Mind wandering, working memory and creative problem solving in adults: Investigating culture, capacity, and task demand

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I, Qiuyu Du confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

This thesis investigated the relationship between mind wandering, working memory capacity (WMC), and creativity. A related construct that has been widely studied in terms of individual variations in mind wandering is WMC, however, the literature presents conflicting findings on whether there is a positive or negative relationship between WMC and mind wandering. While most studies have focused on the negative consequences of mind wandering, for example, its detrimental influence on task performance, some have shown that it may be beneficial in specific contexts, particularly by facilitating divergent thinking. To address these issues, the thesis explored the factors leading to mind wandering and its cultural differences between British and Chinese adults, investigated its relationship with WMC, and examined whether it contributes to creativity. Through empirical studies, the investigation examined mind wandering during different tasks, considering how WMC and task demand shape its effects. The finding revealed that mind wandering can have both positive and negative effects depending on the context, providing insights into the dual nature of it.

Impact statement

This thesis explores the relationships between mind wandering, working memory capacity, and creativity. Within academia, this research contributes to psychology by refining definitions of mind wandering and offering empirical insights into its dual nature, both as a distraction and as a facilitator of creativity. The findings support theoretical models of creativity, which helps us understand the underlying cognitive processes involved. Specifically, mind wandering is a common experience, with minimal cross-cultural variation in occurrence, though perceptions of it and efforts to control it do vary. Task engagement and motivation appear to influence mind wandering more than task demands or working memory capacity. Spontaneous mind wandering can promote low-level insights into solutions to creative problems, but more deliberate reflection on task structure appears to be more important. Beyond academia, the implications of this study are relevant to classroom practice. It emphasises the importance of matching task demands and difficulty to students' capacities and interests to prevent negative effects of mind wandering and enhance motivation. Additionally, the findings suggest a balanced approach within creative contexts: encouraging diffused focus alongside more deliberate reflective strategies for problem-solving.

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Table of Contents

List of Tables

List of Figures

1. Chapter one: General introduction

Most people can recall the experience of their thoughts drifting away, for example, from a lecture they are attending to an upcoming holiday. This is a widely experienced phenomenon known as 'mind wandering'. Research has claimed that people spend approximately 20% of their waking time mind wandering (Seli et al., 2018). While such common experiences had received little scientific attention until recently, this concept has been identified in almost all forms of activity. However, the term 'mind wandering' has been referred to in a number of ways, such as task-unrelated thought (TUT) (Smallwood et al., 2003), stimulus-independent thought (SIT; Mason, 2007) and spontaneous thought (Christoff et al., 2016). The first classifies mind wandering by its contents: the contents of mind wandering episode are unrelated or related to a task. The second way characterizes mind wandering is in terms of a relationship to external stimuli. Lastly, Christoff et al. (2016) define mind wandering as a type of spontaneous thought, highlighting the process of mind wandering rather its content. The prevalence of mind wandering suggests that it plays an important role in understanding the processes that regulate human thoughts and behaviours.

Several hypotheses have been developed to explain the occurrence of mind wandering, such as current concerns (Smallwood, 2013), executive failure (McVay & Kane, 2010), decoupling (Smallwood, 2013) and meta-awareness (Schooler, 2002). According to the current concerns hypothesis, mind wandering is motivated because of a tendency toward personal concerns. According to the executive failure hypothesis, mind wandering arises when executive control over external information fails. The decoupling hypothesis is an explanation for the continuity of internal trains of thought. The meta-awareness hypothesis makes a prediction that mind wandering occurs in the absence of meta-awareness. Working memory capacity (WMC) is one of the important constructs that has been extensively examined in relation to mind wandering, because of its relevance to executive failure, and potentially meta-awareness (Levinson et al., 2012; McVay & Kane, 2009). However, the literature is divided on whether mind wandering is a positive or negative phenomenon (Sio & Ormerod, 2009; Unsworth & McMillan, 2013) and in particular, whether it facilitates creative problem solving, with some sceptical, and others seeing a positive role for mind wandering.

In this chapter, the multiple terms that are used to define the mind wandering experience are summarised and reviewed, and additional relevant material on the mechanism and measures of mind wandering are discussed. The remainder of the chapter covers empirical research on mind wandering as it relates to WMC and creativity. Finally, the main points in the literature review and the planned work for the research are summarised.

1.1 Terminology

Use of the term mind wandering has risen rapidly in recent years, suggesting that increased attention is being paid to this topic (Kawashima et al., 2023). However, the field is characterised by mixed terminology, such as task-unrelated thought (TUT), stimulus-independent thought (SIT), and spontaneous thought; while the different terms that describe the mind wandering experience are sometimes used interchangeably, they are by no means the same thing.

Thoughts that emerge during mind wandering experiences are frequently defined as either task-unrelated or stimulus-independent, both of which emphasise that the experience is independent from an ongoing activity or external stimulus. TUT is a thought that directs away from the current task or situation, while SIT is a thought that is decoupled from current sensory information (Smallwood et al., 2003; Teasdale et al., 1993). That is, SIT is independent of any particular stimuli related to the current task or situation. The mind wanders due to internal processes. By definition, SIT may be unrelated to the current task (e.g., thinking what to cook for dinner), but it can also be related to the current task but not current perceptual stimuli (e.g., thinking about a approach to a task while completing different tasks). TUT can be directed either internally to an individual's current concerns (just like SIT, e.g., an upcoming holiday plan) or externally to stimuli in the environment that are not related to the current task (e.g., seeing a bird outside, as shown in Table 1.1 on the conceptual differences). Therefore, a distinction between TUT and SIT should be made as they describe two separable dimensions of mind wandering episodes.

