contents is assessed with a specific question presented during the task whenever participants report being in a MW state (e.g., Smallwood et al., 2009) or in a questionnaire after the completion of the task (e.g., Stawarczyk, Majerus, Maj, et al., 2011). Many studies reported a bias towards the future in MW contents both in the laboratory and in daily-life (e.g., Baird, Smallwood, & Schooler, 2011; Ruby et al., 2013; Song & Wang, 2012; Stawarczyk, Majerus, Maj, et al., 2011) and this characteristic is interpreted as a reflection of the functional value of MW in enabling the anticipation and planning of relevant future goals (e.g., Smallwood & Andrews-Hanna, 2013). However, it has been also found that a number of variables may affect the temporal focus of thoughts. These factors include individual’s characteristics, such as mood (e.g., Poerio, Totterdell, & Miles, 2013; Smallwood & O’Connor, 2011), working memory capacity (Baird et al., 2011), task interest and experience with a topic (Smallwood et al., 2009) as well as context’s features, such as task demands (Smallwood et al., 2009), self-reflection prior to perform a task (Stawarczyk, Majerus, Maj, et al., 2011), illusion of self-motion (Miles, Karpinska, Lumsden, & Macrae, 2010) or visuo-spatial processing (Vannucci, Pelagatti, Chiorri, & Brugger, 2018).

In particular, as for the individual's characteristics, these studies found that negative mood was associated with retrospective MW, both when inducing negative mood and measuring MW in laboratory (Smallwood & O'Connor, 2011) and when measuring the mood and the temporal focus of MW with experience-sampling questions in daily-life (Poerio et al., 2013). Variables affecting the temporal focus of thoughts were also found in the context of reading (Smallwood et al., 2009, Experiment 2), such that individuals with low interest and high experience with the subject matter showed a retrospective bias in MW collected during the reading task, whereas disinterested individuals with low experience in the subject matter tended to prospect.

As for the context's features affecting the temporal focus of MW, Smallwood et al. (2009) showed that higher task demands make the prospective bias disappear. Indeed, they found that when participants performed an undemanding task (i.e., both CRT and Passive Viewing), they were more inclined to report future-related thoughts, whereas when they performed a task which requested continuous monitoring (i.e., Working Memory Task), this prospective bias was absent (Smallwood et al., 2009). On the contrary, a period of self-reflection (i.e., a writing task in which participants described one or two of their most important current personal projects and the steps that should be taken for reaching them) before performing a sustained attention task was found to stimulate future-related MW during the task (Stawarczyk, Majerus, Maj, et al., 2011). Specifically, in this study, the condition of self-reflection was realised by asking participants to perform a writing task, in which they had to describe one or two of their most important current personal projects and the steps that should be taken for reaching them. This condition was, next, compared with a condition of mental navigation, in which participants had to describe the itinerary from the building where

the experiment took place to a well-known location. From the comparison between these two conditions, an increase in future-oriented MW emerged in the condition of self-reflection (Stawarczyk, Majerus, Maj, et al., 2011). Finally, another line of research investigating the influence of context's features is the one demonstrating how the manipulation of spatial information (apparent movement and visuo-spatial processing) might alter the temporal focus of thoughts, such that the induction of backward vection (i.e., illusion of self-motion) or leftward orienting attention (by means of visual arrows) increased the proportion of past-related MW compared to future-related MW, whereas a reverse pattern was found with the induction of forward vection or rightward orienting attention (Miles et al., 2010; Vannucci et al., 2018).

Meta-awareness

A second dimension by which MW episodes can be differentiated is the awareness of thoughts. The final stage of a MW state is the moment that people notice the current contents of their thoughts and they realise that these thoughts were unrelated to the activity that they were performing (Schooler, 2002). However, people do not always notice that their mind is wandering, and sometimes MW episodes occur without people realising consciously that their mind is wandering. Indeed, meta-awareness is considered as an intermittent process by which people only periodically notice the contents of their mind (Schooler et al., 2011). Two main methodologies are used to measure these episodes which are referred to as "unaware MW". The first one consists in the combination of self-caught and probe-caught sampling methods throughout the same task (Schooler et al., 2011; Smallwood & Schooler, 2015). Self-caught methods require participants to press a button to report when their attention is not focused on the task and allow, therefore, to catch those MW episodes which are consciously

noticed by participants. Probe-caught methods, on the contrary, present participants with probe asking them to report the state of their attention at that time and allow to catch both aware and possibly unaware MW episodes. When they are combined in the same task, whether thought-probes catch MW episodes before people self-caught them, it is considered as an index of unaware MW. Thus, by comparing probe-caught reports with self-caught reports it is possible to measure the relative amount of aware and unaware MW. A number of studies employed this approach for investigating the awareness of thoughts in different circumstances (e.g., Baird, Smallwood, Fishman, Mrazek, & Schooler, 2013; Sayette, Reichle, & Schooler, 2009; Sayette, Schooler, & Reichle, 2010; Schooler et al., 2004) and the same procedure is also used for other spontaneous thought processes (i.e., trauma intrusions, Takarangi, Strange, & Lindsay, 2014). For example, Sayette and colleagues (2009) used this methodology to investigate the role of alcohol intoxication on MW. In their study, social drinkers performed a reading task after consuming a moderate dose of alcohol or a placebo beverage. The combination of thought-probes and self-interruptions to report MW throughout the task revealed that alcohol increased the likelihood of probe-caught MW but unaffected the likelihood of self-caught reports. These results suggest that alcohol increased MW while simultaneously reducing the likelihood of noticing it. Similar findings were also shown with cigarette craving (Sayette et al., 2010). The combination between self-caught and probe-caught methods also contributed to reveal that aware MW episodes (i.e., those self-caught MW episodes) were reported to be more verbal (i.e., in the form of inner speech) compared to probe-caught MW episodes, which are considered to include less aware thoughts (Bastian et al., 2017).

The second approach for measuring awareness of MW consists in a self-classification/judgment of aware and unaware states (Schooler et al., 2011; Smallwood

& Schooler, 2015). Participants are presented with thought-probes asking about the focus of their attention and whether they were aware that they were experiencing thoughts unrelated to the task. The question about awareness may be asked by using a Likert scale, ranging from completely aware to completely unaware (Christoff et al., 2009) or by using a dichotomous choice between aware MW (known as tune-outs) and unaware MW (known as zone-outs) (e.g., Smallwood, McSpadden, & Schooler, 2007, 2008). By using this approach, it has been shown that unaware MW is associated with poorer task performance (Smallwood, McSpadden, et al., 2007, 2008), greater disruptions of everyday tasks (McVay, Kane, & Kwapil, 2009), increases in the risk of an accident while driving a car (Cowley, 2013) and higher level of depression (Deng, Li, & Tang, 2014). For example, Smallwood, McSpadden, et al. (2008) asked participants to read a detective novel and to try solving the crime. Tune-outs and zone-outs were collected throughout the task. Results showed that the occurrence of zone-outs were more disruptive for solving the crime.

Intentionality

The other dimension that has been increasingly becoming important in the investigation of MW is intentionality of thoughts. An early distinction between controlled and uncontrolled shifts of attention (Grodsky & Giambra, 1990; Shaw & Giambra, 1993) proposed that voluntary shifts of attention away from a task seem to involve higher orders of control in information processing, to be motivationally determined and more benign compared to involuntary uncontrolled shifts. Although most research on MW has not considered this distinction between spontaneous and deliberate experiences of MW, several studies have recently shown that they are indeed dissociable cognitive experiences (e.g., Agnoli et al., 2018; Carriere et al.,

2013; Seli, Risko, Smilek, & Schacter, 2016; Vannucci & Chiorri, 2018). To investigate separately these two forms online in the laboratory, a variant of the thought-probe method is commonly used, namely participants are presented with probes asking them to indicate whether their mind was spontaneously or deliberately wandering. Studies found that participants also report some intentional MW episodes during laboratory tasks (e.g., Forster & Lavie, 2009; Seli, Cheyne, Xu, Purdon, & Smilek, 2015; Seli, Risko, & Smilek, 2016) and that these deliberate MW increases with lower motivation in performing the task (Seli, Cheyne, et al., 2015). Moreover, deliberate and spontaneous forms seem to be differently affected by certain experimental manipulations (Phillips, Mills, D’Mello, & Risko, 2016; Seli, Risko, & Smilek, 2016) and to reflect different contents (Seli, Ralph, Konishi, Smilek, & Schacter, 2017).

However, an important contribution to understanding the two kinds of MW has been provided by research on individual differences in MW. Two self-report scales were developed to assess deliberate and spontaneous forms of everyday MW (Mind-Wandering: Deliberate and Mind-Wandering: Spontaneous scales, Carriere et al., 2013; see also Chiorri & Vannucci, 2018). These are four-item self-report scales that are scored using a 7-point Likert scale. Individuals have to select the answer that most accurately reflects their everyday MW, and higher scores reflect a greater tendency to engage in MW deliberately or spontaneously. By using these scales, studies have shown that these two forms are associated with different psychological dimensions (e.g., facets of mindfulness in Seli, Carriere, & Smilek, 2015; attention-deficit/hyperactivity disorder symptomatology in Seli, Smallwood, Cheyne, & Smilek, 2015; obsessive-compulsive disorder symptomatology in Seli, Risko, Purdon, & Smilek, 2017; fidgeting in Carriere et al., 2013; creativity in Agnoli et al., 2018; self-reflection and self-rumination in Vannucci & Chiorri, 2018) and cortical thickness

(Golchert et al., 2017). For example, Carriere and colleagues (2013) showed that self-report measures of fidgeting behaviour were predicted by trait-level measures of spontaneous MW and not deliberate MW. By using the same trait-level measures, Agnoli and colleagues (2018) found that deliberate MW positively predicted originality scores in a divergent thinking task (i.e., Titles task), whereas spontaneous MW was negatively associated with the same dimension.

Given the substantial differences between spontaneous and intentional MW, collapsing the two types of MW together might be detrimental for research. Recent studies investigated the association between the two dimensions of awareness and intentionality of MW episodes (e.g., Seli, Ralph, Risko, et al., 2017). Spontaneous MW episodes should lack of conscious initiation; thus, individuals should not be meta-cognitively aware that their mind is starting to wander. Once these episodes are detected, people might experience surprise or a feeling of a lack of control. However, these MW episodes started spontaneously may be possibly continued intentionally when individuals become aware of them. By contrast, deliberate MW episodes are necessarily associated with a conscious intention to initiate wandering; still, after the initiation, individuals may become so absorbed in their flow of thoughts that they eventually lose awareness of they thoughts. Seli, Ralph, Risko, et al. (2017) performed a study in order to explore the potential overlap between these two dimensions. In the study, awareness of thoughts was measured by using the combination between self-caught and probe-caught methods, while intentionality was asked by using a dichotomous modality (intentional task-unrelated thoughts vs. unintentional task-unrelated thoughts). Participants performed a sustained attention task (the MRT) and were asked to self-catch any MW episode throughout the task and indicate whether this thought was intentional or spontaneous. They were also presented with thought-

probes asking about their preceding attentional state and the relative intentionality. Self-caught reports of MW were considered as aware MW episodes, whereas probe-caught MW episodes were considered as unaware MW episodes. The authors observed that if meta-awareness and intentionality are redundant dimensions, we should not expect that deliberate MW episodes are associated with no meta-awareness of its occurrence and that unintentional MW episodes are associated with meta-awareness. On the contrary, their findings showed that participants reported a significant (non-zero) rate of intentional MW to thought-probes (i.e., considered as unaware) (12%) and a significant (non-zero) rate of spontaneous MW to self-caught (i.e., considered as aware) (74%). Thus, these authors suggested that intentionality and meta-awareness may overlap only at the initial point of a MW episode and, subsequently, they dynamically fluctuate as the episode continues.

1.5 Psychological bases of mind-wandering: four hypotheses

Over the last years, increasing attention has been paid to the investigation of the psychological bases of MW: why does our mind wander? Why does it wander so much? Following Smallwood (2013), we can identify four different hypotheses on the cognitive and motivation bases of mind-wandering. In the following, these theoretical accounts are briefly reviewed.

1.5.1 The executive failure hypothesis

According to the executive failure hypothesis (McVay & Kane, 2010), MW experiences reflect temporary failures in executive maintenance of goal-relevant information. MW is viewed as a form of distraction which would be prevented by an

executive-control system. This control system is known to use both a proactive component (i.e., when executive-control is proactively initiated and maintained in response to task demands) and a reactive component (i.e., when executive-control is reactively initiated to suppress the interference of task-unrelated thoughts as they are started and automatically generated). In this view the internal train of thoughts of MW is activated in a resource-free manner, due to temporary executive-control failures. Some empirical support to this hypothesis has been provided by studies on individual differences in executive functions and MW. Specifically, these studies found negative correlations between off-task thought and executive control abilities during complex span tasks, sustained attention tasks, and reading (McVay & Kane, 2009, 2012; Unsworth & McMillan, 2013). However, this hypothesis does not explain the positive correlation between working memory capacity and task-unrelated self-generated thoughts in undemanding conditions (Levinson, Smallwood, & Davidson, 2012; Rummel & Boywitt, 2014).

In contrast with the executive-failure account, Smallwood (2010) proposed the *global availability hypothesis* (see also the executive-control hypothesis, by Smallwood & Schooler, 2006), which suggests that MW experiences require executive resources instead. As these experiences reach the consciousness, they are globally available to the system and consume temporarily information-processing resources. Thus, instead of preventing MW, executive-resources would enable these task-unrelated thoughts.

According to this account, MW occurs when personal relevant information become available to the system, obtain privileged access to the global workspace (global workspace theory; Baars, 1997) and, consequently, necessitate cognitive resources. Since the global workspace availability is limited, MW compete for the

same resources as task-related information. Strong empirical support for this claim comes from the studies on the negative effects of cognitive load of the task (i.e., perceptual load in Forster & Lavie, 2009; Poh, Chong, & Chee, 2016; working memory load in Rummel & Boywitt, 2014; Smallwood et al., 2009) on the frequency of MW: MW decreases when the attentional and working-memory demands of the task increase. Moreover, when MW does occur during tasks relying on working memory, performance decline (e.g., Cheyne, Solman, Carriere, & Smilek, 2009).

Recently, Smallwood (2013) has tried to reconcile the two contrasting hypotheses (executive-failure and global availability) proposing that the two accounts explain different aspects/moments of the dynamics of MW. Specifically, the executive-failure hypothesis might explain MW occurrence whereas the global availability hypothesis might explain the maintenance of MW over time. The process-occurrence framework proposed by Smallwood (2013) is further described later in this chapter.

1.5.2 The decoupling hypothesis

When MW occurs, attention becomes divided between external and internal information. The decoupling hypothesis suggests that, during MW, processing of perceptual stimuli is attenuated in favour of internal thoughts (Schooler et al., 2011; Smallwood & Schooler, 2006).

Importantly, attention becomes decoupled from the external information only once internal thoughts are already initiated and are turned into the target of attention (Smallwood, 2013). Although perceptual decoupling would be necessary for a coherent internal train of thoughts to continue, it might take place for two possibilities: (i) it might be simply a consequence of limited attentional resources that have stopped to process external information (resource competition account), or (ii) it might play a

specific functional role in inhibiting the processing of information unrelated to the internal thoughts in order to facilitate a focus on personal information (maintenance account) (Smallwood & Schooler, 2015). Either way, it is clear that during MW there should be reduced attention to the external inputs and the representations of environmental stimuli should be superficial (Smallwood & Schooler, 2006).

Evidence for perceptual decoupling comes from behavioural investigations showing decreased accuracy and increased RT variability during sustained attention tasks (McVay & Kane, 2009; Seli, Cheyne, et al., 2013) and impaired text comprehension during reading tasks (e.g., Schooler et al., 2004). For example, in the context of reading, it has been found that periods of MW during the reading of text-passages were associated with poorer text comprehension compared to period of on-task focus, demonstrating that MW experienced during the reading affected participants' ability to comprehend the text (Schooler et al., 2004).

Moreover, attenuated neural processing of external stimuli during MW has been primarily investigated using ERPs (e.g., Kam et al., 2011; Kam, Nagamatsu, & Handy, 2014; Smallwood, Beach, et al., 2008). Using the SART, Smallwood, Beach, et al. (2008) found attenuated P3 to nontarget stimuli immediately preceding both commission errors and subjective reports of MW. However, some subsequent studies did not consistently find a significant reduction in the P3 as a function of MW reports (Kam et al., 2011, Experiments 2 and 3; Kam et al., 2016). Inconsistencies were also reported for early sensory components, such as the P1. Smallwood, Beach, et al. (2008) and Denkova et al. (2018) failed to observe attenuation in the P1 during MW, whereas Kam et al. (2011) found this pattern.

As recently suggested by Denkova and colleagues (2018), possible explanations of these contradictory findings may lie in methodological differences related to the

task (and its cognitive load) and the task stimuli: the load of the task and the complexity of the task stimuli might influence how the external information is processed during MW.

1.5.3 The current concerns hypothesis

This hypothesis originates from the fact that (i) individuals are committed to goals and wishes which extend the here and now, referred to as current concerns¹ (e.g., Klinger, 2013; Klinger, Gregoire, & Barta, 1973), and (ii) the mental life is driven by the most salient experiences. According to the current concerns hypothesis, thus, MW experiences occur when external information is poor/uninteresting and personal internal information has greater salience and relevance, capturing the focus of the individual's attention (Klinger, 2013; Smallwood, 2013). In this view, MW experiences would occur more frequently when internal information has higher value than external perceptual information. In addition, the individual's commitment to current concerns (both positive and negative) sensitise the individual to respond to cues associated with her/his goals and the cues are automatically processed with priority (irrespective of whether noticing these cues is conscious or not). The thematic content of thoughts would be determined by individual's goals as well (Klinger, 2013).

Consistent with this hypothesis, Klinger (1978) demonstrated the effects of personal goals on attention and thought content. He assessed participants' concerns and, a few days later, asked them to listen and pay attention to two distinct but similar audiotaped narratives which were played simultaneously, one narrative to each ear. At

¹ More specifically, according to Klinger (2009, 2013), goal pursuits have beginnings and ends. The beginning is the commitment to that specific goal pursuit, whereas the end is the achievement of the goal. Between these two states, there is a latent state which is a current concern.

some point on this tape, a few words going to one ear had been modified in order to relate to participant's own goals, whereas a few words going, simultaneously, to the other ear had been modified in order to relate to someone else's goals. During the listening, participants could choose, by using a toggle switch, which narrative they paid attention to. Ten seconds after the end of each modified passage, the tape stopped and participants had to report what they were thinking about and the last content that they could recall from the tape. Results showed that participants spent more time listening to sections associated with their own goals than to sections associated with other participants' goals. They also recalled those passages about twice compared to non-concern related passages, and had thought content that was related to concern-related passages about twice compared to the opposite passages (Klinger, 1978).

Further support to this view comes from more recent studies which have shown that thinking and writing an essay about personal current concerns increase MW (and especially future-oriented MW) during a subsequent task (Stawarczyk, Majerus, Maj, et al., 2011) and that also simply listing immediate personal future goals promotes MW (but not TRI) during a subsequent reading task (Kopp et al., 2015). Other authors found that embedding cues related to personal current concerns into the SART increases the frequency of participants' reported MW (McVay & Kane, 2013; see Chapter 2 for further discussion on this study about the relation between MW and external cues).

1.5.4 The meta-awareness hypothesis

A factor that influences the likelihood of MW occurrence is the meta-awareness (Smallwood, 2013). The capacity to re-represent the current contents of consciousness would allow the identification of thoughts that diverge from the actual task-related

goal. As we already reported previously, people are not always aware of their mind's contents, they are only intermittently aware of it (Schooler et al., 2011).

According to this hypothesis, a breakdown in meta-awareness of mental contents causes the decoupling of the attention from perception, facilitating MW experiences (Smallwood & Schooler, 2006). Consequently, authors have proposed that restoring meta-awareness could help the individual to control her/his frequency of MW (Schooler et al., 2011). For example, mindfulness training could have beneficial effects on MW related disruptions, as this practice encourages individuals to routinely notice the current contents of their mind. Indeed, it has been found that an 8-min. mindful breathing exercise reduced behavioural indices of MW during a sustained attention task performed after the mindful breathing exercise (Mrazek et al., 2012) and that a 2-weeks mindfulness training program decreased MW during both reading and working memory performance (Mrazek, Franklin, Phillips, Baird, & Schooler, 2013).

1.6 Neural bases of mind-wandering

Over the last decade, a body of research has proposed a heterogeneous brain network, referred to as Default Mode Network (DMN), as the principal brain system supporting MW and spontaneous thought processes (e.g., Andrews-Hanna, Reidler, Huang, & Buckner, 2010; Andrews-Hanna, Smallwood, & Spreng, 2014; Buckner, Andrews-Hanna, & Schacter, 2008; Christoff et al., 2009, 2016; Fox, Spreng, Ellamil, Andrews-Hanna, & Christoff, 2015; Mason et al., 2007). The DMN was originally identified as a set of brain regions consistently deactivated across externally oriented tasks (Raichle et al., 2001; Shulman et al., 1997) or by varying task-related variables (such as stimulus presentation rate, target discriminability or short term memory load)

(McKiernan, Kaufman, Kucera-Thompson, & Binder, 2003), and activated during passive experimental control tasks (Mazoyer et al., 2001), such that it was defined as “task-negative network” (Andrews-Hanna et al., 2014). Other evidence showed that it is recruited in tasks requiring participants to retrieve episodic, autobiographical, or semantic information, imagine novel scenes, think about future scenarios or appraise emotional information (e.g., Buckner et al., 2008; Spreng, Mar, & Kim, 2009); all of them are activities that need active self-generation of mental contents in order to complete the task-goal (Andrews-Hanna et al., 2014).

To illustrate the areas comprised into this network, we can fractionate it in different sub-systems, each of which arguably has a distinct functional contribution to MW (Andrews-Hanna et al., 2014; Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010; Christoff et al., 2016; Smallwood et al., 2016). The first sub-system, considered to be the core of the network, is composed of the anterior part of the medial prefrontal cortex (amPFC) and the posterior cingulate cortex (PCC). The second sub-system is centred around the medial temporal lobe (MTL) and includes the hippocampal formation, the parahippocampal cortex and cortical projections (such as the retrosplenial cortex and the ventromedial prefrontal cortex - vmPFC). The third sub-system includes the dorsomedial prefrontal cortex (dmPFC), the lateral temporal cortex, the temporopolar cortex (TPC), parts of the inferior frontal gyrus (IFG) and the temporoparietal junction. Each sub-system seems to also include a different part of the inferior parietal lobule (IPL) (Andrews-Hanna et al., 2014; Christoff et al., 2016). These DMN areas are generally associated with different functions: regions within the core sub-system are associated with self-referential processing, simulation of social interaction and making decisions concerning other people valued (e.g., Andrews-Hanna et al., 2014; Spreng et al., 2009); regions in the MTL are notoriously implicated

in constructive simulations, both episodic/contextual retrieval and simulation of the future (e.g., Christoff et al., 2016; Schacter et al., 2012); regions within the dmPFC are associated with social cognitive processes, affective and conceptual processing, mental state inference and metacognition (Andrews-Hanna et al., 2014; Andrews-Hanna, Reidler, Sepulcre, et al., 2010).

The link between DMN and the experience of MW comes mainly from research employing imaging techniques combined with self-reports of MW or task-unrelated thoughts (reflecting MW). Such studies initially demonstrated that as task-unrelated thoughts increased during tasks requiring low external demands, the recruitment of DMN areas increased as well (e.g., Mason et al., 2007; McGuire, Paulesu, Frackowiak, & Frith, 1996; McKiernan, D'Angelo, Kaufman, & Binder, 2006). For example, in the study by Mason and colleagues (2007), participants were firstly asked to perform different blocks (i.e., baseline, practised, or novel) of verbal and visuo-spatial working-memory tasks, in order to explore which task block was associated with a higher incidence of task-unrelated thoughts. Afterwards, participants underwent functional imaging recording while performing the same task without thought-sampling. Results showed that areas within the DMN were strongly recruited during practised blocks (i.e., blocks previously associated with high-incidence thoughts periods) compared to novel blocks (i.e., blocks associated with low-incidence thoughts periods). Moreover, some participants were also asked to complete the Daydream Frequency scale of the Imaginal Process Inventory and their standardized scores on this scale were positively correlated with the change in BOLD signal observed in DMN regions when participants performed practised blocks compared to novel blocks.

Further neurocognitive studies (e.g., Bertossi, Peccenini, Solmi, Avenanti, & Ciaramelli, 2017; Christoff et al., 2009; Smallwood et al., 2016; Stawarczyk, Majerus,

Maquet, & D'Argembeau, 2011) replicated these findings by using more accurate experience-sampling methods. Stawarczyk, Majerus, Maquet, et al. (2011), for example, asked participants to perform the SART with thought-probes asking them to classify thoughts into 4 different categories, associated with different dimensions of task-relatedness and stimulus-dependence of thought: on-task, external distractions, task-related thoughts, MW. fMRI data were obtained while participants performed the task. Analysis of the fMRI data showed that, even though external distractions and task-related thoughts were also associated with higher DMN activity compared to on-task reports, MW reports were associated with the highest degree of DMN activity.

Importantly, the involvement of specific parts of DMN for MW has been also demonstrated in patients with vmPFC lesions (Bertossi & Ciaramelli, 2016) and by employing transcranial direct current stimulation (tDCS) for establishing a causal relationship (Bertossi et al., 2017). Bertossi and colleagues (2017) specifically asked participants to perform the CRT with thought-probes two times and applied cathodal tDCS over the mPFC, a (control) site in the occipital cortex, or sham tDCS before the second task. They found that the stimulation over the mPFC decreased the propensity to mind wander, even though this effect was found only in men (i.e., not in woman; Bertossi et al., 2017).

Moreover, a reduction in the frequency of MW has been found in people at earliest stages of Alzheimer's disease (Gyurkovics, Balota, & Jackson, 2018) and people who are at increased risk of developing Alzheimer's disease, such as individuals with amnesic Mild Cognitive Impairment (Niedźwieńska & Kvavilashvili, 2018). As reported by Niedźwieńska and Kvavilashvili (2018), the beta-amyloid depositions accumulating in the hubs of the DMN (e.g., the PCC) is one of the main pathologies

of Alzheimer's disease. Therefore, the fact that MW is significantly reduced in these people, is a further clear evidence of the role of DMN in MW.

Besides the involvement of DMN, other brain areas, such as the lateral PFC, seem to be involved in task-unrelated thoughts as well (Christoff et al., 2009; Dumontheil, Gilbert, Frith, & Burgess, 2010; Fox et al., 2015; Godwin et al., 2017; but see Hasenkamp, Wilson-Mendenhall, Duncan, & Barsalou, 2012), mirroring the DMN-PFC coupling that occurs during creative ideas evaluation (Ellamil, Dobson, Beeman, & Christoff, 2012).

Christoff and colleagues' study (2009) was the first one to show the involvement of executive areas in MW. During fMRI scanning, participants were asked to perform the SART and presented with thought-probes throughout the task. Each thought-probe asked participants two questions: (i) whether their attention was focused on the task or on something unrelated to the task; (ii) whether or not they were aware of where their attention was focused. Task performance errors were also collected to provide a behavioural measure of MW. Comparing the 10-s interval before off-task reports with the 10-s interval before on-task reports, a recruitment of DMN areas was observed again. Performance errors were preceded by activation in DMN regions as well, converging with subjective measures of MW. Crucially, off-task reports were also associated with a recruitment of executive network regions, such as the dorsal anterior cingulate cortex (dACC) and the dorso-lateral PFC (dlPFC) (see Figure 1.2). As for the awareness of thoughts, results showed that brain recruitment associated with off-task thoughts was most pronounced in the absence of meta-awareness.

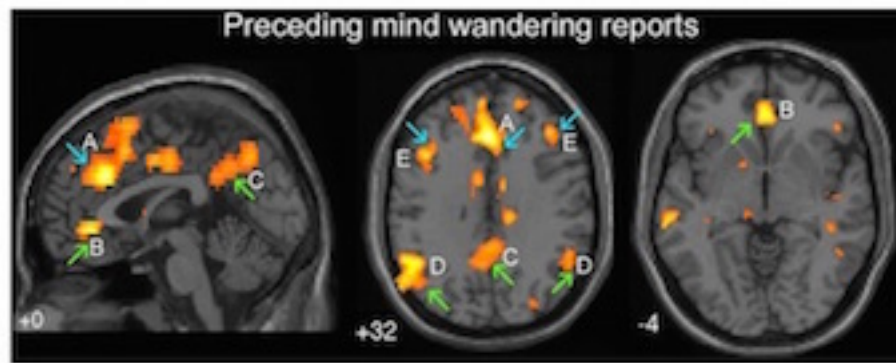


Figure 1.2. Activations preceding reports of MW (intervals prior to off-task versus on-task thought-probes). Upward green arrows: DMN regions; downward blue arrows: executive network regions. Regions of activation included: (A) dACC (BA 32), (B) ventral ACC (BA 24/32), (C) precuneus (BA 7), (D) bilateral temporoparietal junction (BA 39), and (E) bilateral dlPFC (BA 9). Height threshold $p < 0.005$, extent threshold $k > 5$ voxels (from Christoff et al., 2009).

A crucial role for dlPFC in MW has been additionally found by employing tDCS (Axelrod, Rees, Lavidor, & Bar, 2015; Kajimura, Kochiyama, Nakai, Abe, & Nomura, 2016; Kajimura & Nomura, 2015). The stimulation of the dlPFC (anodal electrode over the left dlPFC and cathodal electrode over the right supraorbital area), but not of the occipital cortex or sham stimulation, increased MW propensity during the SART (Axelrod et al., 2015). In contrast, tDCS with the cathodal electrode over left dlPFC and the anodal electrode over right parietal regions decreased MW propensity relative to the reverse stimulation (i.e., cathodal over parietal regions, anodal over left dlPFC) (Kajimura & Nomura, 2015).

Since the dlPFC can be considered as part of the fronto-parietal control network (FPCN) (Christoff et al., 2016) and it is notably involved in executive processing and intentional task-focused thought (e.g., Duncan & Owen, 2000), its recruitment during MW might be somewhat unexpected. However, hypotheses have been proposed for its

recruitment. Consistent with the perceptual decoupling hypothesis, executive resources might be needed to suppress interferences from external stimuli during the processing of task-unrelated thoughts in order to maintain the internal thoughts' flow with no perceptual distractions (e.g., Christoff et al., 2009; Schooler et al., 2011). As already mentioned, the suppression of perceptual interferences is supported by studies revealing deactivations in the primary sensorimotor cortices while experiencing task-unrelated thoughts. The recruitment of the executive network during MW might also explain the impairment in task-performance when MW occurs in demanding task (Christoff et al., 2009).

It is also worth noting that the FPCN, which includes the dlPFC, is anatomically interposed between the DMN and the Dorsal Attention Network (DAN) (Andrews-Hanna et al., 2014), which is recruited when attention is focused on external information, and it might play a modulatory role in the activation or suppression of DMN or DAN based on switching internal/external attentional states (e.g., Andrews-Hanna et al., 2014; Christoff et al., 2016). The temporal relationship between the FPCN and the DMN has been found to dynamically fluctuate across short time-scales (Andrews-Hanna et al., 2014; Chang & Glover, 2010). At the same time, the DAN exhibits negative functional connectivity with the core subsystem of DMN and this coupling fluctuates across time, varies across different cognitive states, and is coordinated with interactions involving FPCN (Dixon et al., 2017; see also Zabelina & Andrews-Hanna, 2016). Although research still has to clearly understand the reason for this dynamic variability, these shifts in connectivity between networks may potentially reflect shifts in attentional focus or information exchange from perception to internal thinking and vice versa (Andrews-Hanna et al., 2014). Specifically, periods of stronger anticorrelation between the FPCN and the DAN, and simultaneous stronger

anticorrelation between the DAN and the DMN regions may reflect a state characterised by a decoupling from perceptual inputs to process internal source of information (Dixon et al., 2017).

Finally, Fox and Christoff (2015) suggested an additional interpretation for the recruitment of dlPFC in MW. These authors, in replying to Axelrod and colleagues' paper (2015; see above), suggested that the stimulation of the dlPFC could have been increased MW reports by also affecting the meta-awareness of thoughts, since studies support the role of lateral PFC regions for meta-awareness of internal thoughts (e.g., Fleming & Dolan, 2012).

Consistent with the idea of the dynamic nature of the brain, initial evidence has shown that these brain areas have a role along different stages of the dynamic of thoughts' flow (Ellamil et al., 2016; Girn et al., 2017; Hasenkamp et al., 2012; Mooneyham et al., 2017).

For example, Ellamil and colleagues (2016) asked to a group of highly experienced meditation practitioners to attend to the rising and falling of the abdomen during fMRI scanning. While attending to the breathing, participants also alternated blocks of monitoring thoughts that arose spontaneously (thought condition) and blocks of monitoring words that appeared onscreen (word condition). Participants were requested to press a first button to indicate when a thought arose or when a word appeared on the screen, and a second button to indicate which type of thought or word it was. The moment associated with the button-press was considered as the moment of the arising of thoughts, whereas the 4sec. time-interval before the button-press was considered as the time prior to the arising. Activations of some parts of the DMN, such as the MTL, the right IPL and the PCC, were found in this interval prior to thoughts' reports. During and following thoughts' reports, a recruitment of other parts of the

DMN, such as the mPFC and the TPC, and parts of the executive network, such as the dlPFC, were observed.

Given the low temporal resolution of fMRI to observe events occurring in rapid sequence, on the basis of Ellamil and colleagues' study (2016), Girn et al. (2017) employed EEG to investigate the temporal dynamics of brain activity underlying thoughts' arising of experienced meditators. They used a task procedure similar to the one by Ellamil et al. (2016) but specified that only thoughts categorised as "verbal/inner speech" were used for analysis. Again, analysis of EEG data revealed different activations during the time-course of thoughts' arising (i.e., from -2 sec. to the button press). Firstly, in the time-interval between 2 sec. and 1.5 sec. before the button press, connectivity between the mPFC and PCC and between right insula and both dorsal ACC and PCC was observed; next, from 1.5 sec. to 1 sec. before the button press, there was left superior temporal gyrus connectivity with the right insula and PCC; from 1 sec. to 0.5 sec. before the button press, a unique dlPFC-mPFC connectivity was found; finally, in the 500 msec. before the button-press a right insula-dlPFC connectivity was found, interpreted as brain recruitment for the initiation of the required behavioural response.

Overall, this study showed again that the thought's generation seems to include temporally distinct processes, distinguishable at the neural level. However, besides the fact that these studies did not employ the common methods to detect specifically MW episodes, they assume that participants have great accuracy in recognising the actual arising of thoughts. Although these investigations are conducted on groups of experienced meditators (i.e., they practice attending to shift in attentional focus and should have an advanced introspective capacity; Girn et al., 2017), one cannot be sure whether the arising of thoughts falls within the few seconds interval immediately

preceding the report. Moreover, meditators may be a special category of people, different from the general population.

In order to understand how the experience of MW evolves over time, from its actual arising to its final ending, research focusing on the dynamics of MW will be especially important in the near future. In the next section, we will focus on recent frameworks that propose, indeed, the importance of distinguishing between different features of the experience of MW for understanding its dynamic over time.

1.7 A new dynamic approach to mind-wandering

The process-occurrence framework presented by Smallwood (2013) offers a perspective to reconcile the different cognitive hypotheses for MW described previously in this Chapter (see section 1.5). This framework suggests that we should consider two distinct and basic elements of MW, that are the occurrence (onset) of a MW episode and the maintenance of this episode over time. The first element can be viewed as the number of times attention shifts from the external to the internal information (or the frequency of MW), whereas the second one can be considered as the length of time spent in this state (or the duration of MW).

With regard to the cognitive hypotheses outlined above, Smallwood (2013) argued that they are aimed at explaining one of these two basic elements of MW and not all of them explain the same element. Specifically, the executive failure hypothesis focuses on the moment that MW begins and would, therefore, explain the frequency of MW episodes. The current-concerns and meta-awareness hypotheses, although they point to different mechanisms, would explain the occurrence and frequency of MW as well. The context-regulation hypothesis is not explicitly described in relation to the

other hypotheses but, since it postulates that individuals regulate MW occurrence depending on the circumstances, it is clear that it would also explain the frequency of MW. On the contrary, the global availability hypothesis and the decoupling hypothesis focus especially on the processes that maintain and ensure the continuity of thoughts' flow over time.

In general terms, we could reason that the likelihood of experiencing a MW state is higher when we have a number of pressing current concerns, we are in an appropriate context and a breakdown in the maintenance of task-relevant information occurs. Afterwards, our MW lasts longer depending on executive-resources and the process of perceptual decoupling that insulates the train of thoughts from external disruption.

Although these accounts offer explanations for the conditions that facilitate MW episodes, they are far from clarifying either the mechanisms of the process of *ignition* (Dehaene & Changeux, 2011) or the dynamics of MW over time. Shedding light on the process of ignition means the understanding of why certain episodes arise at that specific moment in time. Indeed, this is a topic that has been largely neglected in MW research over the last years. According to Smallwood (2013), this lack of research is also probably due to the difficulty that researchers have found in causally linking MW to an imperative stimulus (trigger-event) in order to examine the associated spontaneous events by using, for example, behavioural or physiological measures. Perhaps this possibility has been doubted due to MW being described as a stimulus-independent (Antrobus et al., 1966) phenomenon for a long time. However, more recently, research has been increasingly beginning to consider a role for external cues in triggering internal thoughts (e.g., McVay & Kane, 2013; Plimpton et al., 2015), making space for the investigation of the processes associated with the onset of thoughts. Finding a way to identify the moment of ignition would be also beneficial

for further improving neurocognitive studies that have started to explore the different brain recruitments along the time-course of thoughts' flow (e.g., Ellamil et al., 2016; Girn et al., 2017; see section 1.6 of the present chapter).

Thus, the distinction between onset and maintenance of thoughts' flow is ultimately important for the investigation on the dynamics of MW. Recently, it has been proposed that MW should be viewed as a highly dynamic process in which thoughts move freely (Christoff et al., 2016; Girn et al., 2017) and specific transitions between different MW states exist (Mittner, Hawkins, Boekel, & Forstmann, 2016).

According to Christoff et al. (2016) it would be crucial to discover how mental states arise and change over time and "*only once we consider the dynamics of thought are we able to make crucial distinctions between different types of thought*" (p. 2).

As pointed out by Ottaviani, Medea, Lonigro, Tarvainen, and Couyoumdjian (2015), conceptually "*the term wandering evokes a flow of thoughts that come and go*" (p. 24) whereas other kind of repetitive thinking, such as worry and rumination (i.e., Perseverative Cognition, PC), evokes "*repetition of the same response over and over*" (p. 24).

In the Christoff et al.'s (2016) dynamic framework, the contents of mental states and the transitions from one mental state to another can have different levels of constraints, more or less flexible or automatic, and it's only taking into account the constraints of the flow of thoughts, that MW could be distinguished from rumination or obsessive thoughts: thoughts during rumination tend to remain fixed on a single topic and are marked by a high degree of automatic constraints, whereas thoughts during MW move freely (albeit more-deliberately constrained than dreaming and less deliberately constrained than creative thinking or goal-directed thought) (see also Fox et al., 2018).

Since the two constructs (i.e., MW and PC) have emerged in distinct research domains, they have rarely been directly compared in a study. Empirically, in a laboratory study, Ottaviani et al. (2013) have provided preliminary evidence that MW and PC lie on a continuum, where flexibility plays a role in the distinction: MW is not generally dysfunctional but might be maladaptive (e.g., intrusive thoughts) when flexibility is lost and it becomes a rigid pattern.

More recently, Mills, Raffaelli, Irving, Stan, and Christoff (2018) conducted an experience-sampling study to demonstrate whether the free movement of thought is a key characteristic of MW experiences. Specifically, these authors aimed at verifying whether this dimension (i.e., being free of movement) is dissociable from the task-relatedness dimension and perceptual decoupling, which are two of the most frequently assumed features of MW. In this study, participants were probed with text-messages delivered to their mobile phones during their daily-life. They were probed 10 times per day for 10 days. Each time, participants were asked to report, on a 7-point scale (from 1= not at all, to 7 = very much), the extent to which their thoughts: (i) were moving about freely, (ii) were about something different from what they were currently doing, and (iii) contained awareness of their surroundings. The definition for “freely-moving thoughts” was given to participants, by mainly explaining that thoughts move freely when there is no purpose or direction to the thinking (albeit there may be connection between thoughts), the attention lands spontaneously on something and it may go back and forth between external environment and internal thoughts, and the thoughts seem to flow with ease. Results showed that the freely-moving thought dimension had only weak relationships with the other dimensions (i.e., task-relatedness and perceptual-decoupling). On average, thoughts were both on-task and freely-moving 21.8% of the time, and off-task and constrained 20.2% of the time. According to the authors,

equating being off-task with freedom of movement would have meant misclassifying more than 40% of thoughts in their data. A similar misclassification would be happened for the perceptual-decoupling dimension, since participants reported freely-moving thoughts while being perceptually coupled with their surroundings 26.1% of the time and constrained thoughts while being perceptually decoupled 24.6% of the time. Despite the limitations underlined by the authors of this early work, these results suggest that taking into account unstudied features (such as the freedom of movement or others) related to the dynamics of the thought process (see also Irrmischer, van der Wal, Mansvelder, & Linkenkaer-Hansen, 2018, for temporal dynamics of attentional lapses) should be necessary in further investigations on MW.

In addition to this dynamic framework, the model proposed by Mittner et al. (2016) also emphasize the importance of the dynamics. Their focus is especially on the dynamic of the transitions between different attentional states. These authors consider MW as a not unitary state which comprehends a collection of several different states, each one with different features (such as goals or meta-awareness). Shifting between qualitatively different types/states of MW would involve a transition into an “off-focus” (exploratory) state and back to an “active” MW state. Thus, in this view it would happen that a person shifts into the off-focus state each time she/he moves from a MW state to another, even though she/he never stays into an on-task state during this process. An outstanding question proposed by these author is whether the phenomenon of mind-blanking (Ward & Wegner, 2013; see section 1.1 of the present chapter) could be explained by prolonged time spent in the off-focus state (Mittner et al., 2016). However, this paper once again highlights the need of focusing on the dynamic of MW and the transitions between possibly different attentional states.

1.8 Overview of the present studies and research aims

As we reviewed in the previous sections, MW is a multidimensional cognitive experience, that still needs further investigation. Crucially, some lines of research have suggested the importance of focusing on the dynamics of this process (e.g., Christoff et al., 2016; Girn et al., 2017; Mittner et al., 2016; Smallwood, 2013) in order to further advance our knowledge of this phenomenon. Thus, following the “process-occurrence” framework introduced by Smallwood (2013), in three studies, we aimed to identify and track the onset (i.e., the so called “process of ignition”) and time-course of MW (i.e., maintenance and unfolding over time).

The Study 1 (Chapter 2) was designed to assess the causal role of external cues in triggering and shaping MW episodes. To this aim, we used a vigilance task to record MW episodes in the laboratory and we experimentally manipulated the presence of verbal cues during the vigilance task in two independent groups (i.e., Verbal-cues group and No-cues group) with a between-subject design. To collect MW experiences, we used the self-caught procedure that also allowed us to compute the latency of MW (i.e., the time-interval between the presentation of the stimulus/trigger and the report of MW triggered by that specific stimulus) for those MW episodes reported as triggered by the verbal cues. Our results mainly showed that the exposure to task-irrelevant verbal cues increased the amount of MW reported and biased the temporal focus towards the past.

The Study 2 (Chapter 3) was developed to further extend the results found in Study 1 by coupling self-report measures of MW with physiological ones (i.e., pupillometry). The main aim was, therefore, to examine the pupil activity occurring after external cues indicated by participants as triggers for MW episodes in order to obtain a cover measure associated with the onset and maintenance of MW over time.

To this aim, we employed a modified version of the vigilance task with verbal cues and we recorded pupil measures throughout the task. To collect MW episodes, we used the probe-caught procedure. We mainly found a significantly larger pupil dilation over two trials following MW triggers compared to non-triggers, suggesting that an increase in pupil diameter (i.e., index of emotional and cognitive load) followed the onset of MW and accompanied its unfolding over time.

The Study 3 (Chapter 4) was conducted with the main aim of replicating the results of the previous pupillometry study (Study 2) and extend them further. Specifically, we aimed to replicate the results of higher pupil dilation following MW triggers by collecting only aware MW episodes with a self-caught procedure instead of a probe-caught procedure. Moreover, we also examined whether and how pupil dilation associated with MW was modulated by the emotional valence of MW and, for exploratory purposes, by its cue-dependent/independent nature. Thus, we employed the vigilance task with verbal cues and recorded pupil measures throughout the task. To collect MW experiences, we used the self-caught procedure that allowed us to obtain the latency of MW episodes as well. We mainly found an increase in pupil dilation following triggers of aware MW and, in addition, found that this dilation appeared not to be modulated by the emotional content of MW episodes.

Part of these results have been reported in the following publications:

Vannucci, M., Pelagatti, C., & Marchetti, I. (2017). Manipulating cues in mind wandering: Verbal cues affect the frequency and the temporal focus of mind wandering. *Consciousness and Cognition*, 53, 61–69. doi:10.1016/j.concog.2017.06.004

Pelagatti, C., Binda, P., & Vannucci, M. (2018). Tracking the dynamics of mind wandering: Insights from pupillometry. *Journal of Cognition*, *1(1)*, 38. doi:10.5334/joc.41

Pelagatti, C., Marchetti, I., & Vannucci, M. (2016, July). *When our mind wanders, where does it go? Retrospective bias induced by verbal cues*. 6th International Conference on Memory, Budapest, Hungary.

Pelagatti, C., Binda, P., & Vannucci, M. (2018, May). *Detecting the onset of mind-wandering: Insights from pupillometry*. International Meeting of the Psychonomic Society, Amsterdam, The Netherlands.

Chapter 2

What triggers MW: the causal role of external cues (Study 1)

2.1 Introduction and aims of Study 1

As we mentioned in the General introduction, MW has been largely considered as stimulus-independent (Antrobus et al., 1966) and self-generated (e.g., Smallwood, 2013), highlighting its independence from external stimuli. This observation has raised doubts about the possibility that MW states could be linked to initial events in order to study the onset of these experiences (Smallwood, 2013). However, as argued by Smallwood (2013), any comprehensive account of MW should disentangle and explain the processes associated with the initial occurrence of MW and its maintenance-continuity over time, and in order to determine the onset of MW, it is necessary to have an external stimulus that acts as trigger for this experience. A clear understanding of the role that external triggers may have in MW onset also allow to treat MW as a dynamic process (Christoff et al., 2016) and analyse the entire dynamic of thoughts' flow: only linking MW onset to external events could indeed permit to set an initial point from which the experience develops over time.

Despite the relevance of this investigation for MW research, only recently some studies have started to show a possible relationship between MW and external stimuli, probably by taking advantage of the investigations in the related research field of

involuntary memory (i.e., past episodes which come to mind with no deliberate attempt at retrieve them; e.g., Berntsen, 2010; Kvavilashvili & Mandler, 2004).

In the next section, we will review these published studies suggesting that MW may not completely be a stimulus-independent phenomenon. Next, the specific aims of our study will be presented.

2.1.1 External triggers of MW: cues related to current concerns

The idea that MW is not independent from external inputs comes from early work by Eric Klinger (Klinger, 1978; see also Klinger, 2013; Klinger, Marchetti, & Koster, 2018). Klinger's current concerns theory proposes that one's goals and wishes sensitise the individual to cues (internal or external) that are associated with one or another of the individual's goals, which, upon encountering, would re-activate the goal related material in one's consciousness. As stated by Klinger and co-workers (2018), "*becoming committed to pursuing a goal boosts the cognitive-processing priority for cues related to that goal*" (p. 216). Klinger (1978) empirically verified the effects of concerns' related cues on attention and thoughts' content. As we previously described (see Chapter 1, section 1.5.3), he found that, when participants were allowed to choose, by using a toggle switch, listening to either a narrative including their concerns' related cues or a narrative including others concerns' related cues, they (i) spent more time listening to the passages associated with their own current concerns, (ii) reported thoughts whose contents were related to those passages, and (iii) recalled those narrative's passages more often than the opposite passages (see Chapter 1, section 1.5.3). A large proportion of those thoughts qualified as daydreams. It is therefore evident that the goal relatedness of the cues embedded into the tapes triggered daydream content (Klinger, 1978, 2013).

The sensitivity to goal-related external stimuli and the impact on subsequent MW have been recently investigated using a modified version of SART (McVay & Kane, 2013; van Vugt & Broers, 2016). Specifically, McVay and Kane (2013), embedded current concerns' related words into the perceptual version of the SART. In the initial session of the study, they asked participants to describe their personal goals and concerns across several life domains. In a second session, scheduled 2 days apart, participants performed the perceptual version of the SART with thought-probes to collect MW episodes. In this SART version (McVay & Kane, 2009), each stimulus consists of a word presented on the screen and participants are asked to press a button for lowercase words ("go" trials) and to withhold responding to infrequent uppercase words ("no-go" trials). Crucially, in the study, after the first session and for each participant, three-word cues from the participant's current concerns were created and inserted as three consecutive SART stimuli (i.e., each word in a subsequent "go" trials). Two of the most important, imminent and specific current concerns were selected to be embedded in the SART. A set of control-words (triplets of words not related to the individual's current concerns) was also created and inserted as SART stimuli. Thought-probes appearing shortly after the personal-goal triplets were associated with a 3-4% increase in MW relative to control triplets. Although this effect is small, it provides evidence for a role of current-concerns' related cues in stimulating MW.

In a subsequent study, van Vugt and Broers (2016) used a modified version of the same paradigm but added one more control condition in the task. They included in the SART: (i) thought-probes presented after specific word triplets created from an individual's current concerns, (ii) thought-probes presented after word triplets created from others' responses (statements resulted as idiosyncratic in a pilot study), and (iii)

thought-probes presented randomly in the task (control condition). Results from this study revealed that both participant's own concerns condition and other's concerns condition were associated with higher MW frequency and lower accuracy in task performance (considered as behavioural index of off-task thinking) compared to the control condition. Thus, this study did not report different MW frequency after exposing participants to their specific and important personal concerns. It may be that triplets created from idiosyncratic statements were also significant stimuli compared to the word stimuli not arranged in meaningful triplets during the SART. These findings may suggest that the exposure to external meaningful stimuli generally stimulates MW experiences.