Spontaneous thought captures how a mental state arises. Christoff et al. (2016) defined spontaneous thought as a thought that arises relatively freely due to either the absence of strong constraints on its contents or a transition from one mental state to another. There are two ways in which thought can be constrained: deliberately and automatically. Returning to the example provided in the opening, deliberate constraint occurs when a student deliberately brings their thoughts back to the lecture despite the fact that it is boring. Automatic constraint occurs when thoughts are naturally restricted without conscious effort (Christoff et al., 2016), for example, filtering out the sound of a buzzing insect in a quiet library. In terms of concept, Christoff (2012, p. 52) defines spontaneous thought as 'unintended, nonworking, no instrumental mental content'. This means that spontaneous thought arises without deliberate intention, which is distinct from both TUT and SIT. If mind wandering is defined as TUT, then it can occur either automatically (e.g., when we find our minds wandering off during a lecture) or deliberately (e.g., when we decide to tune out during a lecture due to boredom). SIT can also occur either automatically or deliberately. Spontaneous thought cannot by definition be deliberate.

Table 1.1 Conceptual differences between TUT, SIT, and spontaneous thought

Task type	Stimuli type	
	Internal stimulus	External stimulus
Task related	SIT/spontaneous thought	spontaneous thought
Task unrelated	SIT/TUT/spontaneous thought	TUT/spontaneous thought

A number of neuropsychological studies have been conducted on the three different types of thought. For example, in a functional magnetic resonance imaging (fMRI) study, three prominent regions of the brain – the medial prefrontal cortex, the posterior cingulate/praecuneus region and the temporoparietal junction (widely referred to as the default network) – were more active when the participants were experiencing TUT compared to when they were on task (Christoff et al., 2009; Mason et al., 2007). In research conducted on SIT, the medial prefrontal cortex region of the brain more specially has been implicated (Mason et al., 2007). In addition to the activation of the medial prefrontal cortex being linked to spontaneous thought, Spiers and Maguire (2006) observed the contribution of brain regions outside the default network, finding an association between the temporopolar cortex and the occurrence of spontaneous thought. Therefore, based on the evidence that different and only partially overlapping brain regions are activated, TUT, SIT and spontaneous thought seem to overlap with a degree of separability.

In the existing literature, the terms TUT, SIT and spontaneous thought have been frequently used throughout the last decade of investigations (Seli et al., 2018). These terms have sometimes been used interchangeably; however, as argued above, they are not entirely the same in terms of concept and activated brain regions. Moreover, the existing definitions fail to cover all types of mind wandering episodes. For example, if mind wandering reflects thought that is unrelated to the current task, this definition used in empirical studies would fail to capture thoughts during mind wandering episodes that are task related (e.g., worrying about the previous performance); and mind wandering as a thought stimulus-independent would fail to capture thoughts during mind wandering episodes that are triggered by a task stimulus (e.g., the current stimulus triggering a thought about a shopping plan). Therefore, to avoid confusion in the literature, there should be clarification in the terminology used to describe mind wandering. It would be helpful to distinguish mind wandering from the related terms and propose a clear and appropriate definition of mind wandering. The study described in Chapter 2 attempted to address this issue.

1.2 Cultural differences in mind wandering

Despite the ongoing debate about how to define mind wandering, research has consistently shown that mind wandering is a ubiquitous experience across cultures. From the United Kingdom (Seli et al., 2018) to China (Song & Wang, 2012), and across other countries such as Japan (Yamaoka & Yukawa, 2020) and Brazil (Goncalves et al., 2017), it seems that everyone's mind wanders. Though mind wandering is a universal phenomenon, cultural differences in its occurrence and content have been observed. Sude (2015) tested whether there is a difference in the rates of mind wandering between the European-heritage and the Asian-heritage samples. In this study, participants were required to complete a Sustained Attention to Response task with thought probing and three questionnaires: the Imaginal Process Inventory, the Mind Wandering Questionnaire, and the Mindful Attention Awareness Scale, respectively. The results showed that the Asian-heritage sample reported less mind-wandering than the European-heritage sample, though the types of thoughts experienced were similar. This suggests that while the frequency of mind wandering may vary across cultures, the content of these thoughts may be more universal.

However, Goncalves et al. (2017) failed to find the existence of cultural differences between Portuguese (southern European heritage) and Brazilian (southern American heritage) participants in terms of rates and content of mind wandering. In this study, participants completed the Attention Network task designed for the denotation of the attentional network, the Thought Identification Task, and the Resting State Questionnaire. Although there was no significant difference between the two groups in terms of rates and content of mind wandering, Portuguese participants showed greater attention to the task-related interference information. Similarly, the content of mind-wandering thoughts was comparable across both groups, with both reporting similar patterns of thoughts. This suggests that cultural factors did not substantially impact the types of thoughts experienced during the task, and that cultural differences in mind wandering may not be uniform across all contexts.