2.1.2 External triggers of MW: task-relevant and task-irrelevant meaningful cues

There is initial evidence showing that MW can be elicited not only by specific concerns' related cues but also by other external meaningful cues (Maillet & Schacter, 2016; Plimpton et al., 2015; Song & Wang, 2012). First interesting results have been reported in the daily-life experience sampling study by Song and Wang (2012). The authors collected information about the content and the context of daily MW experiences. Participants were probed with a mobile short message during their everyday activities for 3 days. The probe randomly appeared 6 times from 7:30 a.m. to 11:30 p.m. per day (twice in the morning, afternoon, and evening, respectively). After receiving the probe, participants should judge whether they were mind wandering and complete a questionnaire on some questions, including a question on external/internal cues. Results showed that participants could infer the cue for most MW episodes (88.17%) and, even more interesting, the percentage of external cues (50.57%) was as high as internal cues (49.43%).

More recently, few other studies have addressed the question of the role of meaningful external cues in stimulating MW experiences also in a laboratory setting, by investigating both task-relevant (Maillet & Schacter, 2016) and task-irrelevant (Plimpton et al., 2015) stimuli.

Specifically, in Maillet and Schacter's study (2016), older and young adults performed a word-picture incidental encoding task while being intermittently probed with different questions about their thoughts, including one question asking whether their thoughts were or not triggered by one of the encoding stimuli. Results showed that participants reported overall more thoughts triggered by encoding stimuli compared to thoughts not triggered by those stimuli. In addition, a greater proportion of thoughts triggered by task-relevant external stimuli were about the past relative to the future. These findings provide a first empirical support to the hypothesis that meaningful task-relevant stimuli might stimulate MW, thereby increasing the frequency of MW episodes.

Another important contribution investigating the role of external but task-irrelevant stimuli in triggering MW comes from a recent study by Plimpton and colleagues (2015). In the study, the authors employed a modified version of a paradigm originally developed by Schlagman and Kvavilashvili (2008) to assess involuntary autobiographical memories (IAMs) in the laboratory setting. In this paradigm, participants are exposed to a long sequence of trials of mostly horizontal lines and have to detect infrequent targets (i.e., vertical lines), while being simultaneously exposed to task-irrelevant cue-words (i.e., "relaxing on a beach" or "crossing the street"), presented in the centre of each trial. The experience of IAMs can be assessed by using both self-caught (e.g., Schlagman & Kvavilashvili, 2008) or probe-caught (Vannucci, Batool, Pelagatti, & Mazzoni, 2014). This paradigm elicits a fair amount of IAMs, the

majority of which are reported as being triggered by the cues presented on the screen (e.g., Kvavilashvili, & Schlagman, 2011; Schlagman & Kvavilashvili, 2008; Vannucci et al., 2014; Vannucci, Pelagatti, Chiorri, & Mazzoni, 2016; Vannucci, Pelagatti, Hanczakowski, & Chiorri, 2018; Vannucci, Pelagatti, Hanczakowski, Mazzoni, & Rossi Paccani, 2015).

In the version used by Plimpton and colleagues (2015), participants were stopped during the task and asked to give a brief description of their thoughts at the moment they were stopped (i.e., probe-caught sampling method) and indicate if the thought occurred spontaneously or intentionally and, for the spontaneous thoughts, to specify their triggers (if any). The results revealed that the vast majority of task-unrelated thoughts were reported to have been triggered by task-irrelevant word-phrases on the screen. This pattern was found in both dysphoric and non-dysphoric participants. Moreover, even though the frequency of past episodes was higher than the frequency of thoughts towards the future and the current situations, the word-phrases were more likely to trigger thoughts about the past and the future than the current situation but there was no difference between past and future episodes. These findings suggest that both the frequency of MW and its temporal orientation may be function of the external context rather than being completely self-generated.

2.1.3 Aims of Study 1

In the present study we aimed to capitalize on these recent promising findings described above, by experimentally investigating the *causal role* of external verbal cues in triggering and shaping MW. Specifically, we addressed two questions. First, does exposure to task-irrelevant verbal information directly trigger MW during a vigilance task? If so, we should find a higher frequency of MW during a vigilance task

with verbal cues compared to an identical vigilance task with no verbal cues. Second, does the exposure to verbal information influence the temporal orientation of MW and, specifically, increase past-oriented MW?

In the previous study by Plimpton et al. (2015), given the absence of a direct experimental manipulation of the presence of verbal cues, it is not possible to conclude that the presence of verbal cues was the direct *cause* of the occurrence of MW and the steering of their temporal focus toward the past.

To address these questions, we used the vigilance task already successfully used to induce and assess MW in the laboratory (Plimpton et al., 2015) and we experimentally manipulated the presence of verbal cues during the vigilance task in two independent groups, “Verbal-cues” group and “No-cues” group respectively (*between-subject* design)

In the study, a self-catching procedure was used, thereby instructing participants to report the occurrence of any spontaneous mental content not directly related to the task at hand. Since we employed a self-catching procedure, for those MW episodes triggered by external cues, we could also measure their latency, that is the time in between the presentation of the stimulus/trigger and the report of MW triggered by that specific stimulus. By collecting the latency of MW episodes, we could obtain information about the time needed for the formation of thoughts and for becoming aware of them.

Moreover, in the present study, we distinguished task-unrelated thoughts (TUTs), collected during the vigilance task, in MW and external distractions (EDs), To this regard, in the study by Plimpton et al. (2015), the authors primarily referred to TUTs as a category comprising both MW and EDs, while previous studies have shown that MW and ED are two partially distinct processes, that can be differentiated at the

behavioural (Stawarczyk et al., 2014; Unsworth & McMillan, 2014) and physiological level (e.g., pupillary correlates in Unsworth & Robison, 2016). To our knowledge, it is still unknown whether task-irrelevant verbal cues might have differential effects on the frequency of MW and ED.

Given the association reported in the literature between past-oriented MW and negative mood (e.g., Poerio et al., 2013; Smallwood & O'Connor, 2011), positive and negative affect were measured (through the Positive and Negative Affect Schedule, PANAS) at the beginning of the experimental session. Finally, phenomenological information on each reported thought was acquired.

2.2 Method

2.2.1 Participants

Sixty-two undergraduate students from the University of Florence (48 females, age range 18–29 years, $M = 21.76$ years) volunteered to participate in the study. All participants were Italian native speakers and they had normal or corrected-to-normal vision. Half were randomly assigned to the Verbal-cues condition ($n = 31$; 25 females, age range 18-29 years, $M = 21.26$ years) and the other half to the No-cues condition ($n = 31$; 23 females, age range 18-27 years, $M = 22.26$ years). Groups did not significantly differ in age, gender ratio, and depressive symptoms (assessed by the Beck Depression Inventory-II; Beck, Steer, & Brown, 1996; Italian adaptation in Ghisi, Flebus, Montano, Sanavio, & Sica, 2006).

The experimental protocol was in line with the declaration of Helsinki and with the regulations of the University of Florence that hosted the study.

2.2.2 Materials

Vigilance task

Participants performed a modified version of the computer-based vigilance task developed by Schlagman and Kvavilashvili (2008) and already used in previous studies to investigate both involuntary memories and MW episodes (e.g., Barzykowski & Niedźwieńska, 2016; Plimpton et al., 2015; Vannucci et al., 2015, 2016). This task consisted of 600 trials, presented in a fixed order, each remaining on the screen for 1.5 sec. In each trial, an image (approximately 21.5 cm x 12.5 cm in size) was shown depicting either a pattern of black horizontal (non-target stimuli) or black vertical lines (target stimuli) on a white background. Target stimuli appeared on 12 trials (2% of all trials), with a minimum of 42 and a maximum of 59 trials between each target.

In the Verbal-cues condition, cue-words (e.g., “tumble dryer”, “long hair”, “paper bag”) in 18-CPI Arial font were shown in the middle of the image on 108 (18%) trials. These cue-words were selected from the pool of 800 word-phrases developed by Schlagman and Kvavilashvili (2008) and adapted to the Italian sample² (Vannucci et al., 2015). To check that the temporality of possible cue-words did not affect the results, temporally-oriented cue-words (e.g., “old family photos”, “forgotten appointment”, “stolen car”, “successful career”) were not included in our words sample. Moreover, since emotional valence has been found to affect the likelihood of reporting past or future thoughts (Plimpton et al., 2015), only neutral cues were included in our sample. When necessary, the original word-phrases were slightly modified in order to use them (e.g., “jealous behaviour” was replaced by “behaviour”)

² In the adaptation, ten independent judges (all Italian native speakers) rated the level of familiarity, imageability and concreteness of the original word-phrases on a 7-point Likert scale (1 = low; 7 = high). Specific instructions were given to participants before rating each dimension.

and re-evaluated for the level of familiarity, imageability and concreteness. To verify that the selected cues were actually neutral and atemporal, we asked eight independent judges to evaluate, for each cue-word, the emotional valence (positive, negative or neutral) and the temporal focus, that is whether the cue-word was commonly used in daily life linked to a specific temporal orientation (i.e., past, present, future), more than one (i.e., mixed), or to no specific temporal orientation (i.e., atemporal). Only the cue-words evaluated as neutral and atemporal by at least 6 out of 8 judges (i.e., 75%) were selected for the study.

Thought questionnaire

After completing the vigilance task, participants provided details of their reported mental contents on a questionnaire. For each mental content, they were asked to indicate: (i) the temporal focus, distinguishing among “past”, “present”, “future”, and “atemporal”, (ii) whether it was general or specific, (iii) whether it was self-related or not. As for the temporal focus, participants were told that an “atemporal” mental content would refer to any thought with no specific temporal orientation (e.g., *“I am a very anxious person”*; *“I like very much eating pizza”*), a “present” mental content would refer to any thought related to something occurring either here and now (e.g., *“I miss my dog, that is now with my boyfriend”*) or in the current period of life (e.g., *“I don’t get along with my mother in this period”*), a “past” mental content would refer to any thought related to something occurred prior to start the task (more or less remote), and a “future” mental content would refer to any thought related to something occurring after the end of the task (more or less distant in the future).

Participants were also asked to rate on a 5-point scale their overall level of concentration (1 = not at all concentrated; 5 = fully concentrated) and boredom (1 = not at all; 5 = very bored) experienced during the vigilance task.

Mood questionnaire

Before performing the vigilance task, participants were asked to complete the Positive and Negative Affect Schedule – State (PANAS; Watson, Clark, & Tellegen, 1988; Italian adaptation in Terracciano, McCrae, & Costa, 2003). The Positive and Negative Affect Schedule consists of two 10-item self-report scales, one measuring positive affect (i.e., excited, inspired) and the other one measuring negative affect (i.e., upset, irritable). Each item is rated on a 5-point Likert scale (1 = very slightly or not at all; 5 = extremely), and it measures the extent to which each mood state has been experienced during a specified time frame. Participants completed the PANAS with “the present moment” instructions.

2.2.3 Procedure

Participants were tested individually. After being welcomed into the laboratory, participants were briefly introduced to the research project, presented as a study examining concentration and its correlates, and signed a consent form. Afterwards, they were asked to complete the PANAS. Once this was completed, they received the instructions for the vigilance task. It was explained that they had to detect target stimuli (vertical lines) among a large number of non-target stimuli (horizontal lines), by saying “yes” out loud each time they detected a target stimulus. Participants in the Verbal-cues condition were also told that they would see cue-words in some of the trials and that they were not supposed to do anything with these cue-words. It was explained that

the condition in which they were participating was looking at how people could keep their concentration on the patterns and that participants in another condition would have to concentrate on the cue-words. This was a cover-story and the second condition did not really exist. A schematic of the sequence of experimental trials in both conditions is shown in Figure 2.1.

Participants were, next, told that the task was quite monotonous and that task-unrelated mental contents (e.g., thoughts, plans, considerations, past events, images, etc.) could pop into their mind spontaneously throughout the task. In the event that something came to their mind, they should click the mouse to interrupt the task. After clicking the mouse, they should write a short description of the mental content on a paper sheet and indicate whether it was triggered by something, by selecting one of the following options: internal thoughts, an element in the environment, a cue-word on the screen (for the Verbal-cues group only; participants were also asked to specify the word), no trigger. If the mental content was private and intimate, participants could label it as “personal” and eventually provide only one relevant word instead of reporting a short description. After the instructions, participants were given a short practice of the vigilance task in which they were allowed to behave as it was the experimental session and to stop the presentation if they had any task-unrelated thoughts.

When the vigilance task was over, participants were presented with the short descriptions of their mental contents and asked to report some details about these thoughts on a questionnaire (see Thought questionnaire in the Materials section). Finally, participants were asked whether they had speculated about the actual aims of the study (if so, what they had thought) during the task and then they were debriefed and dismissed. The total session lasted approximately 60–75 min.

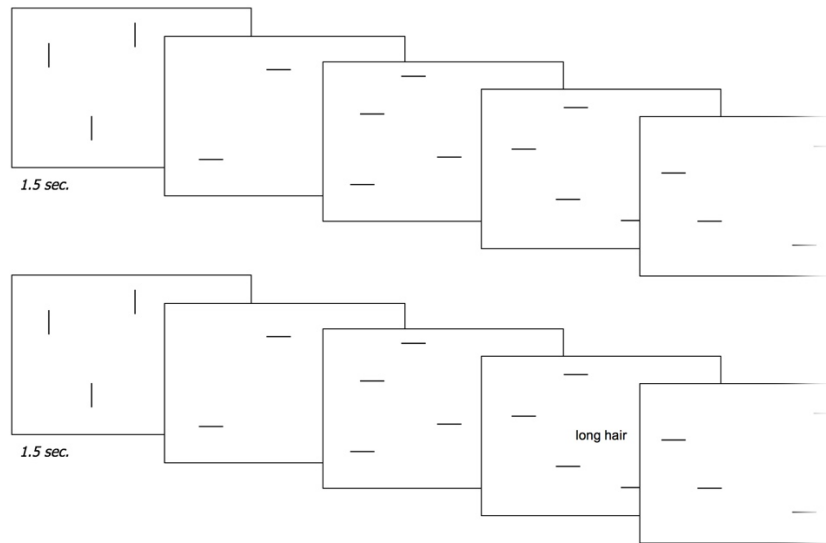


Figure 2.1. Example of the stimulus displays in both conditions. Top: No-cues group; bottom: Verbal-cues group. Horizontal lines: non-target stimuli; vertical lines: target stimuli to be detected by saying “yes” out loud.

2.3 Results

Performance on vigilance task

All 62 participants successfully completed the vigilance task. Only one participant (in the No-cues group) reported a mistake (omission).

An independent sample t-test was performed to compare the level of concentration and boredom experienced during the task between the two groups; Cohen’s d was computed as effect size. There was no significant difference between the two groups with respect to the level of concentration experienced during the task (Verbal-cues group: $M = 3.55$, $SD = 0.81$; No-cues group: $M = 3.45$, $SD = 0.81$; $t(60) = 0.47$, $p = 0.64$, $d = 0.12$), but the No-cues group reported a higher level of boredom ($M = 3.65$, $SD = 1.14$) compared to the Verbal-cues group ($M = 2.84$, $SD = 1.16$), $t(60) = 2.76$, $p = 0.008$, $d = 0.70$.

Mood measures

The PANAS was completed by participants at the beginning of the experimental session. An independent sample t-test was performed to compare the scores of both the Positive and Negative Affective Schedules between the two groups; Cohen's d was computed as effect size. The two groups did not significantly differ in either Positive (Verbal-cues group: $M = 30.97$, $SD = 5.27$; No-cues group: $M = 30.90$, $SD = 5.48$; $t(60) = 0.05$, $p = 0.96$, $d = 0.01$) or Negative Affect Schedule (Verbal-cues group: $M = 13.16$, $SD = 4.20$; No-cues group: $M = 12.52$, $SD = 2.73$; $t(60) = 0.72$, $p = 0.48$, $d = 0.18$).

Amount and type of mental contents reported

Before performing the analyses on the mental contents, all thoughts reported by participants were coded by two independent judges as belonging to different thoughts categories. We based our classification on the categories used in previous studies (e.g., Plimpton et al., 2015; Stawarczyk et al., 2014; Stawarczyk, Majerus, Maj, et al., 2011). Thoughts were coded as either task-related interferences (TRIs) or task-unrelated thoughts (TUTs) and all TUTs were also coded as MW or external distraction (ED). TRIs comprised reports whose content was related to any task features (i.e., "*The position of the lines repeats itself*", "*How long does each image last?*") or to the current performance on the task (i.e., "*I am worried about failing this detection task*"), whereas TUTs did not include references to the task at hand (Plimpton et al., 2015) and included both ED and MW episodes (Stawarczyk et al., 2014; Stawarczyk, Majerus, Maj, et al., 2011). TUTs were coded as EDs when the participant's attention was unrelated to the task at hand but focused on stimuli in the current situation. The content of these thoughts could involve both exteroceptive (e.g., "*I have a ladybird on*

my shoulder” or *“I was distracted by the voices outside the room”*) or interoceptive perceptions (i.e., bodily sensations, such as hunger or cold; e.g., *“I am sweaty and hot”*).

TUTs were coded as MW when the participant’s attention was unrelated to the task at hand as well as decoupled from the external environment. These thoughts could vary in forms and contents, and they could be triggered by internal or external stimuli. For thoughts triggered by external stimuli, it is especially worth noting an important distinction between EDs and MW episodes. When an external stimulus elicits a thought, the following possibilities might happen: (i) the thought’s content keeps including only that stimulus during the thought’s flow and the flow ends before thinking anything else (e.g., *“I was thinking about the sudden train whistle”*), or (ii) the thought’s flow starts from an external stimulus but, in the second place, it moves to a thought associated with that stimulus but decoupled from the current situation (e.g., *“While I was paying attention to the sudden train whistle, I thought about my first trip by myself”*). EDs contents did not involve anything else beyond the stimulus that originated the distraction.

For both categorisations (TRIs vs. TUTs, and MW vs. EDs), we computed Kappa as inter-rater reliability between the coders and the inter-rater agreement resulted to be very good ($Kappa = 0.93$, $SE = 0.02$ and $Kappa = 0.91$, $SE = 0.03$, respectively). Minor disagreements were solved by discussion.

By using the criteria of the median absolute deviation (as suggested by Leys, Ley, Klein, Bernard, & Licata, 2013), we checked for possible outliers in any of the variables we would use for analyses. Out of the 62 participants, one (in the Verbal-cues group) was identified as outlier because of the very high frequency with which she reported MW episodes, and she was excluded from the analyses.

Sixty-one participants reported 444 mental contents. Out of all contents, 77 were categorised as TRIs ($M = 1.26$, $SD = 1.40$, range 0-6) and 367 as TUTs ($M = 6.02$, $SD = 4.79$, 0-21). Out of all TUTs, 324 were classed as MW reports ($M = 5.31$, $SD = 4.70$, range 0-20) and 43 as ED reports ($M = 0.70$, $SD = 1.05$, range = 0-4). All descriptive data are summarised in Table 2.1 and Table 2.2.

Variable	M	SD	range
Task-related interferences (TRIs)	1.26	1.40	0-6
Task-unrelated thoughts (TUTs)	6.02	4.79	0-21
Mind-wandering (MW)	5.31	4.70	0-20
External distraction (ED)	0.70	1.05	0-4

Table 2.1. Means, standard deviations and ranges of thoughts reported.

Variable	Verbal-cues			No-cues		
	M	SD	range	M	SD	range
Task-related interferences (TRIs)	1.07	1.20	0-5	1.45	1.57	0-6
Task-unrelated thoughts (TUTs)	7.60	5.57	0-21	4.48	3.32	0-14
Mind-wandering (MW)	7.27	5.51	0-20	3.42	2.69	0-11
External distraction (ED)	0.33	0.61	0-2	1.06	1.26	0-4

Table 2.2. Means, standard deviations and ranges of thoughts reported as a function of group (Verbal-cues group vs. No-cues group).

Before moving to the main analysis on the effects of cues on TUTs, for the sake of completeness we report the comparison in the number of TRIs between Verbal-cues group and No-cues group. Since we found that the groups differed in the level of

boredom reported during the task, we ran an ANCOVA with the level of boredom as a covariate and the TRIs frequency as dependent variable. The analysis revealed no significant difference between the Verbal-cues group and the No-cues group ($F(1,58) = 1.78, p = 0.19, \eta^2 = 0.03$).

Since we were interested in TUTs, TRIs will not be further considered in the analyses.

Effects of experimental manipulation of verbal cues on TUTs

To assess the effects of the experimental manipulation of cues on the two types of TUTs (i.e., MW and ED), the number of MW and ED reports was entered into a 2 (Group: No-cues vs. Verbal-cues) x 2 (Type of TUTs: MW vs. ED) mixed ANCOVA, with boredom as covariate. Results showed a significant main effect of Group, $F(1,58) = 8.73, p = 0.005, \eta^2 = 0.07$, with the Verbal-cues group reporting a higher amount of TUTs ($M = 3.94$) compared to the No-cues group ($M = 2.11$), and a significant main effect of the Type of TUTs, $F(1,58) = 8.35, p = 0.005, \eta^2 = 0.06$, with MW reports ($M = 5.35$) being much more than ED reports ($M = 0.70$). However, the main effects were qualified by a significant Group by Type of TUTs interaction, $F(1,58) = 14.70, p < 0.0005, \eta^2 = 0.11$. The Verbal-cues group reported a higher amount of MW ($M = 7.40$) compared to the No-cues group ($M = 3.30, p < 0.005, d = 0.91$). The difference between the two groups in the amount of ED was not significant (Verbal-cues: $M = 0.49$ vs. No-cues: $M = 0.92, p = 0.09, d = 0.45$), albeit the not small effect size ($d = 0.20$ is considered a small effect size, $d = 0.50$ a medium effect size; Cohen, 1988). These results are shown in Figure 2.2.

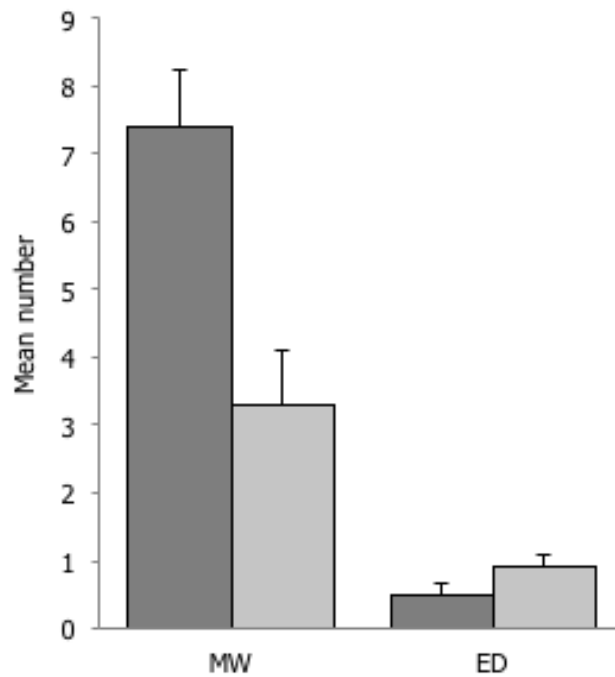


Figure 2.2. Mean number of MW and ED reports as a function of group. Dark grey: Verbal-cues group; light grey: No-cues group. Error bars represent standard error.

Type of reported triggers

Each time participants reported a thought, they were also asked to indicate the trigger of this thought by choosing among different options. The Verbal-cues group could select one of the following trigger categories: cue-words, internal thoughts, environmental stimuli, and no trigger. The no-cues group were presented with the same options except for the one about cue-words.

After finding that the exposure to verbal cues increased the amount of MW, to further investigate the contribution of the cue-words in triggering MW, we examined the number of MW episodes reported to be triggered by different stimuli. In the Verbal-cues group, out of the all MW episodes, 60.09% were triggered by the cue-words, 21.56% were triggered by internal thoughts, 4.59% were triggered by environmental stimuli and 13.76% were reported to have no identifiable trigger.

A one-way repeated measures ANOVA with Type of trigger as independent variable was performed on the mean number of MW episodes reported by the Verbal-cues group. Results showed a significant effect of Type of trigger, $F(1.4,41.3) = 23.92$, $p < 0.000005$, $\eta^2 = 0.33$. Pairwise comparisons with Bonferroni adjustment showed that the mean number of MW reports triggered by cue-words ($M = 4.37$) was significantly higher than those triggered by internal thoughts ($M = 1.57$, $p < 0.0005$, $d = 1.09$), environmental stimuli ($M = 0.33$, $p < 0.00005$, $d = 1.21$) and no trigger ($M = 1.00$, $p < 0.0005$, $d = 1.03$). The mean number of MW reports triggered by environmental stimuli was significantly lower than those triggered by internal thoughts ($p < 0.005$, $d = 0.82$) and no trigger ($p < 0.05$, $d = 0.63$), whereas the difference between the mean number of MW reports triggered by internal thoughts and no trigger was not significant ($p = 0.65$, $d = 0.36$) (see Figure 2.3).

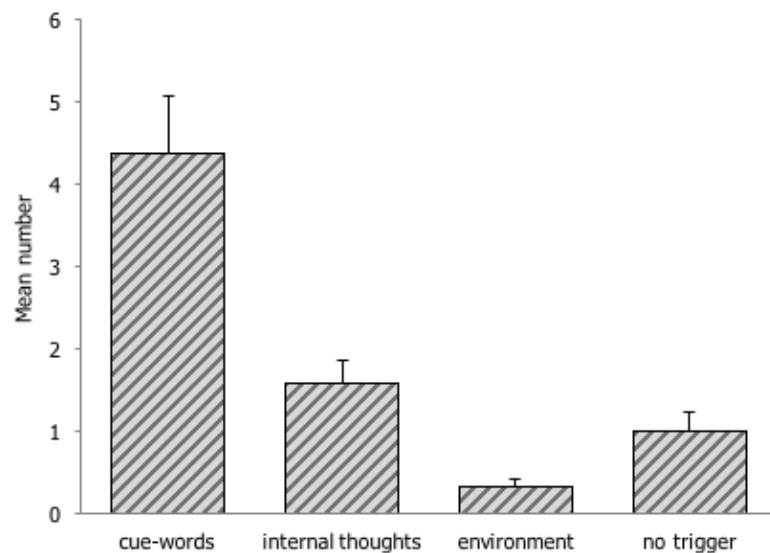


Figure 2.3. Mean number of MW episodes triggered by cue-words, internal thoughts, environmental stimuli and no trigger in the Verbal-cues group. Error bars represent standard error.

In the No-cues group, out of the all MW episodes, 61.32% were triggered by internal thoughts, 15.09% were triggered by environmental stimuli, and 23.59% were reported to have no identifiable trigger. For exploratory purposes, a one-way repeated measures ANOVA with Type of trigger as independent variable was also performed on the mean number of MW episodes reported by the No-cues group. Results showed a significant effect of Type of trigger, $F(1.4,42.3) = 12.11$, $p = 0.000337$, $\eta^2 = 0.19$. Pairwise comparisons with Bonferroni adjustment showed that the mean number of MW reports triggered by internal thoughts ($M = 2.10$) was significantly higher than those triggered by environmental stimuli ($M = 0.52$, $p = 0.003$, $d = 0.94$) and no trigger ($M = 0.81$, $p = 0.001$, $d = 1.05$). The difference between the mean number of MW reports triggered by environmental stimuli and no trigger was not significant ($p = 0.74$, $d = 0.30$) (see Figure 2.4).

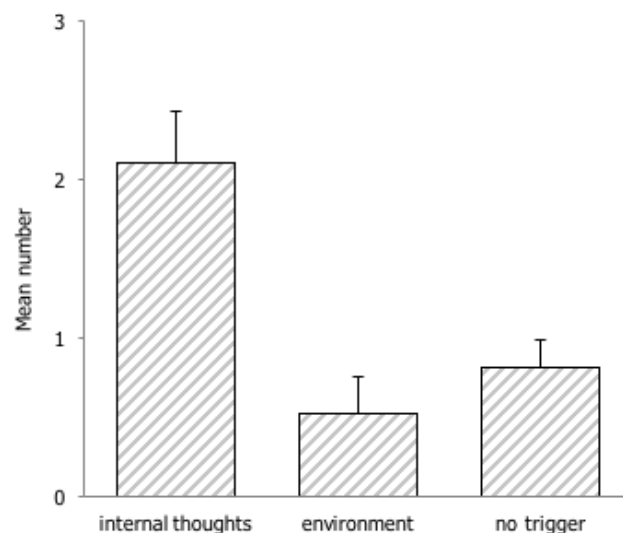


Figure 2.4. Mean number of MW episodes triggered by internal thoughts, environmental stimuli or no trigger in the No-cues group. Error bars represent standard error.

Independent sample t-tests were performed to compare the mean number of MW episodes triggered by internal thoughts, environmental stimuli and no trigger between the two groups. No significant differences emerged from the analyses (MW episodes triggered by internal thoughts: $t(59) = 1.20, p = 0.24, d = 0.31$; MW episodes triggered by environmental stimuli: $t(59) = 0.69, p = 0.49, d = 0.18$; MW episodes triggered by no stimuli: $t(59) = 0.66, p = 0.51, d = 0.17$).

Temporal focus of MW

At the end of the vigilance task, participants coded each of their recorded thoughts as past episode, future thought, thought about a current situation or atemporal thought. Out of the 324 MW reports, 127 reports (39.2%) were classed as past episodes, 81 reports (25%) as future thoughts, 38 reports (11.7%) as present thoughts, and 78 reports (24.1%) as atemporal thoughts. In the Verbal-cues group, out of 218 MW episodes, 97 episodes (44.5%) were classed as past episodes, 40 episodes (18.3%) as future thoughts, 23 episodes (10.6%) as present thoughts, and 58 episodes (26.6%) as atemporal thoughts. In the No-cues group, out of 106 MW episodes, 30 episodes (28.3%) were classed as past episodes, 41 episodes (38.7%) as future thoughts, 15 episodes (14.1%) as present thoughts, and 20 episodes (18.9%) as atemporal thoughts. Descriptive data (mean proportions and standard deviations) as a function of group are reported in Table 2.3.

Variable	Verbal-cues		No-cues	
	M	SD	M	SD
Past-focused MW	0.47	0.25	0.29	0.33
Present-focused MW	0.10	0.13	0.14	0.21
Future-focused MW	0.19	0.19	0.39	0.34
Atemporal MW	0.24	0.18	0.18	0.25

Table 2.3. Mean proportions and standard deviations of different temporal orientations of MW (past, present, future, atemporal) as a function of group (Verbal-cues group vs. No-cues group).

To assess the effects of the experimental manipulation on the temporal focus of MW, the mean proportion of each type of thought (past, present, future and atemporal) was calculated per person and entered into a 2 (Group: Verbal-cues vs. No-cues) x 4 (Temporal focus: past, present, future, atemporal) mixed ANOVA.

The analysis was carried out on participants who reported at least 3 thoughts, and the epsilon correction for the degrees of freedom suggested by Greer and Dunlap (1997) was used to take into account that, for each participant, the sum of the values (proportion) across the conditions of the temporal focus factor is constant, namely 1.

The analysis revealed a significant main effect of Temporal focus, $F(2.6,99.2) = 8.08$, $p < 0.0005$, $\eta^2 = 0.18$. Pairwise comparisons with Bonferroni adjustment indicated that the proportion of present ($M = 0.12$) was significantly lower than past ($M = 0.35$, $p < 0.0001$, $d = 0.94$) and future ($M = 0.30$, $p < 0.005$, $d = 0.69$). The Group x Type of temporal focus interaction was also significant, $F(2.6,99.2) = 5.53$, $p < 0.005$, $\eta^2 = 0.13$. The Verbal-cues group reported a higher proportion of past episodes compared to the No-cues group ($M = 0.45$ vs. $M = 0.26$, $p < 0.01$, $d = 0.53$) and a lower proportion of future events ($M = 0.20$ vs. $M = 0.40$, $p < 0.01$, $d = 0.52$). In the Verbal-

cues group, the proportion of past episodes ($M = 0.45$) was significantly higher than present thoughts ($M = 0.09$, $p < 0.000005$, $d = 1.10$), future thoughts ($M = 0.20$, $p < 0.05$, $d = 0.56$) and atemporal thoughts ($M = 0.26$, $p < 0.05$, $d = 0.54$), and the proportion of atemporal thoughts was significantly higher than present thought ($p < 0.05$, $d = 0.61$). In the No-cues group, the proportion of future thoughts ($M = 0.40$) was significantly higher than present thoughts ($M = 0.15$, $p < 0.05$, $d = 0.62$). These results are shown in Figure 2.5.

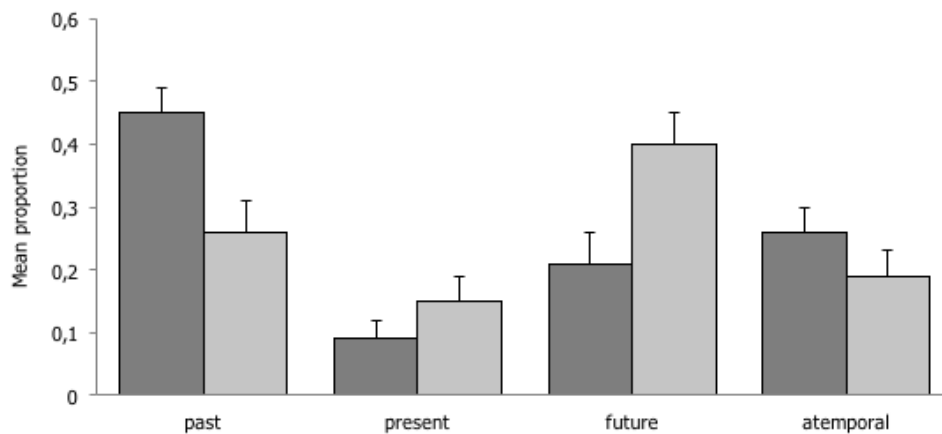


Figure 2.5. Mean proportion of past-focused, present-focused, future-focused, and atemporal MW in the Verbal-cues and No-cues groups. Error bars represent standard error. Dark grey: Verbal-cues group; light grey: No-cues group.

To further investigate this aspect, we ran a secondary analysis limited to the MW episodes that participants reported as being triggered by the verbal cues, and examined the mean proportion of each type of temporal focus (i.e., past, present, future, atemporal) calculated over the total amount of MW triggered by the cue-words.

Again, the analysis was carried out on participants who reported at least 3 MW episodes and the epsilon correction for the degrees of freedom suggested by Greer and Dunlap (1997) was used to take into account that, for each participant, the sum of the

values (proportion) across the conditions of the temporal focus factor is constant, namely 1. The analysis revealed a significant main effect of Temporal focus, $F(1.7,36.1) = 15.35$, $p < 0.00005$, $\eta^2 = 0.42$. Pairwise comparisons with Bonferroni adjustment indicated that the proportion of past ($M = 0.50$) was significantly higher than the proportion of present ($M = 0.08$, $p < 0.000005$, $d = 1.75$) and future ($M = 0.09$, $p < 0.00005$, $d = 1.56$). The proportion of atemporal ($M = 0.32$) was significantly higher than the proportion of present ($p < 0.05$, $d = 0.83$) and future ($p < 0.05$, $d = 0.75$) and it did not significantly differ from the proportion of past ($p = 0.65$, $d = 0.42$).

Phenomenological properties of MW reported

At the end of the vigilance task, participants were asked to specify for each event whether it was general or specific, and whether it was self-related or not. Out of 324 MW reports, 182 reports (56.2%) were classed as specific and 248 reports (76.5%) were classed as self-related. In the Verbal-cues group, out of 218 MW reports, 118 reports (54.1%) were classed as specific and 167 reports (76.6%) as self-related. In the No-cues groups, out of 106 MW reports, 64 reports (60.4%) were classed as specific and 81 reports (76.4%) were classed as self-related.

To assess whether the presence of verbal cues affected these two phenomenological qualities of MW, for each participant we calculated the proportion of specific MW episodes and the proportion of self-related MW episodes. Two independent sample t-tests were performed to compare the mean proportion of specific MW episodes and self-related MW episodes between No-cues and Verbal-cues groups. The results did not reveal any significant difference between the two groups in the mean proportion of specific MW episodes ($t(54) = 0.28$, $p = 0.78$, $d = 0.07$) or in the mean proportion of self-related mental contents ($t(54) = 0.22$, $p = 0.80$, $d = 0.07$).

Latency data

For each MW episode indicated by participants (Verbal-cues group only) as triggered by a cue-word, we could compute the time-interval occurring between the presentation of the cue-word and the moment that participants pressed the button to report a mental content triggered by that cue-word. We referred to these time-intervals as to latency data for MW episodes. Latency data were calculated by adding the time for the present (clicked on) trial, to the times for all the trials back, up to the trial that presented the cue-word that was reported by the participant as the trigger of the mental content. For example, if a triggering word was presented at trial 0 and participants reported the triggered thought after 100 msec. from the beginning of trial 2, we computed 3100 msec. as latency for that thought (see also studies on involuntary memories for a similar procedure to obtain retrieval times; e.g., Schlagman & Kvavilashvili, 2008; Vannucci et al., 2015).

We checked for possible outliers, by transforming each data point into standardised data point and identified data greater than 2.5 in absolute value as outliers. Out of the 129 MW episodes triggered by the cue-words, six were identified as outliers because of the very high time-interval between the trigger and the report of MW.

The mean latency of the remaining MW episodes was 6131.05 msec. ($SD = 4920.82$ msec., range 909-25230 msec.). Since each trial lasted 1500 msec., the mean number of trials being between a trigger and the report of a MW episode triggered by that trigger was 4.09 trials ($SD = 3.28$ trials, range 0-17 trials). Out of the 123 MW episodes, 71 episodes (57.72%) were reported after a latency lower than or equal to 5 sec., 29 episodes (23.58%) were reported after a latency greater than 5 sec. and lower than or equal to 10 sec., 14 episodes (11.38%) were reported after a latency greater

than 10 sec. and lower than or equal to 15 sec., and 9 episodes (7.32%) were reported after a latency greater than 15 sec.

For exploratory purposes, we analysed whether the temporal orientation of MW affected the latency data. We used a multilevel (or hierarchical) dataset in which the unit of analysis was a single MW episode. The use of this strategy of analysis not only allowed us to take into account the non-independence of the units of analysis, but also to accommodate for unequal numbers of data points within participants (Jahng, Wood, & Trull, 2008). We specified random-intercept multilevel models to test for associations of the factor Temporal focus (past, present, future, atemporal) with the latency data (measured in msec.), which was considered as the dependent variable. Given that the latency data were substantially skewed and kurtotic, we conducted the analysis after log transformation of the data.

The analysis revealed no significant differences between temporal focuses, $F(3,107.75) = 0.37, p = 0.77$ (past Estimated Marginal Mean = 3.72, 95% Confidence Interval [CI]: 3.62-3.83; present Estimated Marginal Mean = 3.68, 95% CI: 3.51-3.85; future Estimated Marginal Mean = 3.65, 95% CI: 3.48-3.81; atemporal Estimated Marginal Mean = 3.68, 95% CI: 3.56-3.81).

2.4 Discussion

In the present study, we investigated the causal role of the exposure to verbal cues in triggering and shaping MW. Two groups of participants performed a vigilance task and recorded their MW episodes experienced during the task with a self-caught procedure. One group was also exposed to task-irrelevant verbal cues in some trials of the task, whereas the other group was not exposed to any verbal cues. The findings

showed that the exposure to task-irrelevant verbal cues positively affected the amount of MW, with a significantly higher number of MW episodes reported by the Verbal-cues group compared with the No-cues. The Verbal-cues group also reported a higher proportion of past-oriented MW compared with the other temporal orientations. The higher amount of MW shown by the Verbal-cues group demonstrates that the external context can stimulate the occurrence of MW. This is further confirmed by the fact that in the Verbal-cues group, the number of MW episodes triggered by the cue-words was significantly higher compared with MW episodes triggered by internal thoughts, by environmental stimulus and by no trigger. Moreover, the two groups did not significantly differ with respect to the amount of MW triggered by internal thoughts, environmental stimuli and no trigger, indicating that the difference in the rate of MW is likely attributable to the cue-words themselves.

In addition to this interpretation, it should be also considered the possibility that the mere presence of distractors may reduce participants' attention and make them more susceptible to MW. This explanation would be consistent with previous evidence showing that people with worse performance on attentional tasks are more prone to experience MW (Hu, He, & Xu, 2012). However, our results do not seem to support this view. Besides the fact that the Verbal-cues and the No-cues group did not differ with respect to the amount of MW not triggered by the cue-words, they also did not differ in the level of concentration and the amount of ED reported. In fact, by assessing separately MW and ED, we could show that only MW increased under the exposure to verbal cues. This result additionally confirms previous studies showing that MW and ED are partially distinct processes (e.g., Stawarczyk et al., 2014; Unsworth & McMillan, 2014; Unsworth & Robison, 2016; see also section 1.1 in Chapter 1 of the present work).

The potential contribution of the external context as trigger for MW has not been considered by most of the research on MW and MW episodes has been often described as “stimulus-independent thoughts” (e.g., Antrobus et al., 1966) or “self-generated thoughts” (e.g., Smallwood, 2013). Perhaps, this lack in the research is also caused by the fact that the experimental paradigms that have been mainly used to investigate MW did not allow to distinguish between the initiation of MW and its maintenance over time due to either the nature of the task or the sampling method. For example, by using tasks involving simple stimuli (i.e., digits, letters, shapes), the likelihood that MW is triggered by any external stimulus is clearly reduced. Moreover, the vast majority of studies did not apparently consider the possibility that MW could be triggered by various stimuli and did not include an assessment of the potential triggers of MW. By doing so, the relative contribution of external stimuli and internal processes for MW occurrence might have been overlooked. Only recently, some studies have started addressing the question about the cue-dependent nature of MW (e.g., Maillet & Schacter, 2016; Maillet, Seli, & Schacter, 2017; McVay & Kane, 2013; Plimpton et al., 2015). None of these studies, however, has investigated the causal role of task-irrelevant cues in triggering MW. For example, in a very recent study, Maillet and colleagues (2017) compared MW recorded with thought-probes during a task composed of meaningless stimuli (digits) with that reported during a task composed of meaningful stimuli (words). To identify thoughts triggered by external cues, one of the thought-probes’ questions asked participants about the type of thought experienced: (i) on-task, (ii) thought triggered by a task-stimulus (considered as thoughts dependent from external cues), (iii) thought task-related but not triggered by a task-stimulus, (iv) thought unrelated to the task and not triggered by any task-stimulus. They found that the task with word stimuli was associated with a higher

number of thoughts triggered by task-stimuli and a lower number of thoughts not triggered by task-stimuli compared to the task with number stimuli. Although this study agreed with our findings, it is, however, different from ours because their meaningful stimuli are task-relevant (i.e., their external stimuli are part of the task that participants are explicitly required to process and perform), whereas the verbal cues embedded in our vigilance task are task-irrelevant.

The incorporation of verbal cues into the vigilance task also allowed us to examine the time-interval (or the latency) occurring between the presentation of a verbal cue that acted as trigger for MW and the report of that MW episode. This time-interval might reflect the time spent experiencing a MW state before self-reporting it or the time needed for being aware of that mental content. Interestingly, the measurement of this time-interval made us aware of the variability in times between different MW episodes. In the present study, participants reported some MW episodes after one second or less from the presentation of the cue-word that acted as trigger, and others after 10 seconds or more, suggesting that the latency of MW episodes may actually be very different from a MW episode to another. We explored whether different latencies were associated with different temporal focuses of MW, and we found no significant differences (see also Cole, Staugaard, & Berntsen, 2016, for a similar result on past and future mental time travel). However, future studies should investigate whether the variability in MW latency depends on other characteristics of MW episodes not examined here and/or on participants' characteristics assessed with trait-level measures.

Our results also showed that not only the frequency of MW but also the temporal focus of MW episodes can be manipulated by systematically modifying the external context. Previous studies revealed that, although evidence indicates a prospective bias

in MW (Baird et al., 2011; Song & Wang, 2012; Stawarczyk, Majerus, Maj, et al., 2011), the temporal focus of MW is rather flexible, and specific features, such as cognitive load, negative mood or interest, may affect the temporal orientation of MW (e.g., Baird et al., 2011; Poerio et al., 2013; Smallwood et al., 2009; Smallwood & O'Connor, 2011; see section 1.4 in Chapter 1 of the present work). Our findings suggest that the exposure to external stimuli can bias the temporal focus as well, by increasing the proportion of past-focused MW. This retrospective bias is also consistent with the results of very recent studies (Maillet et al., 2017; Maillet & Schacter, 2016) showing that MW indicated by participants as triggered by external (but not task-irrelevant) stimuli was primarily past-oriented, whereas stimulus-independent MW did not have a temporality bias, that is it was equally likely to be about the past and future. Other evidence reported that, compared to memories (i.e., past-oriented MW), involuntary future thinking is related to and triggered primarily by current concerns (Cole & Berntsen, 2016) and thus less dependent from external stimulation. As suggested by Maillet and Schacter (2016), the association between external stimuli and past episodes *“may be an important mechanism that helps individuals relate the current environmental situation to similar situations they have encountered in the past, which may in turn help guide appropriate action (e.g., Preston & Eichenbaum, 2013)”* (p. 377).

Finally, some future developments of the present study should be considered. Although our results make an important contribution for the role of external, meaningful and task-irrelevant stimuli in MW, the events that control MW occurrence and the mechanisms associated with the onset of thoughts should be further examined. A good way to address this would be to combine self-reports of MW with objective measures. The procedure used in the present study (see also Plimpton et al., 2015)

allow to collect subjective information about which verbal cues triggered MW episodes according to participants and thus to identify the possible onset of MW episodes. Future studies should examine whether the onset of a MW episode (i.e., in the present study, the verbal cue which is, subjectively, reported to have triggered the MW) might be associated with a specific objective marker, such as a change in behavioural measures as well as neural or physiological activity.

Future investigations might also examine the role of external cues in MW by using a probe-caught instead of a self-caught technique. In our study, participants were instructed to stop the task whenever they realised that they were thinking about something and thus they necessarily reported only those MW episodes of which they were aware. Moreover, the presentation of verbal cues, albeit infrequent, might break up the flow of thoughts and induce participants to become aware of their mental contents and report them. Although our findings are in line with the ones found by Plimpton and colleagues (2015) with a probe-caught procedure, future studies might further explore the role of external cues in MW by employing a probe-caught procedure.

Chapter 3

Tracking the dynamics of mind-wandering: a pupillometry study (Study 2)

3.1 Introduction and aims of Study 2

Our findings reported in Chapter 2 support the view of MW as a process possibly triggered by external, meaningful and task-irrelevant stimuli (see also, for example, Maillet et al., 2017; Plimpton et al., 2015). This finding opens to the possibility to investigate the events surrounding the moment of MW onset and the dynamic of thoughts' flow over time, converging with the need of considering MW as a dynamic process (Christoff et al., 2016). The next step is, therefore, to approach towards the strategy of triangulation of measures (Smallwood & Schooler, 2015) and associate stimuli which act as triggers for MW with objective measures of MW onset and maintenance (how MW unfolds over time). A proper index for addressing these aspects may be a physiological measure such as pupil activity. In this introduction, we will briefly present some literature showing how pupillometry can be used as a valid tool for studying high order cognition, and will report previous studies which have already used pupillometry in MW research.

3.1.1 Pupillometry and high-order processes

For a long time, research on pupil activity has focused on the information that pupils could give about sensory processing and perceptual inputs (e.g., the well-known pupillary light reflex). However, a number of studies have demonstrated that pupil measures can also reveal information about high-order cognition (see Eckstein, Guerra-Carrillo, Miller Singley, & Bunge, 2017; Hartmann & Fischer, 2014; Mathot, 2018; Sirois & Brisson, 2014). In the perception field, for example, it has been demonstrated that pupils respond to high-order evaluation of stimuli both presented visually (Binda, Pereverzeva, & Murray, 2013) or imagined (Laeng & Sulutvedt, 2014). When participants were presented with images showing the sun or the moon, pupil constricted to a greater extent to the images of suns, despite controlling for luminance of the images (Binda et al., 2013). This effect was also found by only asking participants to imagine scenes while looking at an empty background: pupil constrictions were higher when participants imagined high luminance scenes (Laeng & Sulutvedt, 2014).

Moreover, a response of pupil dilation is associated with emotional (e.g., an arousing stimulus or mental image) and cognitive load (e.g., working memory load). Some authors stated that something increasing the processing load in the mind also causes the pupil to dilate (Beatty & Lucero-Wagoner, 2000; Loewenfeld, 1958; Mathot, 2018). The seminal work by Hess and Polt (1960, 1964; see also Hess, Seltzer, & Shlien, 1965), and Kahneman and Beatty (1966) showed that pupil size is a reliable indicator of mental effort and arousal. Hess and Polt (1964) asked participants to perform mathematical problems (multiplications) of different levels of difficulty while pupils were recorded. Results showed that pupil dilation indicated mental activity and that the size of the pupil increased with the difficulty of the problems. Similarly,

Kahneman and Beatty (1966) requested participants to perform short-term memory tasks (i.e., strings of digits to be remembered; a string of monosyllabic nouns to be remembered; a string of four digits presented for transformation) while pupils were recorded. The number of the digits to be remembered was varied (three to seven digits per string) and the results showed that a pupil dilation occurred with the presentation of each digit and that the pupil size were directly related to the number of digits that were memorized. Moreover, the comparison between the pupil size recorded in the task of digits' recall and the pupil size recorded during the other more difficult tasks (i.e., recall of words and digits transformation) revealed that pupil dilation was higher when participants performed the more difficult tasks. These results suggest that pupil dilation is related to task difficulty and processing load. This effect of pupil dilation was also found in other studies on working memory (Ahern & Beatty, 1979; Beatty & Kahneman, 1966; Elshtain & Schaefer, 1968) and decision-making processes (Kahneman & Beatty, 1967; see Sirois & Brisson, 2014).