What differences there are appear to be deeply rooted in broader cultural orientations, and are associated with two of the most prominent dimensions of cultural variability, individualism and collectivism. Hofstede (1980) defined individualism and collectivism in terms of the closeness of the relationship between the individual and group. Individualistic cultural orientation is expressed when the individual focuses on his or her own goals. When the emphasis is on relationships with members and groups, a collectivist cultural orientation is expressed. Collectivism is a cultural orientation dominant in East Asia that emphasises the relationship between self and others and places group concerns (e.g., group harmony and cohesion) above individual concerns (e.g., self-improvement), compared to individualism, which is found in Western Europe and North America. In contrast, individualism emphasises the separation of the self from others and places group concerns below individual concerns. This cultural distinction may explain why European-heritage participants in Sude's (2015) study reported more frequent mind wandering. The greater focus on group concerns in collectivist cultures may results in greater concentration on externally set tasks, and hence less mind wandering. For instance, European-heritage participants in Sude's (2015) study reported more thoughts about the task and room, indicating greater meta-awareness and emotional engagement with task. In contrast, Chinese participates may have been more focused on maintaining task performance, leading to fewer instances of mind wandering but similar thought content when they did occur.

These distinct patterns may also reflect broader cognitive processing styles. Eastern cultures, such as China, are often associated with a more holistic style, which emphasises context and relationships. This style involves a broader attentional focus, where individuals pay attention to background details, spatial relationships, and the overall mood of a scene or an image before attending to specific objects (Boduroglu et al., 2009). Western cultures conversely tend to emphasize analytical thinking. This is characterized by a focus on the specific details and components of a situation rather than broader relationships between elements and context. In other words, analytic processing directs attention more selectively, focusing on specific objects or attributes. For instance, when viewing a scene or an image, British individuals may concentrate on salient details and individual object properties before considering the whole context, leading to more frequent mind wandering about personal goals. In contrast, Chinese individuals may focus on the broader context, leading to fewer mind wandering episodes but more thoughts about groups harmony when they do occur. This suggests that cultural values may shape not only the frequency but also the focus of mind wandering.

There was also a difference in the activated brain regions between the two groups while making visuospatial judgments. Compared to east Asians, westerners showed more activation in the frontal, parietal, and occipital areas and greater suppression in the medial frontal, medial temporal, and right middle temporal regions, which are known as the default networks. This network is active when an individual is not focused on the outside world and is instead engaged in internal mental processes. Furthermore, evidence suggests that the recruitment of the regions of the default network co-occurs with mind wandering (Christoff et al., 2009; Mason et al., 2007). Therefore, Westerners may experience *less* mind-wandering than East Asians when processing visual stimuli. There is a reasonable possibility that culture might also be related to the ability to suppress distracting information and maintain attention on task-related information. Although research into cultural differences in mind wandering has been neglected, these complex findings point to the effect of culture on the occurrence and content of mind wandering and provide a framework for exploring cultural differences.

1.3 Measuring mind wandering

The scientific study of mind wandering is complicated by the difficulty in measuring its occurrence given that it is a private, internal experience. As a result, early research into mind wandering has been dependent on self-reported measures. Although the self-reported method is valuable in producing a representative report of an individual's subjective experience – such as mind wandering – its validity in the assessment of mind wandering is doubted. The self-reported method can be problematic as it relies heavily on introspection, which inadvertently influences participants' observations, potentially leading to a retrospective bias (Smallwood & Schooler, 2006). For instance, participants do not remember previous mind wandering experiences accurately, and this inaccuracy may influence subsequent experiments. Since mind wandering experiences are internal, it is difficult for researchers to distinguish the correctness of participants' recollections.

Moreover, many different scales have been used to measure the general tendencies or frequencies of mind wandering experiences, such as the Imaginal Process Inventory (Singer & Antrobus, 1973), the Mindful Attention and Awareness Scale (Brown & Ryan, 2003) and the Attention-Related Cognitive Errors Scale (Cheyne et al., 2006). Despite the widespread tendency to use these scales as measures of mind wandering, they lack face validity as they do not directly test mind wandering. Instead, they focus on related constructs, such as daydreaming (the Imaginal Process Inventory), mindfulness (the Mindful Attention and Awareness Scale) and mistakes caused by failures of attention (the Attention-Related Cognitive Errors Scale). Moreover, there are many differences between the definitions of their related constructs and mind wandering. For example, daydreaming refers to a subjective experience in a non-task situation, while mind wandering emphasises a redirection of attention away from a task. The lack of a scale that directly measures mind wandering led Carriere et al. (2013) to develop the deliberate and spontaneous mind wandering scales, each consisting of four items using a 7-point Likert scale for responses. The items in spontaneous mind wandering scale include statement such as “It feels like I do not have control over when my mind wanders” (p. 22). The deliberate mind wandering scale includes statement like, “I allow any thoughts to wander on purpose” (p. 22). Across Carriere et al.’s (2013) studies, fidgeting was significantly associated with spontaneous but not deliberate mind wandering. However, it is important to note that neither the deliberate nor the spontaneous mind wandering scale is sufficient to test the overall frequency of mind wandering, and the combination of the scales to assess mind wandering is untested (Mrazek et al., 2016). More recently, Mrazek et al. (2016) developed a 5-item scale with high internal consistency and convergent validity to directly assess mind wandering, regardless of whether it was spontaneous or deliberate. The scale includes items like, “I find myself listening with one ear, thinking about something else at the same time”. However, scales as part of self-reported measures that rely on introspection and retrospective recall arguably have the same limitations as those previously discussed.

To reduce introspection and retrospective recall bias, Smallwood and Schooler (2006) proposed two methods for directly measuring in-the-moment mind wandering: the self-caught method and the probe-caught method. In the self-caught method, participants are directly asked to indicate whether they had experienced mind wandering. In the probe-caught method, participants’ thoughts are probed at various points in a task and the sample is recorded either by a verbal or written report. In contrast to the self-caught method, the probe-caught method does not rely as heavily on self-monitoring and it is less likely to be confounded by an awareness of mind wandering. Thus, the use of both the probe-caught and the self-caught methods might be useful for distinguishing whether mind wandering occurs with or without awareness (Smallwood & Schooler, 2006). Since self-caught mind wandering is dependent on meta-awareness, this type of thought probe may be beneficial in determining how well people can detect mind wandering when combined with the probe-caught method.