A relation between pupil dilation and arousal has been also demonstrated (Hess & Polt, 1960; Partala & Surakka, 2003). For example, in the early work by Hess and Polt (1960), participants were asked to look at images that varied in how arousing they were, and whom the images were arousing to (based on the authors' subjective impression of the images). The results showed that when participants viewed images that were arousing to them, their pupils dilated (e.g., men's pupils dilated most to images of naked women, whereas women's pupils dilated most to images of babies and naked men) (see also Partala & Surakka, 2003, for auditory processing of stimuli). Moreover, it has been suggested that pupil dilation may depend on arousal (intense *vs.* neutral) instead of valence (positive *vs.* negative), as it has been found no significant difference whether arousal is triggered by something pleasant or unpleasant (e.g.,

Bradley, Miccoli, Escrig, & Lang, 2008; Partala & Surakka, 2003; but see Libby, Lacey, & Lacey, 1973). Bradley and colleagues (2008) also found that pupillary changes covaried with skin conductance reactions during picture viewing, again providing support for the hypothesis that pupil diameter is associated with arousal.

Other evidence also suggests that pupil dilation is associated to painful stimuli (e.g., Chapman, Oka, Bradshaw, Jacobson, & Donaldson, 1999; Ellermeier & Westphal, 1995) and to interpersonal touch, such that it is higher whether participants are touched by a human hand compared with similar machine touch (Ellingsen et al., 2014).

Research has suggested that pupil activity is related to the functioning of the locus coeruleus-norepinephrine (LC-NE) system in the brain. With the use of single-cell recording in monkeys and brain imaging techniques, robust findings have established that changes in pupillary diameter are tightly correlated to changes in activity in the LC (e.g., Alnaes et al., 2014; Joshi, Li, Kalwani, & Gold, 2016; Rajkowski, Kubiak, & Aston-Jones, 1993; Rajkowski, Majczynski, Clayton, & Aston-Jones, 2004). This has been proposed as support for considering pupil diameter as a proxy for NE-LC activity. An important framework that links pupil activity to the LC-NE system in regulating behaviour is the adaptive-gain theory (Aston-Jones & Cohen, 2005; see also Eckstein et al., 2017; Mathot, 2018). This theory postulates that the LC-NE system balances the trade-off between two different modes of behaviour (i.e., the exploitation and exploration modes) that are alternated to optimize reward. Exploitation refers to a mode when one is engaged in a single activity and is exploiting the rewards associated with that activity, whereas exploration refers to a mode when one is easily distracted and switch from a task to another so as to explore different tasks and find the one that offers the higher rewards. Exploitation would be associated with intermediate, phasic

(evoked by stimuli) LC activity, and, consequently, an intermediate pupil size, whereas exploration is associated with high, tonic (overall sustained) LC activity, and, consequently, large pupils. This relation is also consistent with the Yerkes-Dodson inverted U-curve (Yerkes & Dodson, 1908) relating arousal and performance. Empirical evidence for the adaptive-gain theory has been reported (e.g., Gilzenrat, Nieuwenhuis, Jepma, & Cohen, 2010; Jepma & Nieuwenhuis, 2011). For example, Jepma and Nieuwenhuis (2011) asked participants to perform the Four Armed Bandit task, which leads to exploration-exploitation cycles in behaviour, while collecting pupil measures. Participants had to select a card from one of four possible decks and each deck was associated with a certain pay-off that changed gradually over time. Once participants discovered that a deck had a high pay-off, they kept selecting cards from this deck (i.e., exploitation behaviour). Since pay-off changed gradually, once the high-value deck was no longer profitable, participants started trying other decks (i.e., exploration behaviour). Analyses on pupillary data showed that pupils were larger during exploration than during exploitation behaviours, consistent with the adaptive-gain theory.

3.1.2 Pupillometry and mind-wandering

To date, only a few studies have investigated pupillary correlates of MW and contradictory findings in both pupil diameter and phasic pupillary response have been reported. These divergences may also depend on the employment of different classifications of MW episodes and various tasks (more or less demanding and including or not external stimuli) as well as different time-windows to analyse pupil activity (Grandchamp, Braboszcz, & Delorme, 2014; Unsworth & Robison, 2018). In the present section, we will briefly review these studies.

Two of the first pioneering studies reported a relationship between periods of off-task thinking and specific measures of pupil activity (Smallwood et al., 2012; Smallwood, Brown, et al., 2011), even though they did not combine thoughts' sampling and physiological measures during the same task. For example, Smallwood, Brown, et al. (2011) reported that periods of off-task thinking were associated with higher pupil diameter and reduced phasic pupillary response to external stimuli. Specifically, these authors asked participants to perform two different tasks (i.e., a choice reaction time and a working memory tasks) that required participants to make a choice on some target stimuli and were previously found to be associated with a different rate of off-task thinking, with the choice reaction time stimulating more off-task states. While participants performed these task without thought sampling, their pupils were continuously recorded. The analysis on pupil activity in the 2.5 sec. after the presentation of non-target stimuli showed that an evoked pupil response was recorded in the working memory task but not in the choice reaction time task (see also Kang, Huffer, & Wheatley, 2014, for a replication of the same results by employing the same procedure and controlling for isoluminance of the stimuli), and, according to the authors, corroborated the perceptual decoupling hypothesis, as the pupil response to external stimuli was reduced in the task which should be associated with higher occurrence of off-task thinking. Moreover, they found that in the 1.5 sec. period prior to a non-target stimulus, the average pupil diameter in the choice reaction time task was larger than in the working memory task (Smallwood, Brown, et al., 2011).

These studies are a first step toward demonstrating a relationship between pupil diameter and MW; however, they did not combine pupillometry and MW sampling during the same task.

Next, other studies recording pupil measures and reports of MW simultaneously have been conducted in order to investigate the relationship between MW and both measures of pupil diameter and phasic pupillary response, despite reporting somehow contradicting findings (Franklin et al., 2013; Grandchamp et al., 2014; Konishi et al., 2017; Mittner et al., 2014; Unsworth & Robison, 2016; Uzzaman & Joordens, 2011).

As for pupil diameter, Franklin et al. (2013), for example, employed a reading task with thought-probes, and found that the pupil diameter in the 10 sec. preceding an off-task report (i.e., before a thought-probe where an off-task report was given) was higher than that preceding an on-task report. Other studies found no significant effect on pupil diameter (Unsworth & Robison, 2018, Experiment 2; Uzzaman & Joordens, 2011) or an opposite pattern (Grandchamp et al., 2014; Konishi et al., 2017; Mittner et al., 2014; Unsworth & Robison, 2016; Unsworth & Robison, 2018, Experiment 1) by using completely different tasks (e.g., more demanding; Mittner et al., 2014; Unsworth & Robison, 2016) and different time-interval to measure pupil activity. For example, Grandchamp et al. (2014) found a reduction in pupil diameter associated with off-task by using a more indirect comparison between off-task and on-task states. Specifically, they asked two participants to count backward each of their breath cycles from 10 to 1 (at 1, they had to restart counting backward from 10) and to also indicate whenever they realized they had lost track of their breath count by pressing a button (i.e., these button presses were considered as MW periods). Results showed that the pupil size in the 9 sec. time-interval before button presses was smaller than the pupil diameter in the 9 sec. time-interval after button presses (i.e., re-focusing periods, when participants started the task again after reporting the drift of their attention). Thus, in this study, both the type of the task and the method for comparing the pupil diameter were clearly different compared to the previous one.

A smaller pupil diameter associated with off-task states was also found by Konishi and colleagues (2017; Experiment 2) by using a different task and different time-windows to compare pupil activity again. Specifically, they used a task composed of a 0-back and 1-back conditions that continuously switched from one to the other and thought-probes that included ten questions during the task. The first question of thought-probes requested participants to indicate on a continuous slider scale their focus of attention (from “completely off-task” to “completely on-task”). From the analysis of the pupil diameter in an average time-window of 3.5 sec. before thought-probes, they found that off-task states – particularly those associated with a focus on the past and with an intrusive quality – were associated with a smaller pupil diameter compared to on-task states and that this association between pupil diameter and off-task experience seemed to be only significant in the 0-back condition of the task (i.e., not in the 1-back condition).

As for the studies investigating the relationship between MW and phasic pupillary activity, some studies replicated the results found by Smallwood, Brown, et al. (2011) of reduced phasic pupillary responses to external stimuli during off-task states (Mittner et al., 2014; Unsworth & Robison, 2016, 2018) while others found no significant differences between on-task and off-task states (Konishi et al., 2017). For example, Mittner et al. (2014) employed a stop-signal paradigm (i.e., participants responded as quickly as possible to the orientation of an arrow pointed to the left or to the right and withheld their response whenever they perceived an auditory stop-signal). Thought-probes asked participants to indicate where their attention was on a five-point Likert scale (ranging from task-independent to task-centred). Analyses of pupil activity revealed that off-task trials were associated with reduced pupillary response to task-stimuli.

The same results were obtained by Unsworth and Robison (2016), by using a psychomotor vigilance task (i.e., a quite demanding task compared to a reading task or a choice reaction time task). One valuable aspect of this study is that these authors introduced the distinction among different attentional states (i.e., on-task, task-related interferences, external distraction, MW, blank mind) into thought-probes. Similarly to the previous study, analyses on pupil data showed that task-evoked pupillary response was higher when associated with on-task reports than MW reports and the pupil diameter recorded during a fixation screen before stimulus presentation was smaller when associated with a subsequent MW report than when associated with an on-task report.

Finally, in addition to the findings on pupil diameter and pupillary phasic responses, variability in pupil diameter has been also reported during MW states compared with on-task states (Bixler & D’Mello, 2016).

3.1.3 Aims of Study 2

All the studies described above examined the pupil diameter associated with a MW/off-task state by using a fixed time-window prior to the probe, set by the researcher and identical for each MW episode and for each participant (although different between studies). The main aim of the present study was, instead, to examine the pupil activity occurring after external cues indicated by participants as triggers for MW episodes. In this way, we could extend further the results found in Study 1 (see Chapter 2) by obtaining a covert measure associated with the onset of MW episodes. The association between self-reports of MW and physiological measures could allow to investigate the dynamic of MW onset that was not possible to investigate by using only the self-report measure. Since pupil activity is considered as an index of high-

order cognition and particularly for emotional and cognitive load (e.g., Hess & Polt, 1960; Partala & Surakka, 2003), we could hypothesize that the onset of a MW episode was associated with a change in pupil diameter (i.e., a dilation).

In addition to this main aim, we also analysed the activity occurring before thought-probes, in order to make a comparison with previous pupillometry studies of MW.

Moreover, we examined whether the experience of MW could modify the sensory response of the pupil to weak luminance stimuli presented during our undemanding vigilance task. According to the perceptual decoupling hypothesis (e.g., Schooler et al., 2011), the processing of sensory input should be decreased when the mind wanders toward internal information to insulate the internal train of thought from the external information. In order to verify this hypothesis, we analysed the sensory response of the pupil to the stimuli of the task immediately preceding thought-probes where MW or on-task reports were given.

3.2 Method

3.2.1 Participants

Fifty undergraduate students from the University of Florence (41 females, age range 18-27 years, $M = 20.84$ years, $SD = 2.38$ years) volunteered to take part in the study. All participants were Italian native speakers and they had normal or corrected-to-normal vision. The experimental protocol is consistent with the declaration of Helsinki and with the regulations of the University of Florence that hosted the study.

3.2.2 Apparatus

Task stimuli were generated with the PsychoPhysics Toolbox routines for MATLAB (MATLAB r2010a, The MathWorks) and presented on a LCD colour monitor (Asus MX239H, 51 x 28 cm, resolution of 1920 x 1080 pixels, refresh rate of 60 Hz), driven by a Macbook Pro Retina (OS X Yosemite, 10.10.5). All stimuli were shown in white (55 cd/m^2) against a black background (0.05 cd/m^2).

Participants sat in front of the monitor screen at 57 cm viewing distance, with their heads stabilised by chin rest (see Figure 3.1). Two-dimensional eye position and pupil diameter were recorded binocularly with a CRS LiveTrack system (Cambridge Research Systems) at 30 Hz, using an infrared camera mounted below the screen. Pupil diameter measures were transformed from pixels to millimetres after calibrating the tracker with an artificial 4 mm pupil, positioned at the approximate location of the participants' left eye. Gaze position data were linearized with a standard 9-point calibration, run prior to each session.



Figure 3.1. Illustration of the apparatus used for each participant in the study.

3.2.3 Materials

Vigilance task

Participants performed a modified version of the computer-based vigilance task developed by Schlagman and Kvavilashvili (2008) and used in previous studies on spontaneous thought processes (e.g., Plimpton et al., 2015; Vannucci et al., 2015, 2016; see also Chapter 2 of the present work). This task consisted of 1120 trials, presented in a fixed order, each remaining on the screen for 2 sec. A white fixation point (0.2 deg diameter) was presented in the centre of the screen for each trial. In each trial, an image was shown depicting a pattern of white horizontal (non-target stimuli) or white vertical (target stimuli) lines (4.1 x 0.2 deg) on a black background. Target stimuli appeared on 68 trials (~6% of all trials) and they were presented pseudo-randomly, with a minimum of 9 and a maximum of 31 trials between each target stimulus. In addition to the lines, a white cue-word (e.g., “exquisite dinner”; 0.88 deg height) was also shown under the fixation spot in 210 trials (18.75% of all trials) (see Figure 3.2 for an example of the experimental trials). These word-phrases were selected from the pool of word-phrases developed by Schlagman and Kvavilashvili (2008) and adapted to the Italian sample (Vannucci et al., 2015; see also Chapter 2 of the present work). Equal numbers of positive ($n = 70$), negative ($n = 70$) and neutral ($n = 70$) cue-words were included.

Thought-probes

At 28 fixed points (separated by an average of 40 trials, $SD = 7.50$, corresponding to an average of 80 sec., $SD = 15$ sec.) during the presentation, the vigilance task was stopped by a thought-probe that requested participants to answer some questions before continuing the task. First, participants were asked about what they were

thinking just immediately prior to the probe. They could report that they were focused on the task (on-task report) or that they were thinking about something else or that their mind was blank. Second, if participants reported that they were thinking about something else, they should (i) give orally a short description of their thoughts (recorded by the experimenter), (ii) indicate if the thoughts occurred spontaneously (i.e., simply popped into their mind), if they deliberately decided to think about them or if they were not sure about the answer, and (iii) indicate whether the thoughts had been triggered by the environment, by internal thoughts, by a cue-word on the screen (if so, they had to specify the cue-word) or if there was no trigger.

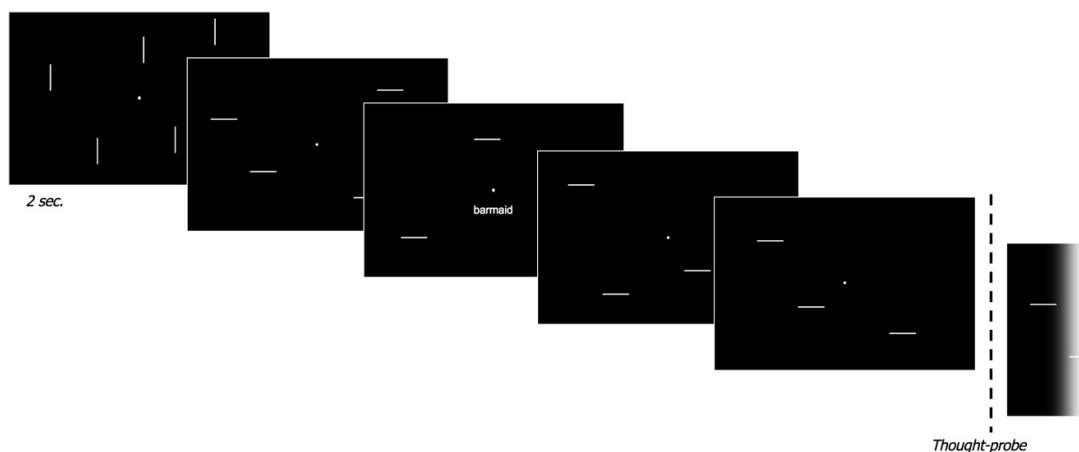


Figure 3.2. Schematic of the experimental task. Horizontal lines: non-target stimuli; vertical lines: target stimuli to be detected by pressing a button.

3.2.4 Procedure

Participants were tested individually. After being welcomed in the laboratory, participants were briefly introduced to the research project and eye-tracking recording, being informed that they would take part in a study on concentration and its correlates, and signed a consent form. Afterwards, they received the instructions for the vigilance

task. It was explained that they had to detect target stimuli (vertical lines) in a stream of non-target stimuli (horizontal lines), by pressing the space-bar each time a target was detected. Moreover, they were told that they would also see cue-words in some of the trials and that they were not supposed to do anything with these task-irrelevant cue-words. It was explained that the condition they were taking part in was looking at how people could keep their concentration on the lines and that participants in another condition would have to concentrate on the cue-words (it was a cover story). Next, participants were informed that the task was quite monotonous and that they could find themselves thinking about other things (e.g., thoughts, plans, considerations, past events, images, etc.). These mental contents could pop into their mind spontaneously or they could be intentionally generated. Participants were told that they would be interrupted during the performance and presented with thought-probes consisting of questions about (i) their focus of attention just immediately prior to the probe, (ii) whether their thoughts (if they reported any) were spontaneous or deliberate, (iii) the trigger of these thoughts (if they reported any) (see Materials, Thought-probes section). If the mental content was private and intimate, participants could label it as “personal” and eventually provide only one relevant word instead of reporting a short description. Finally, they were also requested to focus on the fixation spot for the whole duration of the task.

Participants were given a 20-trials practice session, and a 5-minutes break was allowed between the two halves of the task. Finally, participants were asked whether they had speculated about the actual aims of the study (if so, what they had thought) during the task and then they were debriefed and dismissed. The total session lasted approximately 120 minutes.

3.2.5 Analyses of pupillometry data

Analyses were carried out on 42 out of 50 participants³. First, an off-line analysis examined the eye-tracking output in order to exclude time-points with unrealistic pupil-size recordings (i.e., values outside the 90th percentile of each 2 sec. long trial) and interpolated the remaining time-points at 20Hz. This procedure yielded smooth and consistent pupil traces, excluding only 4.45% of trials due to excessive signal loss (> 60% of the time-points). This approach, however, retains for analysis trials where a blink might have occurred.

Second, in order to perform our main analyses, trials were selected based on the responses given to thought-probes by each participant. Specifically, before analysing the data, all the mental contents reported by participants were read by two independent judges and classified into distinct categories. The categorization was based on the categories already used in previous studies (e.g., Plimpton et al., 2015; Unsworth & Robison, 2016; see also Chapter 2 of the present work). When probed, participants could report that they were on-task, that they had their mind blank or that they were thinking about something else (see Thought-probes section in the Materials). All the on-task reports (i.e., when participants' attention was fully focused on the task) were combined in a single category (OT) and all the blank reports (i.e., when participants' attention was not focused on the task and they appeared thinking about nothing at all, that is their mind was a complete blank) were combined in a single category as well. As for the other contents reported orally by participants and concerning various thoughts, they were classified by the judges as either task-related interferences (TRIs)

³ Five participants were excluded due to non-compliance with task instructions; two participants were excluded due to self-reported mental illness; one participant was excluded due to technical failures in data recording. The sample used for analyses included thus 42 participants (34 females, age range 18-27 years, $M = 20.64$ years, $SD = 2.35$ years).

or task-unrelated thoughts (TUTs). TUTs were next classified as either MW reports or external distraction (ED) reports. As we already explained in the previous chapter (see Chapter 2), TRIs comprised reports whose content was related to any task features or to the current performance on the task, whereas TUTs included no references to the task at hand and comprised both ED and MW episodes. TUTs were classified as EDs when the participant's attention was unrelated to the task at hand and focused on stimuli in the current situation (either exteroceptive or interoceptive perceptions, such as bodily sensations), whereas they were coded as MW episodes when the participant's attention was unrelated to the task at hand and decoupled from the external environment. These thoughts could be triggered by internal or external stimuli. For both categorisations (TRIs vs. TUTs, and MW vs. EDs), Kappa was computed as inter-rater reliability between the coders and the inter-rater agreement resulted to be very good ($Kappa = 0.99$, $SE = 0.01$ and $Kappa = 0.98$, $SE = 0.01$, respectively). Minor disagreements were solved by discussion. Moreover, intentional MW episodes were excluded from the analyses (see Results section for further details).

This classification allowed us to identify thought-probes associated with MW, OT or other reports for each participant. Trials associated with cue-words reported as triggers for MW episodes were identified for each participant as well.

In the first analysis, we compared the time-course of pupil diameter observed in three conditions: after cue-words indicated by participants as triggers for spontaneous MW episodes, after cue-words with emotional content which were followed by on-task reports, and after other "control" cue-words (i.e., all the cue-words that were neither MW triggers nor emotional cue-words followed or preceded by on-task states). In order to perform the analyses on the pupillometry data, trials were sorted based on their timing relative to a cue-word identified as triggering or not triggering a MW

episode (i.e., 0, 1, 2 trials after the cue-word, where the trial 0 was the trial including the cue-word) (see Figure 3.3, top panel). We used as “baseline” pupil diameter the average diameter at the reference event (i.e., the trial 0 where the trigger/non-trigger cue-word was presented) and we studied the time-course of pupil diameter over trials after subtracting this baseline.

In the second analysis, we compared the pupil diameter observed in three conditions: before cue-words indicated by participants as triggers for spontaneous MW episodes, before cue-words with emotional content which were followed by on-task reports, and before other “control” cue-words (i.e., all the cue-words that were neither MW triggers nor emotional cue-words followed or preceded by on-task states). In order to perform the analyses on the pupillometry data, trials were sorted based on their timing relative to a cue-word identified as triggering or not triggering a MW episode (i.e., 0, 1, 2 trials before the cue-word, where the trial 0 was the trial including the cue-word). We used as “baseline” pupil diameter the average diameter in the second half of the reference event (i.e., the trial 0 where the cue-word was presented).

In the third analysis, we compared the pupil diameter observed in three conditions: before thought-probes where a MW report was given, before thought-probes where an on-task report was given, and before any other thought-probe responses. Thus, trials were sorted based on their timing relative to a MW, OT or other report (i.e., 1, 2, 3 trials before the probe where the participant reported being in a MW, in an OT or other state; the trial 1 is the last trial immediately preceding the probe) (see Figure 3.3, bottom panel). We used as “baseline” pupil diameter the average diameter at the reference event (i.e., the trial 1 that was the last trial immediately before the probe).

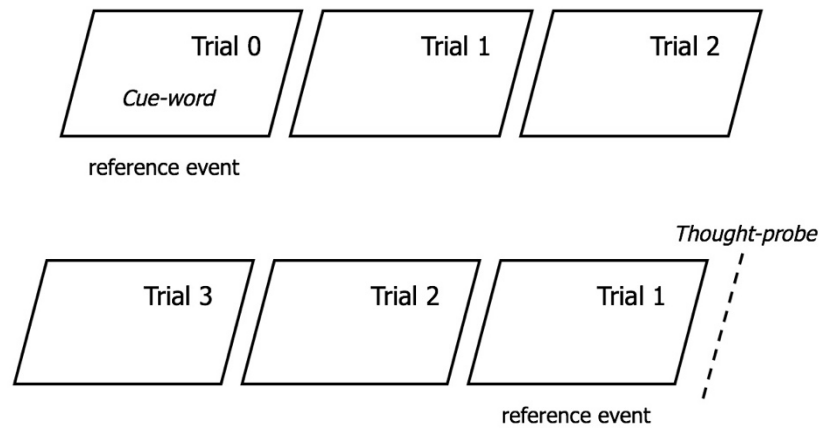


Figure 3.3. Schematic showing trials used for analyses on the time-course of pupil diameter after MW trigger/non-trigger (top), and before thought-probe where a MW/OT/other reports where given (bottom).

In the fourth analysis, we examined the pupil response to the white/light horizontal lines in trials immediately preceding a thought-probe where a MW or OT report was given. For this analysis, the baseline pupil diameter in the first 250 msec. of each individual trial was subtracted from the trace, allowing to evaluate the amplitude of the light evoked pupillary constriction.

Given the considerable sample size variability across participants, statistical analyses relied on a linear-mixed model approach. Individual trials from all participants were compared with a model comprising both the effect of experimental variables (“fixed effects”) and the variability across participants (“random effects”). Random effects were coded by allowing subject-by-subject variations of the intercept of the model. In all cases, the dependent variable was the “baseline corrected pupil diameter”, which we obtained by averaging pupil diameter in a pre-specified temporal window of each trial (e.g., in the interval 500:1000 msec., when the pupil-constriction in response to the task-stimulus is expected to peak), and subtracting the average pupil diameter in a “baseline” temporal window (e.g., in the first 250 msec. of the trial).

Please refer to the results section for specific definitions of the temporal windows for averaging and baseline-subtractions.

We used standard MATLAB functions provided with the Statistics and Machine Learning Toolbox (R2015b, The MathWorks). Specifically, the function “fitlme(data, model)” fit the linear-mixed model to the data, yielding an object “lme” with associated method “ANOVA” that returns F statistics and P values for each of the fixed effect terms and “CoefTest” for post-hoc comparisons.

3.3 Results

Performance on the vigilance task

Performance on the vigilance task was near-perfect for all participants. Out of 68 targets, there were 0.33 ($SD = 0.69$) misses and 0.79 ($SD = 1.14$) false alarms.