Furthermore, a mind wandering episode may only contain incomplete thoughts or images, and requiring participants to express experiences that may be difficult to put into words might result in the distortion of experimental results. In other words, participants may tend to report fewer frequencies of mind wandering to avoid wasting time verbalising their experiences. Thus, giving participants a set of response options would appear to be a better option to avoid such circumstances (McKiernan et al., 2006). Recent research has employed a new way to probe thoughts that allows participants to indicate a category for their thought, e.g. TUT, task-related thought or task-related interference (Smallwood & Schooler, 2006). These categorical probes do not interrupt the task for overly long periods of time (McVay & Kane, 2009) and provide more information on participants' internal thoughts.

In addition to this, numerous studies have employed behavioural and neuroscientific indices to investigate mind wandering, such as reaction time (McVay & Kane, 2009), fMRI activity (Andrews-Hanna et al., 2010), electroencephalography activity and pupil dilation (Smallwood et al., 2008, 2011). The Sustained Attention to Response Task (SART) is one of the most common tasks used to study mind wandering (Smallwood et al., 2004). During the SART, individuals are required to respond to frequent non-targets and withhold responses to infrequent target stimuli. A large amount of non-target stimuli causes individuals to form an automated-stimulus button response. Individuals who are unable to sustain constant attention to the stimulus are less likely to inhibit the infrequent non-target stimulus button response. If the individual has mind wandering when the target stimulus appears, the result is an incorrect reaction to the target stimulus. The failure to withhold responses to target stimuli, referred to as an action slip, is typically used in inhibitory control tasks to infer mind wandering, and as the thought at this moment is considered a shift from task-relevant information to task-irrelevant information (Roberson et al., 1997). McVay and Kane (2009) used the SART and thought probes to verify that mind wandering is connected to performance errors on the SART. In their experiment, participants committed more errors on target trials, during which they reported more off-task than on-task thoughts. The findings also showed that individual differences in participants' overall accuracy correlated negatively with their rate of off-task thoughts. Based on the fact that reports of off-task thoughts are accompanied by more performance errors than on-task thoughts, many researchers have employed the SART in the study of mind wandering. However, while the SART is useful for measuring mind wandering, it may not effectively capture the varying cognitive loads needed to study this phenomenon in different contexts.

1.4 Theories of mind wandering

In addition to the uncertainty around the definitions of mind wandering, the reasons behind its occurrence continue to be a major issue for debate. Four hypotheses have been developed in an attempt to explain the mechanism behind this phenomenon: current concerns, executive failure, decoupling and meta-awareness.

1.4.1 Current concerns hypothesis

The current concerns hypothesis was first proposed by Klinger et al. (1973). It relies on the idea that the mind maintains focus on a task to achieve a goal. According to this hypothesis, mind wandering results from a focus on resolving a discrepancy; in other words, a gap between the current state and an unresolved goal (Klinger, 2009). To resolve a discrepancy, behaviour will be modified to get closer to the goal, until the goal is either met or abandoned. Smallwood (2013) supported Klinger's statement, stating that 'mind wandering might occur more frequently when self-generated thought has higher incentive value than incoming perceptual information' (p. 523). He argues that in the process of pursuing a goal, the mind is more attracted to internally generated thoughts related to the goal than the weaker salience of perceptual information, which may result in mind wandering. Furthermore, there are two features of the persistence of current concern: continuous and automatic (Klinger, 2009). In other words, persistence will continue until the goal is either attainted or abandoned. Additionally, an individual's mind is attracted automatically to the most salient information either in the external environment or in the internal process, without their awareness. When the internal system has more salient information, attention tends to focus on self-generated information. From a conceptual perspective, the current concerns hypothesis is more consistent with SIT and spontaneous thought than with TUT, as it emphasises more the internal thought processes and the automatic or spontaneous characteristics of the occurrence of this phenomenon, whereas TUT has a narrower focus on the relevance to the task itself.

1.4.2 Executive failure hypothesis

McVay and Kane (2010) proposed the executive failure hypothesis of mind wandering. According to this hypothesis, mind wandering stems from the failure of executive control, which is the capacity to regulate attentional control or to recover from lapses in goals (Randall et al., 2014). From this perspective, having greater control of executive attention means that individuals can maintain their attention on task-related information and block task-distracting information, which avoids the shift from on-task thoughts to distracting information. Therefore, under conditions of reduced executive control, individuals are less likely to be able to maintain their attention on task goals and avoid their attention drifting away. For example, in Sayette et al.'s (2009) study into the effects of alcohol consumption on experiential consciousness, they found that participants who drank the alcohol were more likely to report mind wandering than those who drank the placebo. Similarly, individuals with strong executive control abilities, which are implicated in working memory capacity (WMC; Engle & Kane, 2004), should exhibit less frequent occurrences of mind wandering. In a study conducted to examine the relationship between WMC and mind wandering in a SART task, the researchers found that participants who differed in WMC also varied in their mind wandering experiences (McVay & Kane, 2009). Participants with lower WMC experienced more mind wandering than those with higher WMC. As with the current concerns hypothesis, this framework claims that the presence of mind wandering is automatic and that it occurs because of the failure of executive control. Unlike current concerns, though, it aligns better with TUT, because it addresses the ineffective regulation of attention, leading to the lapses in executive control, thus such thoughts might occur.