Given the very few mistakes reported by participants and the paucity of target-stimuli presented, we were not able to check whether MW reports were associated with worse task performance (i.e., target detection or response times) than on-task reports.

Type and amount of reports collected by probes

Out of the total thought-probes, 309 reports (26.28%) were classed as on-task (OT) reports ($M = 7.36$, $SD = 5.52$, range 0-19), 154 reports (13.10%) were classed as blank mind reports ($M = 3.67$, $SD = 3.79$, range 0-14), 89 reports (7.57%) were classed as TRI reports ($M = 2.12$, $SD = 2.23$, range 0-9), 594 reports (50.51%) were classed as TUT reports ($M = 14.14$, $SD = 5.27$, range 3-23). Out of the all TUTs, 91 reports (15.32%) were classed as ED reports ($M = 2.17$, $SD = 1.75$, range 0-9) and 503 reports

(84.68%) were classed as MW reports ($M = 11.98$, $SD = 5.02$, range 2-22) (see Table 1 for a summary of these descriptive data).

As for the distinction between spontaneous and intentional MW episodes, out of the all MW, 402 episodes (79.92%) were reported as spontaneous MW ($M = 9.57$, $SD = 4.26$, range 2-19) and 88 episodes (17.50%) were reported as intentional MW episodes ($M = 2.10$, $SD = 2.13$, range 0-8) (see Table 3.1); the remaining 13 MW reports (2.58%) were reported with uncertain spontaneity/intentionality (i.e., participants reported that they were not sure whether these thoughts were spontaneous or intentional) ($M = 0.31$, $SD = 0.60$, range 0-3). Besides the fact that we were primarily interested in spontaneous MW episodes, participants reported too few intentional MW episodes and thus these reports were not further considered in our analyses.

Variable	M	SD	range
On-task	7.36	5.52	0-19
Blank mind	3.67	3.79	0-14
Task-related interferences (TRIs)	2.12	2.23	0-9
External distraction (ED)	2.17	1.75	0-9
Mind-wandering (MW)	11.98	5.02	2-22
Spontaneous MW	9.57	4.26	2-19
Deliberate MW	2.10	2.13	0-8

Table 3.1. Descriptive data (means, standard deviations and ranges) of reports collected by thought-probes.

Out of the 402 spontaneous MW episodes, 212 reports (52.74%) were reported by participants as triggered by a specific cue-word shown on the screen ($M = 5.05$, $SD = 2.59$, range 1-12), 18 reports (4.48%) by internal thoughts ($M = 0.43$, $SD = 0.70$,

range 0-2), 25 reports (6.22%) by environmental triggers ($M = 0.60$, $SD = 1.33$, range 0-7), and 119 reports (29.60%) by no trigger ($M = 2.83$, $SD = 2.76$, range 0-13). The remaining 28 MW episodes were indicated by participants as elicited by multiple cue-words (i.e., more than one specific cue-word; $n = 18$), or by unknown cue-word(s) (i.e., participants reported that they did not remember which cue-word triggered the MW episode; $n = 10$).

As for the reports of spontaneous MW triggered by cue-words, there was a mean of 8.97 trials, $SD = 10.37$ ($M = 17.94$ sec., $SD = 20.74$ sec.), between a MW trigger and the thought-probe where the report of MW triggered by that specific cue-word was given.

Finally, out of the all spontaneous MW episodes triggered by the cue-words, 39 reports (18.40%) were triggered by neutral cue-words ($M = 0.93$, $SD = 0.97$, range 0-4), 97 reports (45.75%) were triggered by positive cue-words ($M = 2.31$, $SD = 1.44$, range 0-7), and 76 reports (35.85%) were triggered by negative cue-words ($M = 1.81$, $SD = 1.55$, range 0-7). Thus, the vast majority (81.60%) of these reports were elicited by cue-words with emotional valence.

Analyses of pupillometry data

We conducted four analyses on the pupillary data: (i) the first analysis was conducted on the pupil diameter over two trials after cue-words identified as triggering or not triggering MW episodes; (ii) the second analysis was conducted on the pupil diameter before cue-words identified as triggering or not triggering MW episodes; (iii) the third analysis was conducted on the pupil diameter before thought-probes associated with a MW, OT or any other report; (iv) the fourth analysis was conducted on the pupil response to the white/light horizontal lines in trials immediately preceding

a thought-probe where a MW or OT report was given. These analyses are reported below.

First analysis: MW onset and its unfolding over time. We compared the pupil diameter over two trials after a cue-word identified as triggering or not triggering a MW episode. Cue-words identified as triggering a MW episode were the cue-words that were reported by participants as triggers for MW reports. Cue-words identified as not triggering a MW episode were (i) emotional cue-words that were presented just before a thought-probe where OT reports were given (i.e., indicating that participants were not experiencing any MW state before those thought-probes), (ii) “control” cue-words, that is other cue-words that were neither MW triggers nor emotional cue-words followed or preceded by OT reports. Since the majority of cued MW reports were triggered by emotional cue-words, and pupil dilation is affected by emotional load, we used as a main comparison condition emotional cue-words followed by OT (not triggering words, but with similar emotional valence).

Assuming that the reported trigger of MW acted as a trigger for MW, we analysed and compared the time-course of pupil diameter over two trials after the cue-word (see Figure 3.3, top panel). We only considered cue-words that were followed by at least two trials with successful pupil recording. From this 6-sec. time-course (each trial lasted 2 sec.), we subtracted the average pupil diameter during the first trial (i.e., the word-cue presentation, lasting 2 sec.). This approach left 194 MW trigger cue-words, 215 emotional cue-words followed by an OT report, and 7391 other cue-words. For the statistical analysis of the traces, we summarized time-courses by taking the average pupil diameter in the last second of each trial (the farthest from the reference). These values were entered in a Linear-Mixed Model analysis, with two fixed-factors: type of

cue-word (MW trigger, emotional followed by OT, other control cue-words) and time from the cue (coded as number of trials: 1st trial, 2nd trial), plus the random effect of subjects modelled as variable intercept of the model. This revealed a significant interaction between the two fixed factors ($F(2,23394) = 10.21610, p = 0.00004$). A series of post-hoc tests showed that the type of cue-word had a significant effect over the two trials that followed the cue-word, where there was a significant difference between pupil diameter following MW triggers and emotional cue-words followed by an OT report (1st trial following the cue-word: $F(1,407) = 4.12330, p = 0.04295$; 2nd trial: $F(1,407) = 8.51346, p = 0.00372$). MW triggers were also significantly different from the other control cue-words (1st trial following the cue-word: $F(1,7583) = 12.66170, p = 0.00038$; 2nd trial: $F(1,7583) = 19.97163, p = 0.00001$), whereas emotional cue-words followed by OT were not significantly different from the other control cue-words (1st trial following the cue-word: $F(1,7604) = 1.93229, p = 0.16455$; 2nd trial: $F(1,7604) = 2.23358, p = 0.13508$) (see Figure 3.4).

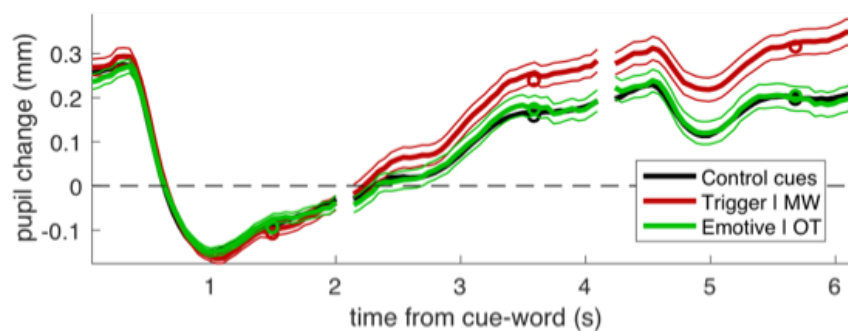


Figure 3.4. Time-course of pupil diameter after cue-word presentation. The pupil traces are aligned to the average pupil diameter during the cue-word presentation (from 0 to 2 sec.). Red lines: traces associated with cue-words reported as triggers for MW episodes; green lines: traces associated with emotional cue-words presented before OT reports; black lines: traces associated with other cue-words presented during the task. Thick lines: average across all trials; thin lines: standard error; circles: average values entered the LMM analysis (average over the second half of each trial).

Second analysis: pupil diameter before MW triggers. Additionally, we compared the pupil diameter before a cue-word identified as triggering or not triggering a MW episode, in order to examine whether the differences in pupil diameter originated from the cue-words or they existed even before. Similar to the previous analysis, the cue-words identified as triggering a MW episode were the cue-words that were reported by participants as triggers for MW reports, whereas cue-words identified as not triggering a MW episode were either emotional cue-words that were presented just before a thought-probe where OT reports were given or other “control” cue-words. We only considered cue-words that were preceded by at least two trials with successful pupil recording. We used as baseline pupil diameter the average diameter in the second half of the trial where the cue-word was presented.

This left 199 MW trigger cue-words, 214 emotional cue-words followed by an OT report, and 7461 other cue-words. For the statistical analysis of the traces, we summarized time-courses by taking the average pupil diameter in the second half of each trial. These values were entered in a Linear-Mixed Model analysis, with two fixed-factors: type of cue-word (MW trigger, emotional followed by OT, other control cue-words) and time from the cue-word (coded as number of trials: 1st trial before the cue-word, 2nd trial before the cue-word), plus the random effect of subjects modelled as variable intercept of the model. Neither the effect of type of cue-word ($F(2,23616) = 0.70888, p = 0.49220$) nor the interaction ($F(2,23616) = 0.66248, p = 0.51558$) were significant, suggesting that there was no significant difference between the conditions (see Figure 3.5).

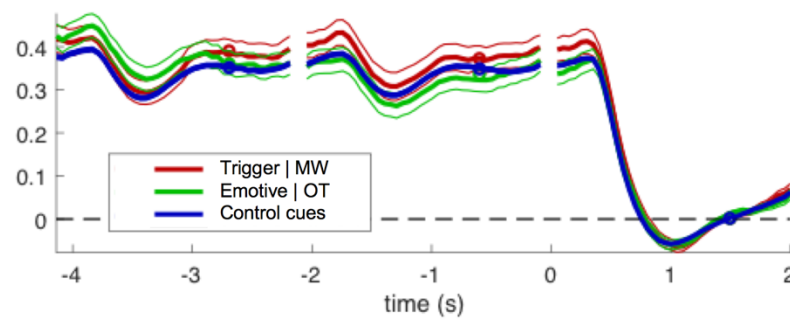


Figure 3.5. Time-course of pupil diameter before cue-word presentation. The pupil traces are aligned to the average pupil diameter during the second half of the cue-word presentation (from 0 to 2 sec.). Red lines: traces associated with cue-words reported as triggers for MW episodes; green lines: traces associated with emotional cue-words presented before OT reports; blue lines: traces associated with other cue-words presented during the task. Thick lines: average across all trials; thin lines: standard error; circles: average values entered the LMM analysis (average over the second half of each trial).

Third analysis: pupil diameter before thought-probes. The third analysis of pupillometry data was conducted on the time-course of pupil diameter over three trials before thought-probe where reports of MW, OT or other reports were given. We aligned traces to the last trial before thought-probe and separated those where reports of MW, OT or other reports were given. We only considered thought-probes that were preceded by at least three trials with successful pupil recording. From this 6-sec. time-course, we subtracted the average pupil diameter during the last trial before thought-probes.

This left 188 MW reports, 144 OT reports, and 236 other reports. For the statistical analysis of the traces, we aligned traces to the average pupil diameter on the last trial before the thought-probe, and assessed pupil diameter on each trial as the mean pupil diameter in the first second of the trial. These values were entered in a Linear-Mixed Model analysis, with two fixed-factors: type of report (MW, OT, others) and time from the thought-probe (coded as number of trials: 3, 2, 1), plus the random

effect of subjects modelled as variable intercept of the model. The Linear-Mixed Model analysis revealed a significant interaction between the fixed-factors type of report and time from the thought-probe ($F(2,1698) = 3.89778, p = 0.02047$). At three trials preceding the thought-probe, pupil diameter leading to MW or OT reports could be clearly differentiated ($F(1,330) = 6.71401, p = 0.00999$) (see Figure 3.6).

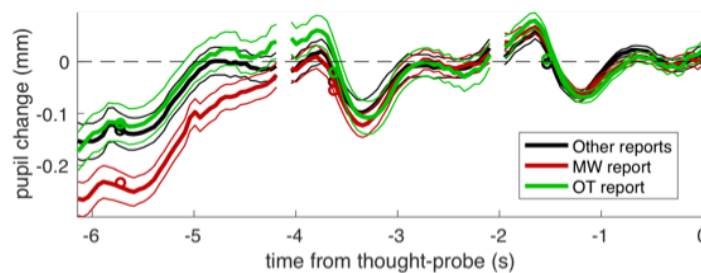


Figure 3.6. Time-course of pupil diameter before thought-probe. The pupil traces are aligned to the average pupil diameter during the last trial before the thought-probe (from -2 to 0 sec.). Red lines: MW reports; green lines: OT reports; black lines: other reports. Thick lines: average across all trials; thin lines: standard error; circles: average values entered the LMM analysis (average over the first half of each trial).

Fourth analysis: pupil light response before MW/OT reports. We also examined whether sensitivity to sensory stimuli is weakened during MW. To address this, we analysed the pupil constriction evoked by the white horizontal lines stimuli in the last trial before thought-probes where MW or OT reports were given (all the trials were not preceded by a cue-word, which would shift the baseline diameter and mask the light response). From each trial, we subtracted the baseline pupil diameter in the first 250 msec. and computed the average constriction in the interval [500:1000 msec.] into the trial, where the pupil response peaked. For the Linear Mixed Model analysis with type of report (MW vs. OT) as fixed factor and the random effect of participants as variable intercept of the model, we had 372 traces for MW reports and 298 traces for

OT reports. The analysis did not reveal a significant difference between the two types of report ($F(1,645) = 0.02219, p = 0.88163$) (see Figure 3.7).

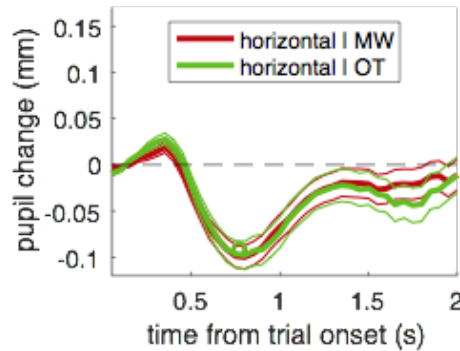


Figure 3.7. Amplitude of the pupil light response in the last horizontal trials before thought-probes where participants reported MW or OT states. The pupil traces are aligned to the average pupil diameter during the first 250 msec. of each trial. Red line: MW report; green line: OT report. Thick lines: average across all trials; thin lines: standard error; circles: average values entered the LMM analysis (average over the [500:1000 msec.] interval).

3.4 Discussion

Very recently, a number of studies have started examining the contribution of the external environment to MW, showing that MW can be triggered by external stimuli (e.g., Maillet et al., 2017; Plimpton et al., 2015; see also Chapter 2). In the present study, we extended these findings further, by combining self-report measures of MW with physiological measures, namely pupil diameter. By employing a vigilance task with task-irrelevant verbal cues that could potentially act as triggers for MW episodes and by tracking the time-course of pupil size over periods of 6 seconds after a MW trigger and a non-trigger (i.e., emotional cue-words associated with OT reports and any other control cue-words), we could monitor the dynamics of MW, tracking its unfolding over time.

We found a significantly larger pupil dilation following MW triggers compared to non-trigger words. These results suggest that an increase in pupil diameter follows the onset of MW and it accompanies its unfolding and maintenance over time. We also found that there was no significant difference in pupil diameter before (1-trial pre and 2-trials pre) MW triggers and non-triggers. This result provides further evidence that the cues reported by participants as trigger of MW did act as triggers.

Following previous work investigating MW by using pupillometry (e.g., Franklin et al., 2013; Unsworth & Robison, 2016), we also compared the pupil diameter recorded before thought-probes associated with MW reports, OT reports or other reports. Also in this case, we obtained the same pattern, such that there was more pupil dilation leading up to a MW report than there was to an OT or other report.

Previous research has linked pupil dilation and emotional and cognitive load (e.g., Hess & Polt, 1960; Kahneman & Beatty, 1966; Partala & Surakka, 2003). Thus, the dilation associated with MW onset could be explained in terms of the increased mental load (i.e., emotional and cognitive processing) involved in MW compared with focused attention to the simple vigilance task (see for similar results, Franklin et al., 2013; Smallwood, Brown, et al., 2011). In line with this interpretation, most of the contents of the MW episodes reported by our participants were personal projections into the personal past (i.e., autobiographical memories) and the future, including emotional states and responses.

Apart from the investigation on MW onset, we also investigated whether MW states affected the sensory and attentional processing of the simple visual stimuli (i.e., white lines) in the vigilance task, by analysing the pupil constriction evoked by the stimuli. According to the perceptual decoupling hypothesis (Schooler et al., 2011; Smallwood & Schooler, 2006), during MW the representations of environmental

stimuli should be superficial and the processing of sensory inputs should be decreased, in order to insulate the internal thoughts' flow from external disruptions. Other studies employing pupillometry found an impairment in sensory processing during MW compared to on-task states (e.g., Smallwood, Brown, et al., 2011; Unsworth & Robison, 2016). In contrast to these studies, we found no significant difference between light responses to stimuli (lines) before a MW or an on-task report (but see Konishi et al., 2017, for similar results). Since our study employed a very simple task with simple visual stimuli (i.e., simple white lines) compared to the other studies, methodological differences could account for this discrepancy. It has been proposed that simple visual stimuli suffer no costs of divided attention, compared to complex visual stimuli (hypothesis of unlimited-capacity parallel processing of multiple simple stimuli, Busey & Palmer, 2008; Palmer, 1994; White, Runeson, Palmer, Ernst, & Boynton, 2017). Our findings are consistent with this view and suggest that the interference between different sources of information (i.e., external stimuli versus internal information) might selectively occur for perceptually and semantically complex stimuli. However, we should also contemplate the possibility that the modulation of pupil activity during MW was too weak to be detected in our set-up.

Although our findings make an important contribution to our understanding of the onset of MW episodes, they deserve further investigation. For example, future studies are needed to investigate whether and how changes in pupil diameter associated with MW are modulated by its emotional content. Comparing different kinds of MW episodes, namely neutral *vs.* emotional (positive and negative), might help clarifying the mechanisms underlying and subserving the onset and maintenance of MW.

Another dimension that was not taken in account in the present study is the meta-awareness of thoughts. Previous studies showed that people do not always notice that

their mind is wandering and sometimes MW episodes occur without people realising it consciously. Meta-awareness is considered as an intermittent process by which people only periodically notice the contents of their mind (Schooler et al., 2011). Some findings revealed that “unaware” MW episodes are associated with poorer performance (e.g., Smallwood, McSpadden, et al., 2007, 2008) and with a most pronounced brain recruitment of DMN and dlPFC areas (Christoff et al., 2009). Here, we used a probe-caught method to collect MW episodes without distinguishing between aware and unaware MW episodes. However, on the basis of previous findings, one could argue that aware and unaware MW might be associated with differences in pupil activity. Thus, future studies might extend our findings in two ways. One approach might be to investigate whether and how the level of meta-awareness of MW affects changes in pupil size by adding a question on meta-awareness during thought-probes or by coupling self-caught with probe-caught in the same task (see section 1.4 of Chapter 1). A second approach might be to explore whether the results are replicated by using the same task but a self-caught procedure instead of a probe-caught procedure. The self-caught procedure could allow to collect only aware MW and thus to verify whether these results are replicated on the subsample of aware MW episodes.

Chapter 4

Tracking the dynamics of aware mind-wandering: a pupillometry study (Study 3)

4.1 Introduction and aims of Study 3

As discussed previously, the dynamics of MW and the distinction between the onset and the maintenance of this process (Smallwood, 2013) are significant questions that any comprehensive account of MW should address. Our studies described in the previous chapters explored the two questions of the onset of MW (*when* the mind starts wandering) and its maintenance over time (*how* it unfolds over time). Specifically, in Study 1 and Study 2, we showed that MW might be triggered by external, task-irrelevant meaningful stimuli, as verbal cues. Moreover, in Study 2, we showed that the onset of cue-dependent MW is marked by a physiological change, such as an increase in pupil size. This dilation accompanies the unfolding of MW over time. In both studies, we employed a vigilance task with task-irrelevant verbal cues that might potentially act as triggers for MW experiences during the task and this paradigm has consistently found to be effective.

In the present study, we aimed to replicate the results of the pupillometry study (Study 2) and to extend them further, by employing a different procedure of thought

sampling. In Study 2, we used the probe-caught method, that is we intermittently interrupted participants and probed them regarding the contents of their experience. In the present study, instead, we employed the self-caught method, and asked participants to press a button every time they noticed by themselves that they had been mind wandering. This procedure provides a straightforward assessment of the number of MW episodes that reach meta-awareness (see Schooler et al., 2011, for a discussion). By contrast, probes might catch people mind wandering before they notice it by themselves, thereby assessing both “aware” and “unaware” MW episodes.

Moreover, for MW episodes triggered by the cue-words presented on the screen, the use of the self-caught method allows to measure the time-interval occurring between the trigger of the MW episode and the report. In order to be able to report a MW episode, an individual needs to experience a MW episode and to notice it. For this reason, the time it takes participants to report such MW episode depends on the time for the initial generation of the spontaneous thought (arising/forming of thoughts) and for becoming aware of it and being able to report it. In this regard, the coupling of the self-caught method with the vigilance task with cue-words allows for studying the “natural” time-course of MW, from its onset/initial generation to the subsequent monitoring and awareness of thoughts.

As we have already mentioned in Study 1, the question about the duration of MW is still open and it has been largely overlooked. Indeed, it was examined in an early stage of MW research, by Klinger (1978) and Pope (1977). Klinger (1978) trained participants who took part in his study to accurately recognise and assess certain elements of their inner experiences. Out of all the elements, they were specifically trained to estimate the duration of short time intervals so that they would be able to estimate the duration of their thoughts either during a task in the laboratory or in daily-

life. After the training session, participants performed experimental thought-sampling sessions and, interspersed with the experimental sessions, out-of-the-laboratory thought-sampling sessions. In the laboratory, participants listened dichotically to two simultaneous 15-min narratives and indicated continuously to which track they were attending. At certain times, they were interrupted by a tone and answered some questions about their thoughts. Two questions asked them to estimate the duration of the latest thought-segment and the previous segment (open-ended questions). On each out-of-the-laboratory occasion, participants received a device that emitted a tone at random intervals. At each tone, participants filled out a roughly identical questionnaire which included the same questions on the duration of thoughts. The median estimates of thought-segment duration were 5 sec. in both settings, with a mean of 9 sec. in the laboratory and 14 sec. outside the laboratory. Participants rated their confidence in their estimates as “very confident” 64% of the time and as “moderately confident” 35% of the time (Klinger, 1978, 2013). As reported by Klinger (2013), Pope (1977) agreed approximately with these results since he asked participants in a laboratory to signal with a key-press each time their mind shifted to a new topic and found that it happened on average about 5 or 6 sec. apart.

More recently, Grandchamp and colleagues (2014) asked two participants to indicate the duration of their MW episodes by employing a self-caught procedure in several laboratory sessions. Specifically, in each session, participants had to count backward each of their breath cycles (inhale/exhale) from 10 to 1 (at 1, they were instructed to restart counting backward from 10), and to indicate whenever they realised that they had lost track of their breath count (i.e., reflecting the fact that their attention had drifted) by pressing a button. Following the button press, participants were asked to characterize their MW episodes by completing a questionnaire. This

questionnaire included a question asking participants how long the MW episode was. They answered by choosing one option among the following ones: very short (< 2 sec.), short (< 10 sec.), medium (< 30 sec.), long (> 30 sec.). The results showed that a larger number of MW episodes were reported as “short” (i.e., longer than or equal to 2 sec. and shorter than 10 sec.).

However, the vast majority of MW studies has not included any assessment of the potential duration of MW, despite it would have been relevant for the aims of some studies. Indeed, several investigations have examined measures associated with MW states (i.e., reaction time variability, eye movements behaviour, BOLD signal) by using predetermined and fixed time-windows before self-reports of MW states and therefore assuming that MW episodes occurred precisely into those windows and lasted for that period of time. Different time-windows have been used among studies (e.g., 10 sec. in Christoff et al., 2009, and Franklin et al., 2013; 6.5 sec. in Seli, Cheyne, et al., 2013; 3 to 8 sec. in Frank et al., 2015; 5 sec. in Smilek et al., 2010, and Uzzaman & Joordens, 2011; 4.8 sec. in McVay & Kane, 2009; 3.5 sec. on average in Konishi et al., 2017) and each study has used the same time-window for each participant and for each MW episode. In these studies, the use of the time-windows was necessary because MW was not linked to preceding events and participants were not even asked to estimate the duration of their thoughts (except for Grandchamp et al., 2014).