1.4.3 Decoupling hypothesis

The decoupling hypothesis states that mind wandering is not the result of an absence of executive control, but refers to a redistribution of executive attention from the external environment to internal processes of limited executive resources (Smallwood, 2013). In other words, mind wandering reflects a shift in executive resources. For example, executive resources are involved in the regulation of external information in the same way that they are required to support the continuity of internal trains of thought, which is contrary to the executive failure hypothesis. One special feature of this hypothesis is its emphasis on the role of the maintenance of mind wandering rather than determining the occurrence of mind wandering (Smallwood, 2013). Once executive attention focuses on the internally generated thought, executive resources shift to the internal process (i.e. mind wandering experiences) to maintain its continuity.

The decoupling hypothesis was supported during a reading task in which mind wandering was associated with ageing (Krawietz et al., 2012). As predicted by the hypothesis, older adults with smaller WMC, resulting from the reduced cognitive flexibility with age (Lee et al., 2022), were less likely to report mind wandering compared to younger adults with greater WMC. Under these circumstances, it was argued that younger adults with greater WMC have residual resources to engage in mind wandering as they do not have to put all of their resources into a reading task. However, this data is inconsistent with the hypothesis developed from the executive failure perspective, where older adults would report more mind wandering experiences than younger adults. The decoupling hypothesis aligns better with SIT, as it directly explains the reason for the shift from the externa or sensory stimuli to internal generated thought in that executive resources primarily maintain internal generated thought rather than external information. It also aligns with spontaneous thought, as both involve internal processing.

1.4.4 Meta-awareness hypothesis

The meta-awareness hypothesis suggests that individuals have the self-monitoring ability to regulate and correct their thoughts (Schooler, 2002). Under this hypothesis, individuals with greater awareness of their current thoughts are more capable of mobilising their attention to the current task in order to suppress future mind wandering. Unlike the role executive control plays in the executive failure hypothesis, the meta-awareness hypothesis emphasises the capacity to correct conscious thoughts that deviate from the goal state. Meta-awareness, in short, can be seen as a factor that influences the likelihood that mind wandering will happen. As predicted by the hypothesis, individuals with an awareness of their thoughts are thought to have better control over their attention, which reduces the likelihood of the occurrence of mind wandering compared to those without awareness. Using the self-caught (awareness of mind wandering) and probe-caught (not aware of mind wandering) methods, Christoff et al. (2009) found that participants made more errors on the SART during mind wandering without awareness compared to mind wandering with awareness because they were able to correct the latter. The meta-awareness hypothesis is more consistent with TUT. Individuals with meta-awareness are better able to identify and correct these unrelated thoughts.

Although the mechanisms behind these four hypotheses are different, they all attempt to explain both why mind wandering occurs and what events are involved. The current concerns hypothesis suggests that mind wandering is caused by a tendency toward the personal concerns. The executive failure hypothesis argues that the experience of mind wandering occurs when executive control over external information has failed. The meta-awareness hypothesis makes a prediction that mind wandering occurs in the absence of meta-awareness. The current concerns, executive failure and, meta-awareness hypotheses explain what might determine the occurrence of mind wandering, while the decoupling hypothesis explains its function rather than the mechanism of its occurrence. According to the decoupling hypothesis, mind wandering reflects a redistribution of executive attention from the external environment to internal processes. Additionally, the executive failure hypothesis claims that the presence of mind wandering does not consume executive resources, which is similar to the current concerns hypothesis. Contrary to executive failure, the decoupling hypothesis requires executive resources to support the continuity of internal trains of thought (see Table 1.2 for a summary of all four hypotheses). The current concerns, executive failure and decoupling hypotheses rely heavily on executive resources. In order to understand the competing perspectives on executive resources, it is also necessary to discuss the concept of executive resources and its relationship with mind wandering. This is addressed in greater detail in section 1.5.

Table 1.2 A summary of the four hypotheses on mind wandering

Hypothesis	Focus	Executive resources
Current concerns	Occurrence of internal thought	Resource free
Decoupling	Continuity of internal thought	Resource demanding
Executive failure	Occurrence of internal thought	Resource free
Meta-awareness	Occurrence and regulation of internal thought	

1.4.5 The region of proximal learning and mind wandering

Building on these theories, the Region of Proximal Learning (RPL) model offers a complementary framework for understanding mind wandering by focusing on the role of task difficulty and cognitive engagement. Xu and Metcalfe (2016) tested the impact of difficulty on mind wandering, and proposed the region of proximal learning framework as part of their findings. The framework suggests that tasks that are too simple might cause boredom while tasks that are too challenging can cause irritation. The most beneficial learning setting is represented by the easiest yet unmastered resources, which are just outside the learner's current level of proficiency. In their study, participants were faced with three levels of Spanish words, simple, moderate, and complex, and they exhibited less mind wandering when studying words within their RPL. Mind wandering frequency increased when words were either too simple or too challenging. Similarly, Randall et al. (2019) manipulated the difficulty of math tasks into high, moderate, and low demands, and found that mind wandering was most frequent during high and low conditions compared to moderate conditions, forming a U-shaped relationship with task demand.

The RPL model challenges the traditional view that the relationship between task demand and mind wandering is linear, but it still provides a coherent framework for understanding the occurrence of mind wandering. The executive failure hypothesis suggests that mind wandering occurs when executive control over attention fails, particular in individuals with low WMC. These individuals are likely to report more mind wandering experiences when tasks are too demanding due to their limited cognitive resources, or when tasks are too easy, as their attention is not sufficiently engaged. The RPL model aligns with this hypothesis by proposing that tasks within the RPL that are moderately challenging optimise cognitive resource allocation, reducing the likelihood of executive failure and mind wandering in low WMC individuals.