In conclusion, in the present study, we had the following aims. First, we aimed to replicate the results of the pupillometry study (Study 2) and to extend them further. To this aim, we employed the same vigilance task with verbal cues previously used and recorded pupil measures throughout the task. However, to collect MW experiences, we used the self-caught procedure instead of the probe-caught procedure. In order to replicate the previous findings of pupil dilation associated with the onset and

maintenance of MW triggered by cue-words, we compared the time-course of pupil diameter observed after cue-words indicated by participants as triggers for MW episodes with that observed after emotional cue-words appearing onscreen after participants resumed the task following a self-interruption.

In the present study, we also examined whether and how pupil dilation associated with MW was modulated by some characteristics of MW, such as its emotional valence and its cue-dependent/independent nature. To this aim, we compared the pupil size associated with MW episodes rated as emotional (either negative or positive) with that associated with MW episodes rated as neutral. The results of this comparison may contribute to further clarify the nature of the mechanisms underlying the pupil dilation observed during MW compared to on-task report, that is whether this dilation reflects only an increased cognitive load associated with MW or also an increased emotional load associated with this phenomenon.

We also examined, for exploratory purposes, whether reports of self-generated MW and MW triggered by external cues were associated with a different pupil diameter.

Finally, as we have already mentioned above, the use of the self-caught procedure also allows to collect latency data, that is to calculate the time-interval between the presentation of the trigger and the MW report. This interval reflects the time needed for the arising of thoughts and the awareness of them. Here, we analysed these data to have a further insight on this temporal dimension of MW and we also examined whether and how the latency data might be affected by some phenomenological properties of MW episodes (i.e., temporal focus, specificity, emotional valence).

4.2 Method

4.2.1 Participants

Twenty-eight undergraduate students from the University of Florence (16 females, age range 19-32 years, $M = 21.61$ years, $SD = 3.06$ years) volunteered to participate in the study. All participants were Italian native speakers, they had normal or corrected-to-normal vision, and they were screened for depressive symptoms (Beck Depression Inventory-II, Beck et al., 1996; Italian adaptation in Ghisi et al., 2006).

The experimental protocol is in line with the declaration of Helsinki and with the regulations of the University of Florence that hosted the study.

4.2.2 Apparatus

The apparatus was the same as the one used in Study 2 (see Chapter 3 and Figure 3.1).

Task stimuli were generated with the PsychoPhysics Toolbox routines for MATLAB r2010a (The MathWorks) and presented on a LCD colour monitor (Asus MX239H, 51 x 28 cm, resolution of 1920 x 1080 pixels, refresh rate of 60 Hz), driven by a Macbook Pro Retina (OS X Yosemite, 10.10.5). All stimuli were shown in white (55 cd/m^2) against a black background (0.05 cd/m^2).

Participants sat in front of the monitor screen at 57 cm viewing distance, with their heads stabilised by chin rest. Two-dimensional eye position and pupil diameter were recorded binocularly with a CRS LiveTrack system (Cambridge Research Systems) at 30 Hz, using an infrared camera mounted below the screen. Pupil diameter measures were transformed from pixels to millimetres after calibrating the tracker with an artificial 4 mm pupil, positioned at the approximate location of the participants' left

eye. Gaze position data were linearized with a standard 9-point calibration, run prior to each session.

4.2.3 Materials

Vigilance task

Participants performed a modified version of the computer-based vigilance task developed by Schlagman and Kvavilashvili (2008) (see Study 1 and 2). The task consisted of 1020 trials, presented in a fixed order, each remaining on the screen for 2 sec. A white fixation point (0.2 deg diameter) was presented in the centre of the screen for each trial. In each trial, an image was shown depicting either a pattern of white horizontal (non-target stimuli) or white vertical (target stimuli) lines (4.1 x 0.2 deg) on a black background. Target stimuli appeared on 30 trials (~3% of all trials) and they were presented pseudo-randomly, with a minimum of 26 and a maximum of 40 trials between each target stimulus. In addition to the lines, a white cue-word (e.g., “jet lag”, “long hair”; 0.88 deg height) was also shown under the fixation point in 192 trials (18.8% of all trials) (see Figure 4.1 for an example of the experimental trials). These word-phrases were selected from the pool of word-phrases developed by Schlagman and Kvavilashvili (2008) and adapted to the Italian sample (Vannucci et al., 2015; see also Chapter 2 of the present work). Equal numbers of positive ($n = 64$), negative ($n = 64$) and neutral ($n = 64$) cue-words were included.

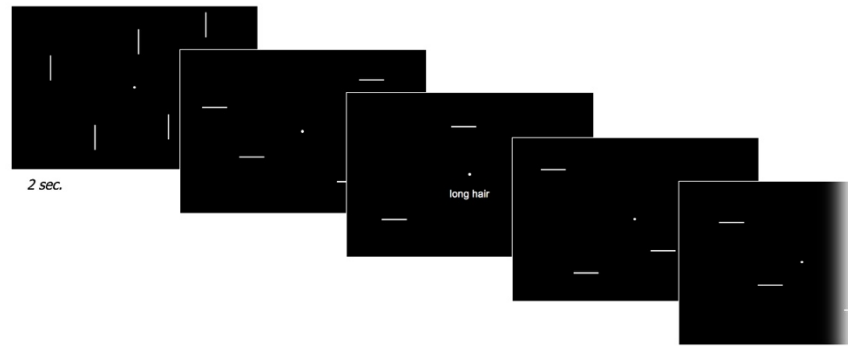


Figure 4.1. Schematic of the experimental task. Horizontal lines: non-target stimuli; vertical lines: target stimuli to be detected by pressing a button.

Thought questionnaire

After completing the vigilance task, participants were asked to indicate some details of their reported mental contents on a questionnaire. For each content, they were asked to indicate: (i) the temporal focus, distinguishing among “past”, “present”, “future”, and “atemporal”, (ii) whether it was general or specific, (iii) the emotional valence of the thought on a 7-point scale (-3 = very unpleasant; 0 = neutral; +3 = very pleasant).

Participants received instructions on how to distinguish the different temporal focus categories. Specifically, as in Study 1 (see Chapter 2), they were told that an “atemporal” mental content would refer to any thought with no specific temporal orientation (i.e., “*I am a very anxious person*”; “*I like very much eating pizza*”), a “present” mental content would refer to any thought related to something occurring either here and now (i.e., “*I miss my dog, that is now with my boyfriend*”) or in the current period of life (i.e., “*I don’t get along with my mother in this period*”), a “past” mental content would refer to any thought related to something occurred prior to begin the task (more or less remote), and a “future” mental content would refer to any thought

related to something occurring after the end of the task (more or less distant in the future).

Participants were also asked to rate on a 7-point scale their overall level of concentration (1 = not at all concentrated; 7 = fully concentrated) and boredom (1 = not at all; 7 = very bored) experienced during the vigilance task.

4.2.4 Procedure

Participants were tested individually. After being welcomed into the laboratory, participants were briefly introduced to the research project and eye-tracking recording, being informed that they would take part in a study on concentration and its correlates, and signed a consent form. Afterwards, they received the instructions for the vigilance task. It was explained that they had to detect target stimuli (vertical lines) in a stream of non-target stimuli (horizontal lines), by pressing the space-bar whenever a target was detected. Moreover, they were told that they would also see cue-words in some of the trials and that they were not supposed to do anything with these task-irrelevant cue-words. As a cover story, it was explained that the condition in which they were participating was looking at how people could keep their concentration on the lines and that participants in another condition would have to concentrate on the cue-words. This second condition did not really exist. Next, participants were informed that the task was quite monotonous and that task-unrelated mental contents (e.g., thoughts, plans, considerations, past events, images, etc.) could pop into their mind spontaneously throughout the task. In the event that something came to their mind, they should press a button on the keyboard (corresponding to the letter L, that was made clearly noticeable by attaching a white sticker on it) to interrupt the task. After pressing the L button, participants should give orally a short description of the mental

content and indicate whether it was triggered by internal thoughts, an element in the environment, a cue-word on the screen (if so, they had to specify the word) or there was no trigger. These responses were recorded by the experimenter. If the mental content was private and intimate, participants could label it as “personal” and eventually provide only one relevant word instead of reporting a short description. Finally, they were also requested to focus on the fixation spot for the whole duration of the task.

After the instructions, participants were given a 20-trials practice of the vigilance task in which they were requested to behave as it was the experimental session and to stop the presentation if they had any task-unrelated thoughts.

When the vigilance task was over, participants were presented with the short descriptions of their mental contents and asked to report some details about these thoughts on a questionnaire (see Thought questionnaire in the Materials section), and indicate their level of concentration and boredom experienced during the task. Finally, participants were asked whether they had speculated about the actual aims of the study (if so, what they had thought) during the task and then they were debriefed and dismissed. The total session lasted approximately 105-120 min.

4.2.5 Analyses of pupillometry data

All the analyses were carried out on 24 out of 28 participants⁴. Before performing all the analyses (including those on pupillary data), all the mental contents reported by participants were read by two independent judges and classified into distinct

⁴ Four participants were excluded due to non-compliance with task instructions. Thus, the sample used for analyses included 24 participants (14 females, age range 19-32 years, $M = 21.50$ years, $SD = 3.26$ years).

categories. As in Study 1 and Study 2 (see Chapter 2 and Chapter 3), the coding was based on the categories used in other studies (e.g., Plimpton et al., 2015; Unsworth & Robison, 2016). The mental contents could be classified as either task-related interferences (TRIs) or task-unrelated thoughts (TUTs). TUTs were next classified as either MW reports or external distraction (ED) reports. As explained in Study 1 and Study 2, TRIs comprised reports whose content was related to any task features or to the current performance on the task, whereas TUTs included no references to the task at hand and comprised both ED and MW episodes. TUTs were classified as EDs when the participant's attention was unrelated to the task at hand and focused on stimuli in the current situation (either exteroceptive or interoceptive perceptions, such as bodily sensations), whereas they were coded as MW episodes when the participant's attention was unrelated to the task at hand and decoupled from the external environment. These thoughts could be triggered by internal or external stimuli. For both categorisations (TRIs vs. TUTs, and MW vs. EDs), Kappa was computed as inter-rater reliability between the coders and the inter-rater agreement resulted to be very good ($Kappa = 0.96, SE = 0.03$ and $Kappa = 0.99, SE = 0.01$, respectively). Minor disagreements were solved by discussion.

Next, an off-line analysis examined the eye-tracking output in order to exclude time-points with unrealistic pupil-size recordings (i.e., values outside the 90th percentile of each 2 sec. long trial) and interpolated the remaining time-points at 20Hz.

In order to perform our main pupillometry analyses, trials were selected based on the specific reports given by each participant. After performing the classification of contents described above, trials associated with the self-interruptions to report MW episodes as well as trials associated with cue-words reported as triggers for MW episodes were identified for each participant.

In the first analysis, we compared the time-course of pupil diameter observed in two conditions: after cue-words indicated by participants as triggers for MW episodes, and after emotional cue-words appearing onscreen after participants resumed the task following a self-interruption. In order to perform the analyses on the pupillometry data, trials were sorted based on their timing relative to a cue-word coded as “trigger” or “post-report” (i.e., 0, 1, 2 trials after the cue-word, where the trial 0 was the trial including the cue-word).

In the second analysis, we examined differences between emotional and neutral MW episodes, comparing the time-course of pupil diameter observed in two conditions: after cue-words indicated as triggers for positive or negative (i.e., emotional) MW episodes, and after cue-words indicated as triggers for neutral MW episodes. In order to perform the analyses on the pupillometry data, trials were sorted based on their timing relative to a cue-word coded as “trigger” (i.e., 0, 1, 2 trials after the cue-word, where the trial 0 was the trial including the cue-word).

In the third analysis, we further examined differences between emotional and neutral MW episodes, comparing the pupil diameter observed in the two following conditions: in the last trial preceding reports of positive or negative (i.e., emotional) MW episodes, and in the last trial preceding reports of neutral MW episodes.

Finally, in the fourth analysis, we examined differences between cue-dependent (triggered by cue-words) and cue-independent (triggered by internal thoughts or by no trigger) MW episodes, comparing the pupil diameter observed in two conditions: in the last trial preceding reports of cue-dependent MW episodes, and in the last trial preceding reports of cue-independent MW episodes.

Given the considerable sample size variability across participants, statistical analyses relied on a linear-mixed model approach. Individual trials from all

participants were compared with a model comprising both the effect of experimental variables (“fixed effects”) and the variability across participants (“random effects”). Random effects were coded by allowing subject-by-subject variations of the intercept of the model. In all cases, the dependent variable was the “baseline corrected pupil diameter”, which we obtained by averaging pupil diameter in a pre-specified temporal window of each trial, and subtracting the average pupil diameter in a “baseline” temporal window. Please refer to the results section for specific definitions of the temporal windows for averaging and baseline-subtractions.

We used standard MATLAB functions provided with the Statistics and Machine Learning Toolbox (R2015b, The MathWorks). Specifically, the function “fitlme(data, model)” fit the linear-mixed model to the data, yielding an object “lme” with associated method “ANOVA” that returns F statistics and P values for each of the fixed effect terms and “CoefTest” for post-hoc comparisons.

4.3 Results

Performance on the vigilance task

Performance on the vigilance task was near-perfect for all participants. Out of 30 targets, there were 0.46 ($SD = 0.66$) misses and 0.17 ($SD = 0.38$) false alarms. The mean reaction time associated with correct detections was 767.13 msec. ($SD = 124.42$ msec.).

The mean level of concentration experienced during the task was 4.92 ($SD = 1.06$) and the mean level of boredom was 3.04 ($SD = 1.57$).

Type and amount of mental contents reported

Participants reported a total of 400 mental contents ($M = 16.67$, $SD = 16.83$, range 1-63). Out of the all mental contents, 28 reports (7%) were classed as TRI reports ($M = 1.17$, $SD = 1.58$, range 0-6), and 372 reports (93%) were classed as TUT reports ($M = 15.50$, $SD = 16.47$, range 1-60). Out of the all TUTs, 44 reports (11.83%) were classed as ED reports ($M = 1.83$, $SD = 2.20$, range 0-7) and 328 reports (88.17%) were classed as MW reports ($M = 13.67$, $SD = 14.89$, range 0-53) (see Table 4.1 for a summary of descriptive data).

Variable	M	SD	range
Task-related interferences (TRIs)	1.17	1.58	0-6
Task-unrelated thoughts (TUTs)	15.50	16.47	1-60
Mind-wandering (MW)	13.67	14.89	0-53
External distraction (ED)	1.83	2.20	0-7

Table 4.1. Means, standard deviations and ranges of thoughts reported.

Out of the 328 MW episodes, 225 reports (68.60%) were reported by participants as triggered by a specific cue-word shown on the screen ($M = 9.38$, $SD = 10.93$, range 0-42), 13 reports (3.96%) by internal thoughts ($M = 0.54$, $SD = 1.44$, range 0-7), 15 reports (4.57%) by environmental triggers ($M = 0.63$, $SD = 1.50$, range 0-7), and 59 reports (17.99%) by no trigger ($M = 2.46$, $SD = 2.54$, range 0-10). The remaining 16 MW episodes were indicated by participants as elicited by multiple cue-words (i.e., more than one specific cue-word; $n = 6$), by unknown cue-word(s) (i.e., participants reported that they did not remember which cue-word triggered the MW episode; $n = 6$), or by multiple triggers (e.g., participants reported that their thoughts were elicited

by both a cue-word presented onscreen and a sound occurring outside the room at the same time; $n = 4$).

Finally, out of the all MW episodes triggered by the cue-words, 60 reports (26.67%) were triggered by neutral cue-words ($M = 2.50$, $SD = 3.36$, range 0-11), 79 reports (35.11%) were triggered by positive cue-words ($M = 3.29$, $SD = 4.10$, range 0-12), and 86 reports (38.22%) were triggered by negative cue-words ($M = 3.58$, $SD = 4.64$, range 0-22). Thus, the vast majority (73.33%) of these reports were elicited by cue-words with emotional valence.

Latency data for MW

For each MW episode indicated by participants as triggered by a cue-word, we computed the time-interval occurring between the presentation of the cue-word and the moment that participants pressed the button to report a mental content triggered by that cue-word. As in Study 1 (see Chapter 2), we referred to these time-intervals as to latency data for MW episodes. Latency data were calculated by adding the time for the present (pressed on) trial, to the times for all the trials back, up to the trial that presented the cue-word that was reported by the participant as the trigger of the mental content (see also studies on involuntary memories for a similar procedure to obtain retrieval times; e.g., Schlagman & Kvavilashvili, 2008; Vannucci et al., 2015).

We checked for possible outliers, by transforming each data point into standardised data point and identified data greater than 2.5 in absolute value as outliers. Out of the 225 MW episodes triggered by the cue-words, 5 episodes were identified as outlier because of the very high time-interval between the trigger and the report of MW.

The mean latency of the remaining MW episodes was 7291.11 msec. ($SD = 5807.83$ msec., range 1383.99-32480.72 msec.). Since each trial lasted 2 sec., the mean number of trials being between a trigger and the report of a MW episode triggered by that trigger was 3.65 trials ($SD = 2.90$ trials, range 0-16.24 trials). Out of the 220 MW episodes, 91 episodes (41.36%) were reported after a latency lower than or equal to 5 sec., 76 episodes (34.55%) were reported after a latency greater than 5 sec. and lower than or equal to 10 sec., 35 episodes (15.91%) were reported after a latency greater than 10 sec. and lower than or equal to 15 sec., and 18 episodes (8.18%) were reported after a latency greater than 15 sec.

In Study 1 (see Chapter 2), we found no significant effect of the temporal focus of thoughts on the latency data. Here we verified whether the same effect was replicated. In addition, we analysed whether other characteristics of MW (i.e., specificity and emotional valence) assessed in the present study affected the latency data. We used a multilevel (or hierarchical) dataset in which the unit of analysis was a single MW episode. The use of this strategy of analysis not only allowed us to take into account the non-independence of the units of analysis, but also to accommodate for unequal numbers of data points within participants (Jahng et al., 2008). With regard to the valence of thoughts, participants rated each episode on a 7-point Likert scale (-3 = very negative; 0 = neutral; +3 = very positive). We classified each MW episode as negative, positive or neutral on the basis of the score given by participants (i.e., all MW episodes that obtained a score ranging from -3 to -1 were classed as “negative”; all the MW episodes that obtained a score ranging from +1 to +3 were classed as “positive”; all the MW episodes that obtained a score equal to 0 were classed as “neutral”). We specified random-intercept multilevel models to test for associations of the factors Temporal focus (past, present, future, atemporal), specificity (general,

specific), valence (negative, neutral, positive) with the latency data (measured in msec.), which was considered as the dependent variable. Given that the latency data were substantially skewed and kurtotic, we conducted the analysis after log transformation of the data.

No significant difference between temporal focuses was found, $F(3,201.24) = 0.33, p = 0.806$ (past Estimated Marginal Mean = 3.83, 95% Confidence Interval [CI]: 3.67-3.98; present Estimated Marginal Mean = 3.77, 95% CI: 3.57-3.96; future Estimated Marginal Mean = 3.82, 95% CI: 3.65-3.99; atemporal Estimated Marginal Mean = 3.80, 95% CI: 3.64-3.95). Moreover, there was no significant difference between episodes associated with different emotional valences, $F(2,202.64) = 0.41, p = 0.665$ (neutral Estimated Marginal Mean = 3.79, 95% Confidence Interval [CI]: 3.63-3.95; negative Estimated Marginal Mean = 3.82, 95% CI: 3.67-3.97; positive Estimated Marginal Mean = 3.82, 95% CI: 3.67-3.98), and no significant difference between specific and general episodes, $F(1,205.13) = 3.47, p = 0.064$ (specific Estimated Marginal Mean = 3.84, 95% Confidence Interval [CI]: 3.69-3.98; general Estimated Marginal Mean = 3.78, 95% CI: 3.63-3.93).

Characteristics of MW episodes reported

Out of the all MW episodes, 133 episodes (40.55%) were classed as past-oriented thoughts, 21 episodes (6.40%) were classed as present-oriented thoughts, 52 episodes (15.85%) were classed as future-oriented thoughts, and 122 episodes (37.20%) were classed as atemporal thoughts. Moreover, out of the all MW episodes, 166 episodes (50.61%) were classed as specific, whereas 162 episodes (49.39%) were classed as general. Finally, 92 episodes (28.05%) were rated as neutral, 117 episodes (35.67%) were rated as negative, and 119 (36.28%) were rated as positive.

We explored whether there was an association between the characteristics of MW episodes and the type of occurrence of these episodes (i.e., being triggered by cue-words, that is “cue-dependent”, and being triggered by internal thoughts or no cue, that is “cue-independent”).

Out of the 225 cue-dependent MW episodes, 103 episodes (45.78%) were past-oriented, 13 episodes (5.78%) were present-oriented, 23 episodes (10.22%) were future-oriented, and 86 episodes (38.22%) were atemporal. Moreover, 108 episodes (48%) were specific, whereas 117 (52%) were general. Fifty-four episodes (24%) were rated as neutral, 87 episodes (38.67%) were rated as negative, and 84 episodes (37.33%) were rated as positive.

Out of the 72 cue-independent MW episodes, 21 episodes (29.17%) were past-oriented, 7 episodes (9.72%) were present-oriented, 24 episodes (33.33%) were future-oriented, and 20 episodes (27.78%) were atemporal. Moreover, 47 episodes (65.28%) were specific, whereas 25 episodes (34.72%) were general. Twenty-six episodes (36.11%) were rated as neutral, 19 episodes (26.39%) were rated as negative, and 27 episodes (37.50%) were rated as positive.

Three chi-square tests of independence were performed to examine the relationship between type of MW (cue-dependent vs. cue-independent) and temporal focus, specificity and valence of MW episodes. The association between type of MW and temporal focus was significant, $X^2(3, N = 297) = 24.94, p = 0.000016$. The association between type of MW and the specificity of MW was also significant, $X^2(1, N = 297) = 6.53, p = 0.011$. The relationship between type of MW and emotional valence of MW was not significant, $X^2(2, N = 297) = 5.27, p = 0.072$.

Analyses of pupillometry data

We conducted four analyses on the pupillary data: (i) the first analysis was conducted on the time-course of pupil diameter over two trials after cue-words identified as triggering or not triggering MW episodes; (ii) the second analysis was conducted on the time-course of pupil diameter over two trials after cue-words triggering emotional (either positive or negative) MW episodes or triggering neutral MW episodes; (iii) the third analysis was conducted on the pupil diameter before reports of emotional MW episodes or before reports of neutral MW episodes; (iv) the fourth analysis was conducted on the pupil diameter before reports of cue-dependent MW episodes (i.e., MW episodes triggered by cue-words) or before reports of cue-independent MW episodes (i.e., MW episodes triggered by internal thoughts or no trigger).

These analyses are reported below.

First analysis: time-course of MW (triggered by cue-words). We compared the pupil diameter over two trials after a cue-word identified as triggering or not triggering a MW episode. Cue-words identified as triggering a MW episode were the cue-words that were reported by participants as triggers for MW reports. Cue-words identified as not triggering a MW episode were emotional cue-words that were presented just after a self-interruption. Since the majority of cued MW reports were triggered by emotional cue-words, and pupil dilation is affected by emotional load, we used as comparison condition emotional cue-words reported just after self-interruptions (not triggering cue-words, but with similar emotional valence)

We analysed the time-course of pupil diameter over two trials after the cue-word and we only considered cue-words that were followed by at least two trials with

successful pupil recording. We used as “baseline” pupil diameter the average diameter in the last 200 msec. of the trial where the cue-word was presented. This approach left 68 MW trigger cue-words, and 287 emotional cue-words after self-interruptions.

For the statistical analysis of the traces, we summarized time-courses by taking the average pupil diameter over the second half of each trial. These values were entered in a Linear-Mixed Model analysis, with two fixed-factors: type of cue-word (MW trigger, cue-word after self-interruption) and time from the cue (coded as number of trials: 1st trial, 2nd trial), plus the random effect of subjects modelled as variable intercept of the model. This revealed a significant interaction between the two fixed factors ($F(1,966) = 17.56464, p = 0.00003$). Post-hoc test showed that the type of cue-word had a significant effect over the two trials that followed the cue-word, where there was a significant difference between pupil diameter following MW triggers and emotional cue-words after reports (1st trial following the cue-word: $F(1,319) = 7.69446, p = 0.00587$; 2nd trial: $F(1,323) = 25.17870, p < 0.00001$) (see Figure 4.2).

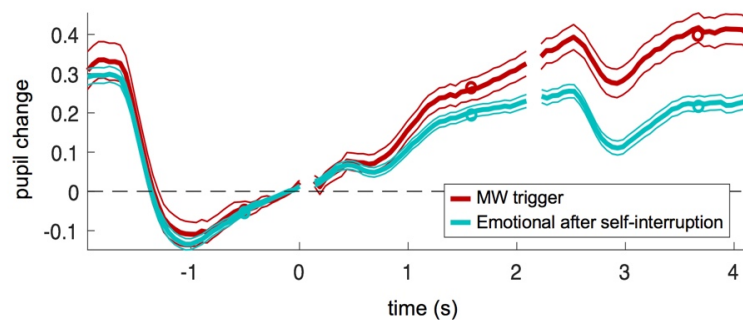


Figure 4.2. Time-course of pupil diameter after cue-word presentation. The pupil traces are aligned to the average pupil diameter during the last 200 msec. of the cue-word presentation (i.e., the cue-word presentation is from -2 to 0 sec.). Red lines: traces associated with cue-words reported as triggers for MW episodes; sky-blue lines: traces associated with emotional cue-words presented just after self-interruptions. Thick lines: average across all trials; thin lines: standard error; circles: average values entered the LMM analysis (average over the second half of each trial).