Similarly, according to the decoupling hypothesis, mind wandering reflects a distribution from external environment to internal thoughts, suggesting that high WMC participants would report more mind wandering experiences in low demanding tasks. The RPL model complements this hypothesis by suggesting that tasks within the RPL can reduce mind wandering in high WMC individuals by providing sufficient challenge to keep them engaged in external task. This supports the hypothesis proposed in this study that the relationship between mind wandering and WMC is context-dependent. In high demanding tasks, the executive will be dominant. Conversely, in low demanding tasks, the decoupling hypothesis will dominate.

1.5 Mind wandering and working memory capacity

The discussion of the current concerns, executive failure, decoupling, and meta-awareness hypothesis provides some clarity on the mechanisms and processes that research suggests are involved in the occurrence of mind wandering. One significant implication of this discussion is that it shows the role of working memory capacity (WMC) may play in the occurrence of mind wandering. The executive failure and decoupling hypothesis reveal a different relationship between WMC and mind wandering. The executive failure hypothesis claims that mind wandering is the result of executive control failure and that the presence of mind wandering does not consume executive resources. Contrary to executive failure, the decoupling hypothesis requires executive resources to support the continuity of internal trains of thought. In order to further understand the two competing perspectives on mind wandering, it is necessary to discuss the related terms of WMC and its relationship to mind wandering.

While there are several models of working memory, the most enduring is provided by Baddeley and Hitch (1994). The model proposes the presence of three systems: the phonological loop, the visuospatial sketchpad and the central executive. The first two systems are responsible for storing short-term information; the phonological loop receives and transmits verbal information and visual and spatial information contained within the visuospatial sketch pad. The central executive system regulates the information held in attention and maintains the information that is selected for processing. In this way, the central executive system is responsible for the allocation of attentional focus. For example, when two activities come into conflict, such as conducting an ongoing task and planning dinner, the central executive directs attention to selective tasks (e.g., concentrating on the task) and inhibits the distractor (e.g., planning dinner). In the working memory model advanced by Baddeley (2000), an additional component, the episodic buffer, was presented as a way to integrate information from different working memory subsystems and long-term memory.

Engle and Kane (2004) argued the fundamental predictor of individual variations in WMC is executive control abilities and that differences in WMC are due to varying abilities to control attention (Engle & Kane, 2004). This aligns with Baddeley's (1994) concept of the central executive, but this model is somewhat differentiated from the Baddeley and Hitch's model of working memory, as it is less about the storage of information but rather than the ability to manage attention which is needed to maintain task goals and prevent a focus on distracting stimuli (Engle & Kane, 2004; Kane et al., 2007). According to this view, individuals with high WMC have greater attention control abilities compared to individuals with lower WMC; thus, they are better able to maintain information in the presence of distracting stimuli (McVay & Kane, 2009). Similarly, the Cowan's embedded process model emphasises attention control as a critical factor in WMC, in which the focus of attention determines what information is processed in work memory (Cowan, 1999).

Recently, some work has suggested a role for WMC in mind wandering, but the literature is mixed in terms of what that role is. The resource-demanding view (i.e., the decoupling hypothesis which requires executive resources to support the continuity of internal trains of thought) proposes that executive resources are required in sustaining the mind wandering state and thus suggests that individuals with high WMC (more executive resources) will report more mind wandering experiences than individuals with low WMC. Evidence for this claim was provided by Levinson et al. (2012) who investigated the frequency of mind wandering in an undemanding task. In the experiment, participants were required to complete visual search tasks that placed a low demand on WM, based on the assessment of WMC, for example, an operation span task. The results revealed that participants with higher WMC reported greater mind wandering during low-load tasks, which justified the assumption of the occurrence of mind wandering in decoupling hypothesis. However, such data cannot fully explain why high-WMC participants' minds wander more during low-load tasks than during high-load tasks.

Other theorists have provided the resource-free view (i.e., the executive failure hypothesis which claims that mind wandering is the result of executive control failure and does not consume executive resources) and argued that WMC is strongly linked to mind wandering through its associated executive control capacities, which enable people to prevent the interference of mind wandering and focus on a current task. Higher WMC allows more control of executive attention; therefore, individuals with high WMC may be less prone to mind wandering than individuals with low WMC. Evidence comes from laboratory work that show a negative association between WMC and mind wandering (McVay & Kane, 2009, 2010). In McVay and Kane's (2009) study, participants completed the three versions of SART tasks, with three different types of stimuli (i.e., sematic, perceptual, perceptual-sematic) and responded to thought probes during each block. Three complex-span tasks: operation span, symmetry span, and reading span were adopted to measure WMC. The result showed that participants who differed in WMC varied in SART performance and mind wandering experience. Individuals with high WMC mind wandered less during the SART tasks than did individuals with low WMC, which suggests that mind wandering represent an executive failure.