Second analysis: pupil diameter after triggers of emotional vs. neutral MW. We also compared the time-course of pupil diameter over two trials after a cue-word identified as triggering emotional (either positive and negative) MW episodes or neutral MW episodes. We analysed the time-course of pupil diameter over two trials after the cue-word. We only considered cue-words that were followed by at least two trials with successful pupil recording. We used as “baseline” pupil diameter the average diameter in the first 200 msec. of the trial where the cue-word was presented. This approach left 46 emotional MW triggers, and 13 neutral MW triggers. For the statistical analysis of the traces, we summarized time-courses by taking the average pupil diameter over the second half of each trial. These values were entered in a Linear-Mixed Model analysis, with two fixed-factors: type of MW (emotional vs. neutral) and time from the cue (coded as number of trials: 1st trial, 2nd trial), plus the random effect of subjects modelled as variable intercept of the model. This showed neither a significant main effect of type of MW ($F(1,169) = 0.57062, p = 0.45107$), nor a significant interaction ($F(1,169) = 0.03066, p = 0.86122$) (see Figure 4.3).

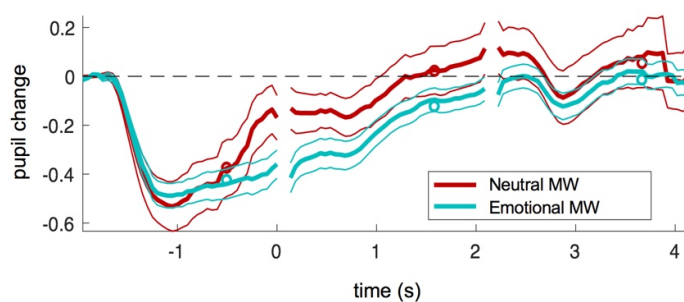


Figure 4.3. Time-course of pupil diameter after cue-word presentation. The pupil traces are aligned to the average pupil diameter during the first 200 msec. of the cue-word presentation (i.e., the cue-word presentation is from -2 to 0 sec.). Red lines: traces associated with cue-words reported as triggers for neutral MW episodes; sky-blue lines: traces associated with cue-words reported as triggers for emotional MW episodes. Thick lines: average across all trials; thin lines: standard error; circles: average values entered the LMM analysis (average over the second half of each trial).

Third analysis: pupil diameter before reports of emotional vs. neutral MW. Next, we compared the pupil diameter in the last trial before self-interruptions where reports of emotional MW or neutral MW were given. We considered self-interruptions that were preceded by at least three trials without cue-words. By performing this selection (i) the last trial immediately before the report was preceded by at least two trials without any trigger cue-words and thus these trials did not overlap with the ones examined in the previous analysis, (ii) the trial before the report was preceded by at least two trials without any triggering or not triggering cue-words that could affect the pupil diameter. Also, we only considered self-interruptions that were preceded by at least one trial with successful pupil recording. This left 59 emotional MW reports, and 17 neutral MW reports. For the statistical analysis of the traces, we aligned traces to the last 200 msec. of each trial preceding reports, and assessed pupil diameter over the second half of the trial. These values were entered in a Linear-Mixed Model analysis, with the fixed-factor type of report (emotional MW and neutral MW), plus the random effect of subjects modelled as variable intercept of the model. The Linear-Mixed Model analysis revealed no significant effect of type of report ($F(1,136) = 0.45770$, $p = 0.49985$) (see Figure 4.4).

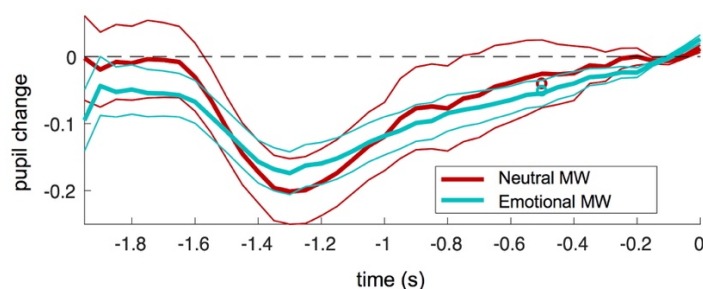


Figure 4.4. Pupil diameter before self-interruptions preceded by at least three trials without cue-words. The pupil traces are aligned to the last 200 msec. of the trial. Red lines: neutral MW reports; sky-blue lines: emotional MW reports. Thick lines: average across all trials; thin lines: standard error; circles: average values entered the LMM analysis (average over the second half of each trial).

Since this approach left few pupil traces for analyses, we conducted a secondary analysis by considering self-interruptions that were preceded by at least two trials without cue-words. This left 107 emotional MW reports, and 37 neutral MW reports.

The Linear-Mixed Model analysis, with the fixed-factor type of report (emotional MW and neutral MW) and the random effect of subjects modelled as variable intercept of the model, revealed no significant effect of type of report ($F(1,256) = 0.61901$, $p = 0.43214$) again (see Figure 4.5).

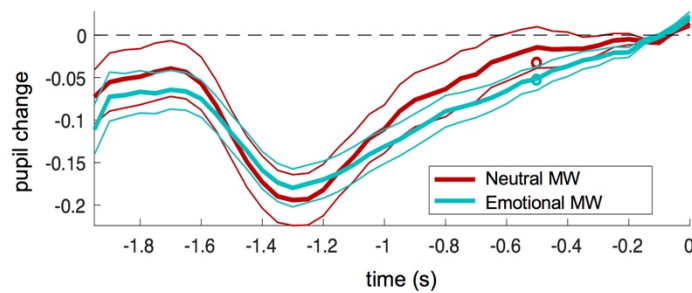


Figure 4.5. Pupil diameter before self-interruptions preceded by at least two trials without cue-words. The pupil traces are aligned to the last 200 msec. of the trial. Red lines: neutral MW reports; sky-blue lines: emotional MW reports. Thick lines: average across all trials; thin lines: standard error; circles: average values entered the LMM analysis (average over the second half of each trial).

Fourth analysis: pupil diameter before reports of cue-dependent vs. cue-independent MW. Finally, we compared the pupil diameter in the last trial before self-interruptions where reports of cue-dependent MW or cue-independent MW were given.

We considered self-interruptions that were preceded by at least three trials without cue-words and we only considered self-interruptions that were preceded by at least one trial with successful pupil recording. This left 36 cue-dependent MW reports, and 36 cue-independent MW reports.

For the statistical analysis of the traces, we aligned traces to the last 200 msec. of each trial preceding reports, and assessed pupil diameter over the second half of the trial. These values were entered in a Linear-Mixed Model analysis, with the fixed-factor type of MW (cue-dependent MW vs. cue-independent MW), plus the random effect of subjects modelled as variable intercept of the model. The Linear-Mixed Model analysis revealed no significant effect of type of report ($F(1,132) = 0.79770, p = 0.37341$) (see Figure 4.6).

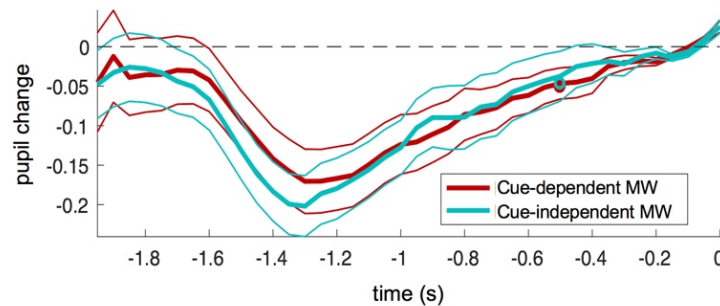


Figure 4.6. Pupil diameter before self-interruptions. The pupil traces are aligned to the last 200 msec. of the trial. Red lines: cue-dependent MW reports; sky-blue lines: cue-independent MW reports. Thick lines: average across all trials; thin lines: standard error; circles: average values entered the LMM analysis (average over the second half of each trial).

4.4 Discussion

In the present study, participants performed the vigilance task with verbal cues while their pupils were continuously recorded during the task. To collect MW experiences, participants were asked to stop the presentation each time they realised that they were thinking anything else than the task (self-caught procedure), and to indicate their thoughts as well as the trigger (if any) of them. With this procedure, we replicated the finding of increased pupil dilation following MW triggers (see Study 2) by using a different sampling method and, in addition, showed that this dilation

appeared not to be modulated by the emotional content of MW episodes. We also examined, for exploratory purposes, whether reports of self-generated MW and externally-triggered MW were associated with a different pupil diameter and we found no significant difference.

Moreover, following Study 1, we obtained information about the latency of MW episodes (i.e., the time-interval occurring between the presentation of triggering cue-words and the self-reports of MW episodes) and we mainly found a mean latency of approximately 7 sec. as well as a high percentage of MW (41.36%) reported after a time less than or equal to 5 seconds from the triggering cue-words. In the following sections, all the physiological and behavioural findings are discussed.

First, by analysing the pupil measures collected throughout the task and comparing the pupil diameter recorded after MW triggers and after the first (emotional) cue-words presented onscreen when participants resumed the task after self-reports, we found higher pupil dilation following MW triggers over two trials. This finding replicated our previous results (see Study 2) by using a different thought-sampling method, that is a self-caught method instead of a probe-caught method. In Study 2, by using a probe-caught method, we presumably collected both aware and unaware MW episodes. However, since studies reported differences between the two types of MW, such as different level of performance (e.g., Smallwood, McSpadden, et al., 2007) and brain recruitment (e.g., Christoff et al., 2009), we aimed to extend our previous findings by exploring whether they were replicated in the sub-sample of aware MW episodes. Thus, contrary to Study 2, here the self-caught method allowed us to collect only aware MW episodes and to specifically show that the finding of increased pupil dilation following MW triggers was replicated in the sub-sample of aware MW episodes. In addition, after selecting only MW triggered by the cue-words,

we studied the pupil size over two trials following cue-words triggering MW episodes rated as emotional (i.e., with a negative or positive content) and MW episodes rated as neutral, and we found that emotional MW episodes were not associated with a significantly different pupil diameter than neutral MW episodes. Moreover, by including the total amount of MW collected (i.e., not only MW triggered by the cue-words) and comparing the pupil size recorded before reports of emotional MW and neutral MW, we again found no significant difference between emotional and neutral MW episodes. We carried out these comparisons in order to verify whether the pupil dilation associated with MW reflected only an increased cognitive load or also an increased emotional load. What we found makes us hypothesize that the increase in pupil dilation associated with MW is mostly related to the cognitive load imposed by a mental process (e.g., Kahneman & Beatty, 1966; Sirois & Brisson, 2014).

Future studies should better investigate whether the pupil dilation might depend on different cognitive dimensions of thoughts (e.g., vividness, or amount of components such as people, objects, actions, etc.).

Here, we also explored whether reports of self-generated MW (i.e., MW episodes triggered by internal thoughts or no triggers) and MW triggered by external cue-words were associated with a different pupil diameter prior to self-reports. There is increasing interest in the possible distinction between self-generated MW and cue-dependent MW and previous evidence suggest that these two sub-types of MW episodes could be somehow different, at least with regard to the temporal focus of thoughts (e.g., Maillet & Schacter, 2016; see also Study 1). Moreover, self-generated MW might be more related to current concerns than MW triggered by the cue-words, whereas the second one might need more cognitive processes before coming into awareness (i.e., processing of cue-words that activate the thought). In particular, this last difference

could be reflected in the physiological measures. However, from this comparison, we did not find any significant difference associated with the reports of cue-dependent and cue-independent MW. It has to be noted, however, that we could not know the beginning of self-generated MW episodes and the analysis of the pupil diameter in the last trial before the report did not guarantee that all the self-generated MW episodes were already started. This concern could be attenuated by the fact the mean latency recorded for the MW episodes triggered by the cue-words was much longer than this duration, even though we cannot be sure that it could be generalised to all the MW episodes. Further studies should better investigate possible differences between self-generated (or cue-independent) and triggered (or cue-dependent) MW episodes.

Second, by collecting latency data for MW episodes, we found consistent data with Study 1 (see Chapter 2). The latency of a MW episode could be considered as the time needed for the initial generation of the thought (arising/forming of thoughts) and for becoming aware of it in order to report it. The high percentage of MW episodes reported after a time less than or equal to 5 seconds means that certain MW episodes are indeed reported really quickly, at least in this type of task, and it could depend on the short time needed for the formation/construction of the thought, or on the short time needed for being aware of the mental experience, or both. There are some differences between the procedure employed here and the one used in Study 1 (see Chapter 2), such as the duration of each trial (2 sec. *vs.* 1.5 sec., respectively), target frequency (~3% *vs.* 2%), cue-words frequency (18.8% *vs.* 18%), colour of the stimuli (white stimuli on a black background *vs.* black stimuli on a white background), position of the cue-words (slightly under a centred fixation spot *vs.* in the centre of the screen without fixation spot), the time length of the whole vigilance task (almost 34 min. split in two halves *vs.* 15 min.), and different cue-words (e.g., emotional and

neutral vs. only neutral and atemporal). Despite these differences, both studies employed a similar monotonous vigilance task and found similar latency data, even though the times seem a bit longer in this study compared to the other.

Consistent with Study 1, we also found a certain variability in latency data between episodes again. We also analysed whether different latencies were associated with different characteristics of MW episodes (i.e., temporal focus, specificity, emotional valence). Only few characteristics were assessed due to the specific procedure employed, and we did not find any significant differences (see also Study 1 for the temporal focus). The results on the temporal focus are in line with the ones of Study 1 as well as with the findings reported by Cole et al. (2016) on spontaneous past and future thinking, even though they used partially different instructions in their study. They presented two groups of participants with a similar vigilance task but explicitly instructed a group to report only any involuntary future thoughts and the second group to report only any involuntary past representations. They did not find any significant difference with regard to the latency data between future and past episodes, although they found shorter times than those reported in our studies.

Apart from the comparison between different sub-types of MW episodes, as suggested by Klinger (1978), *“there do seem to be clear individual differences in estimated duration of thought segments”* and it is possible that it represents *“at least in part real differences among individuals in duration of thought segments”* (p. 248). Thus, further studies might collect trait-level measures and examine whether and how different participants’ characteristics might contribute to the variability of MW latency.

Maybe further investigations might also re-include the self-estimates of MW duration (see Grandchamp et al., 2014; Klinger, 1978) in our vigilance task while

recording the time-interval occurring between a MW trigger and the self-report, and compare the subjective estimates (with confidence ratings) with the latency measurement. This approach could help to understand whether there is correspondence between the two measurements or specific underestimation/overestimation of subjective latency. Any underestimation/overestimation of subjective latency could be related to any MW or participants' characteristics as well.

Chapter 5

General discussion

5.1 Summary of the main findings

The empirical studies reported in the present work focused on the cognitive phenomenon of MW. Although the investigation of MW has obtained increasing interest by neurocognitive scientists over the last years, some key features of MW are still overlooked. Particularly, crucial questions concern the dynamics of MW processes: recent research suggests that MW should not be studied merely from a content-based perspective but should be also considered as a highly dynamic process, and it will be clearly understood only once the dynamic of thoughts are considered (Christoff et al., 2016; Girn et al., 2017). In order to further advance the investigation into the dynamics of MW, we need to distinguish two basic elements of MW, namely the moment of ignition (i.e., the onset) and the maintenance of thoughts over time (Smallwood, 2013). Our studies have been developed following this approach and have hopefully provided new contributions to this line of research.

Below, we will summarise the main findings that emerged from the studies and will next propose how these findings might be further extended in the future.

First, we found that the exposure to external and meaningful (i.e., verbal cues) task-irrelevant stimuli increased the amount of MW and steered its temporal orientation towards the past compared to a condition of no exposure to cues (Study 1;

see Chapter 2). The increase in the number of MW episodes suggests that the nature of MW is not necessarily stimulus-independent (Antrobus et al., 1966) or self-generated (e.g., Smallwood, 2013), but that it might possibly be cue-dependent, in terms of the cues that trigger MW in the first place. This is consistent with the suggestion proposed by Plimpton and colleagues (2015), namely that MW episodes might be dependent from external stimuli at the beginning and become stimulus-independent only once thoughts are set in motion. In Study 1 (see Chapter 2), we also analysed the number of MW episodes triggered by internal thoughts, by other environmental stimuli and by no trigger in the “Verbal cues” group and “No cues” group, and we found no significant differences between the two groups. This confirms that the increase in the amount of MW when exposed to verbal cues actually depends on the additional number of MW episodes elicited by the verbal cues. Moreover, we found a considerable number of MW episodes reported as triggered by external stimuli (i.e., verbal cues) by using both a self-caught (60.09% in Study 1; 68.60% in Study 3) and a probe-caught (52.74% in Study 2) method.

Second, we extended further these results by associating self-report measures with physiological measures (Study 2 and Study 3). Specifically, we found that the verbal cues indicated as triggers for MW episodes were followed over two trials by a higher pupil dilation compared with similar verbal cues that did not act as triggers for MW episodes. We found this dilation associated with MW onset by using both a probe-caught (Study 2) and a self-caught (Study 3) method. In Study 2, with the use of the probe-caught method, we possibly analysed both aware and unaware MW episodes, whereas by using the self-caught method in Study 3, we could especially focus only on aware MW episodes and thus replicate our previous result in this specific subsample of MW episodes. Since the pupil dilation is an index of emotional and cognitive

load (Hess & Polt, 1960; Partala & Surakka, 2003), the increase in pupil diameter associated with MW might depend on the emotional and cognitive load imposed by the mental process. By comparing emotional MW episodes and neutral MW episodes, we also showed that this increase in pupil diameter appeared not to be primarily linked to the emotional nature of thoughts (Study 3).

Third, the use of the vigilance task with task-irrelevant verbal cues allowed not only to link MW to preceding triggers but also, when combined with the self-caught sampling method (Study 1 and Study 3), to measure the latency of MW episodes (i.e., the time-interval occurring between the triggering stimuli and the self-reports of MW elicited by those stimuli). We found that these latency times ranged from a few msec. to more than 25 sec. This high level of variability was consistently found in two studies, with slightly different versions of the vigilance task (see Study 1 and Study 3). Beside this, in both studies, a high percentage of MW episodes was reported after a latency lower than or equal to 5 sec. from the triggering stimuli (i.e., 57.72% in Study 1; 41.36% in Study 3), and the mean latency was around 6 sec. in Study 1 and around 7 sec. in Study 3. The latency that we measured might correspond to the time needed for constructing the MW episode and for being aware of the mental content in order to report it. Our findings suggest that this time could be very different from a MW episode to another, even though most of the episodes seem to need only 5 sec. or less. Finally, it has to be noted that the mean latency found in our studies seems to be slightly longer than the latency reported in previous studies on involuntary mental time travel (Cole et al., 2016). Cole and colleagues (2016) used a similar version of our vigilance task, even though some differences exist among our and their studies. For example, they used partially different instructions, as they explicitly instructed a group of participants to report only any involuntary future thoughts and a second group to report only any

involuntary past representations. Moreover, another important aspect might be the difference in the number of verbal cues presented in the vigilance task. Cole et al. (2016) had verbal cues in each slide of the vigilance task, whereas we presented the cues only in some images of the task (see Study 1 and Study 3). Thus, one might hypothesize that the paucity of verbal cues could possibly promote the absorption with one's thoughts and consequently lengthen the time needed to notice a MW episode and report it (i.e., longer latency times; but see Vannucci et al., 2015, for an evidence of no effect of the cues frequency on involuntary memories and thoughts).

5.2 Implications for future research on mind-wandering

The findings presented here open up several new avenues of research in MW. In the following, we discuss some lines of research that could benefit from our results and extend them further.

In the first place, we moved further towards investigating the dynamics of MW. Indeed, we demonstrated that it is possible to identify the moment of ignition of MW and study the maintenance of MW starting from that point. Although Smallwood (2013) already proposed that MW experiences are composed of two distinct elements (i.e., the onset and the maintenance of thoughts), he stated that the onset of MW could be barely isolated from the subsequent stages due to the difficulty in linking MW to preceding events. This possibility was likely doubted because MW has been considered as a self-generated and stimulus-independent process for a long time. However, we showed that MW experiences can be triggered by task-irrelevant external cues and thus MW can be actually linked to preceding events in order to identify the onset of the process. Moreover, we also showed that the onset of MW and its unfolding

over time was accompanied by a physiological index, such as pupil dilation. Collectively, these findings contribute to the investigation of the dynamics of thought flow. For example, recent neurocognitive research has enrolled experienced meditators in order to study the brain areas recruited during the flow of MW states since their arising (e.g., Ellamil et al., 2016; Girn et al., 2017). In these studies, meditators are asked to press a button when they realise that they were thinking something else than the task, and researchers take advantage of the experience of meditators in recognising the arising of their thoughts. However, a procedure that makes us able to identify the initial stages of MW would be more useful than one based on the assumption that people can recognise the arising of their mental contents quickly.

Second, a dimension of MW that needs to be further investigated is the meta-awareness. Previous studies on MW have shown that people are not always meta-aware of their thought content (e.g., Schooler et al., 2011). For example, by presenting participants with thought-probes that ask about the focus of their attention and whether they were aware that they were experiencing thoughts unrelated to the task, it has been found that participants reported various levels of meta-awareness, sometimes being fully aware of their MW, and at other times reporting that they were not aware of it until the thought-probe was presented. Unaware MW has been reported to be different compared with aware MW: for example, it has been associated with poorer task performance (Smallwood, McSpadden, et al., 2007, 2008) or greater recruitment of brain activity (Christoff et al., 2009).

Given the differences between aware and unaware MW episodes, one could hypothesize that they might be associated with differences in pupil diameter. In our studies, we did not explicitly assess meta-awareness of MW, but we examined pupil

size associated with MW experiences sampled with two different sampling methods: the probe-caught procedure (Study 2) and the self-caught procedure (Study 3). The probe-caught allowed us to catch both MW with meta-awareness and MW which had not been spontaneously identified (i.e., MW without awareness), whereas the self-caught procedure allowed us to collect only MW with meta-awareness (i.e., participants were explicitly instructed to report their thoughts whenever they noticed their mind had wandered). In both cases, we found an increase in pupil dilation following MW triggers compared to non-triggers. However, future studies might extend further these results by assessing meta-awareness with a specific question included in thought-probes or by coupling probe-caught and self-caught into the same task.

Third, by using the vigilance task that allows to identify the onset of MW and the self-caught procedure, we showed that it is also possible to obtain information about the latency of MW without resorting to subjective estimation of the duration of MW episodes (Grandchamp et al., 2014; Klinger, 1978). The high levels of intra-individual and inter-individual variability in the latency data deserve future investigation. Specifically, future studies should investigate whether and how this variability might be explained by some characteristics of MW experiences as well as by participants' characteristics.

In terms of the properties of MW, for example, one might argue that the association between triggering cues-MW contents and pressing current concerns (e.g., Klinger, 2009, 2013) might be a factor that speeds the formation of MW experiences, thereby reducing the latency data. In terms of trait-level individual characteristics, a high tendency to be mindful in daily life (as measured with the FFMQ, Baer, Smith,

Hopkins, Krietemeyer, & Toney, 2006) might be associated with a reduced latency of MW, with people being faster in noticing and becoming aware of their MW state.

Finally, the studies reported in this work were conducted in samples of healthy young adults. Future research might extend our investigations to other samples of special interest, such as elderly people. Studies have consistently indicated that older adults report less MW than do young adults both in the laboratory (e.g., Jackson & Balota, 2012; Maillet & Schacter, 2016; Seli, Maillet, Smilek, Oakman, & Schacter, 2017) and in daily-life (Maillet et al., 2018). However, Maillet and Schacter (2016) found that during an incidental-encoding task, older adults, despite reporting fewer thoughts compared to young adults, reported a reduction in proportion of thoughts cued by internal stimuli, but an increase in proportion of thoughts cued by external stimuli. These authors suggest that the age-related reductions in MW frequency could be due to a wider reduction in the capacity to internally trigger and maintain representations (Maillet et al., 2017; Maillet & Schacter, 2016). This could lead elderly people to become environment-dependent (Lindenberger & Mayr, 2014). Contrary to these findings, very recently, Warden, Plimpton, and Kvavilashvili (2018) found no age effects on the frequency of spontaneous thoughts in daily-life. Moreover, they did not find a difference in the type of triggers (external, internal or no triggers) that elicited thoughts between young and older adults. Combining our behavioural paradigm with pupillometry might advance the understanding of the experience of MW in elderly people and help clarifying the mechanisms associated with any age-related changes.

Another sample of special interest might be patients with vmPFC lesions. The vmPFC is part of a sub-system of the DMN, which is the principal brain system supporting MW and spontaneous thought processes (e.g., Andrews-Hanna, Reidler,

Huang, et al., 2010; Christoff et al., 2016). Bertossi and Ciaramelli (2016) found that vmPFC patients reported reduced MW compared to both control patients (i.e., with lesions not involving the vmPFC) and healthy controls. Moreover, vmPFC patients reported a reduced proportion of future thoughts and a higher proportion of present thoughts. Our behavioural paradigm with pupillometry might also be helpful for investigations in samples of vmPFC patients in order to further examine these reported changes.

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