These apparently contradictory findings indicate that task demand might influence the role of WMC. That is, under a non-demanding task, executive control acts to support the continuity of internal trains of thought, following the rule of the decoupling hypothesis. Individuals with high WMC will report more mind wandering as the demand for executive control is low and there is no need to suppress mind wandering. However, in a high-demanding task, the need for executive control is high and executive control resources are required to maintain attention on an ongoing task and inhibit mind wandering. In this case, mind wandering is the result of executive control failure. Therefore, individuals with high WMC will suppress the occurrence of mind wandering and are less prone to experience it. The evidence provided by Kane et al.'s (2007) study supports this, finding that high-WMC individuals reported fewer mind wandering experiences compared to low-WMC individuals while the mind wandering task was considered challenging. However, while there is evidence supporting the hypothesis that task demand moderates the role of WMC, there is a lack of sufficient direct empirical data on the contrasting effects to draw a conclusion because most of the evidence supporting this hypothesis comes from either high demanding tasks or low demanding tasks. For these reasons, various tasks with different demands are employed in this PhD project to provide more direct empirical investigation of the association between WMC and mind wandering.

1.6 Attention in mind wandering and creative cognition

Mind wandering, as a form of inattention, seems to be negatively correlated with attention. Hu, He, & Xu (2012) provided empirical evidence for such inverse correlation by a study focusing on the connection between attention and mind wandering. Attention based on the conception of attentional networks was measured via three components: alerting, orienting, and executive control (Posner, & Petersen, 1990). Alerting is the ability to perceive any salient stimuli from the environment, no matter whether internal or external. Orienting means focusing attention on the relevant things, involving two types of conditions: one is about deliberately choosing to pay attention to something, and the other is when attention is drifting to the sudden stimuli (e.g., a sudden loud noise). Executive control refers to the ability to make decision and solve problems, especially when there are different options or conflicting thoughts (i.e., helping decide the priority and manage time). Mind wandering was measured by inserting thought probes in the SART. The results revealed a negative relationship between mind wandering and orienting, suggesting that when individuals are less able to focus their attention on relevant stimuli, they are likely to experience mind wandering. However, no significant relationship was found between mind wandering and other components of the attentional network.

The interference of mind wandering in attention appears to vary depending on the type of cognitive tasks employed, however, Gonçalves et al. (2017), used The Attention Network Test in which participants were presented with a target stimulus (e.g., a row of five arrows, ← ← → ← ←) and then were asked to identify the direction of the central target stimulus. The flanking arrows functioned as distractors. There was no significant effect of mind wandering on alerting, orienting, or executive control in this study. These results imply a complex relationship between mind wandering, cognitive abilities and types of tasks. There is also evidence that the kind of defocused attention involved in mind wandering might not always be detrimental to cognitive tasks, especially given the lack of a negative effect observed in this study.

Several studies have found the facilitative role of different forms of attention in creative processes. Diffused attention, which refers to a cognitive pattern where an individual struggles to ignore irrelevant stimuli, leading to an increased awareness of stimuli in the surroundings, is claimed to be associated with creativity (Zabelina et al., 2015). A study by Ansburg & Hill (2003) also evidenced the relationship between diffused attention and creativity. In this study, participants were asked to memorise a given list of words and ignore a list of words being read. Then they were given anagram tasks. One third of the anagram solutions was from the memorised words, one third of solutions was from the ignored words, and one third of solutions had not been previously presented. Subsequently, participants were required to complete the divergent thinking task, during which they were required to generate original and novel responses as much as possible. The results showed a positive association between creative performance and the participants' ability to solve anagrams for which the solutions were words from the ignored list. This implies that awareness of environment hints, even when participants were instructed to ignore them, facilitated their performance on creative tasks. Those who perform well in creative task might have a diffused attention, engaging in the information beyond the current focus.

In line with this assertion, individuals with attention deficit hyperactivity disorder (ADHD) marked by diffused attention can perform well in creativity. White and Shah (2011) compared participants clinically diagnosed with ADHD and non-ADHD group in the creative test, the Torrance Test for Adults, and found that the group with ADHD outperformed their counterparts. However, this positive aspect of ADHD is limited. A review found no evidence regarding creativity and convergent thinking performance that focuses on finding a correct answer to a specific problem through 31 behavioural studies (Hoogman et al., 2020). The poor performance on convergent thinking might mean that the main impairment in ADHD is deficient executive inhibition (White & Shah, 2011). Inhibitory control, a key executive function, refers to the ability to control attention, behaviours, thoughts, and emotions (Diamond, 2013). It helps focus on selective stimuli by ignoring distractors. Therefore, deficient inhibitory control may be advantageous while performing divergent thinking tasks; conversely, it may be detrimental when performing convergent thinking activities.

Carson et al., (2003) found that the reduction in latent inhibition, which refers to the ability to filter out stimuli previously thought to be irrelevant from the current focus of attention was associated with improved divergent thinking. In a recent study, Radel et al., (2015) directly manipulated participants' inhibitory resources by continuously exposing them to a conflict task that exhausted the limited executive resources. They used The Simon Task, during which participants were required to press buttons as fast as possible. There were two versions of the task: congruent, where the spatial location of stimuli was matched with the required response button (e.g., a stimulus presented on the right side of the screen required a right key press), and incongruent, where the spatial location of stimuli did not match the required response button (e.g., a stimulus on the right side of the screen required a left key press). To confirm the change in inhibition performance, participants were asked to conduct the Eriksen Task, a type of the attention network test, during which they were asked to response to a target stimulus typically located in the centre of a row of stimuli (e.g., > > < > >, in this case participants should press button corresponding to the left). Subsequently, participants were assigned to complete both divergent thinking and convergent thinking tasks. Results supported the relationship between inhibition and creativity that the decreased inhibitory ability had an advantage in divergent thinking, but no association with convergent thinking. While mind wandering disrupted certain components of attention, the facilitative role of diffused attention and reduced inhibition suggests that mind wandering might contribute positively to creativity by altering attentional focus.

1.7 Mind wandering and creative problem solving

Mind wandering is ubiquitous, which means it can occur in almost all forms of activity. In traditional research, the focus of mind wandering has always been on its negativity. As shown in the aforementioned study by McVay and Kane (2009), even those with high degrees of executive control appear prone to engage in mind wandering when they feel they are free to do so, which can significantly impair individuals' task performance. Unsworth and McMillan (2013) found a negative relationship between mind wandering and reading comprehension, suggesting the overall accuracy of reading comprehension is impeded by the occurrence of mind wandering. Mind wandering might also be a source of distraction when driving. Yanko and Spalek (2014) provided evidence consistent with the supposition that mind wandering has an influence on driving behaviour and endangers drivers' safety. As a result, mind wandering may be costly in some situations; however, it also has some unique functions. Researchers have found that mind wandering has an important contribution to some common contexts, such as in creativity. Thus, this PhD project will attempt to delve into the positive aspects of mind wandering.

Sawyer (2011) proposed that mind wandering may play a role in problem solving.

Temporarily diverting conscious attention away from the task at hand may provide the mind with periods of "mini incubation" (Sawyer, 2011, *p.* 9) that enhance opportunities for insights to arise. The process of creative problem solving involves four stages: preparation, incubation, illumination and verification. It has long been known that the incubation period – which is a period of time in which a problem is set aside before further attempts to solve – can improve creative problem solving (Sio & Ormerod, 2009; Wallas, 1926). Indeed, in a recent meta-analytic review of studies that examined the incubation effect on creative problem solving, Sio and Ormerod (2009) identified that longer incubation periods yielded a positive effect on problem solving. They also noted that low-demand tasks maximised the incubation effect more than high-demand tasks. This was supported by a study that tested the effect of mind wandering on creative performance (Baird et al., 2012). In Baird et al.'s study, participants performed the unusual uses task (UUT), a divergent thinking task in which they were asked to generate as many unusual uses as possible for a common object, such as a brick, in a set amount of time. The number and originality of the answers were considered an index of creative thinking. The results showed an improvement in UUT performance after an incubation period where the participants engaged in an undemanding task (in which participants' minds were allowed to wander) compared to after a break when they engaged in a demanding task. In a retrospective questionnaire, participants engaged in the undemanding task also reported higher levels of off-task thinking. In other words, doing an undemanding activity during the incubation period was linked to greater mind wandering and incubation effects on creative thinking. This association is in line with the meta-analytic analysis that revealed that engaging in a simple task that allows the mind to wander may facilitate creative problem solving.

However, the finding in Baird's (2012) research showed that while mind wandering facilitates the incubation effect, there was no direct correlation between scores on creative problem solving and mind wandering. Moreover, the improvement was only observed for repeated-exposure problems; that is, the incubation effect had a significant effect in the repeated-exposure condition rather than resulting in a general improvement in creative problem solving. Smeekens and Kane (2016) employed similar materials to those used in Baird et al.'s (2012) study. They found that mind wandering, which they measured using online thought probing, did not predict creative problem solving, casting doubt on Baird et al.'s (2012) conclusion. Thus, findings on the relationship between mind wandering and creativity are inconsistent and it remains unclear if mind wandering directly assists creative problem solving.

These two studies of Baird et al. (2012) and Smeekens and Kane (2016) investigated the role of mind wandering in divergent thinking tasks, such as UUT. However, Sio and Ormerod (2009) found that, across studies, different problem types contributed to various sizes of incubation effect. Interestingly, divergent thinking tasks seemed more effected by incubation than insight tasks. To understand this finding, it is essential to introduce two terms created by Guilford (1975) associated with creative problem solving: divergent and convergent thinking. Divergent thinking is a creative thinking process that produces a diverse response to an open-ended question. Problems related to divergent thinking concentrate on the generation of original and unusual responses (Razumnikova, 2013). Convergent thinking is a creative thinking process that leads to a single, correct solution to a well-defined problem. The insight problem is one of the most common tests used to measure convergent thinking. In the insight problem, participants are asked to generate a unique and correct solution that requires a restructuring of task representation. Tests on both divergent and convergent thinking have revealed two facts regarding creative thinking; divergent thinking is unrestricted by rules and is a process that illustrates how creative individuals produce multiple ideas, while convergent thinking is an inductive process in which innovative individuals must restructure a situation to find a single, correct answer.

While tests of divergent thinking and convergent thinking are widely utilised to assess creativity, there are still issues regarding the measurement of creativity. Much of the uncertainty around measurement might be attributable to the diversity of its definitions, which indicates the complexity of measuring creativity. Creativity definitions, in general, reflect one of the four perspectives: creative cognitive processes (process), personality traits (person), creative products (product), and working environment (press) (Said-Metwaly et al., 2017). Instruments are typically divided into four approaches that correspond to the four key areas of creative definitions: process, product, person, and press. Researchers holding the process perspective in creativity emphasising divergent thinking and problem solving often use tests of divergent thinking to measure, while researchers holding the person perspective in creativity highlighting personality traits are associated with creative individuals often use instruments such as the Creative Personality Scale (Gough, 1979) to look at these traits. The product perspective focuses on the quality of creative outcome and often utilises the Consensual Assessment Technique (Amabile, 1982) to evaluate creative works. The press emphasises the influence of the environment, using scales like the Work Environment Scale to measure factors that facilitate creativity (Moss, 1986). As a result, the instruments utilised by these researchers have a somewhat restricted focus and represent just a narrow aspect of creativity. Apart from that, the measurements widely used for measuring creativity, divergent and convergent tests, typically restrict individuals' creative performances to these specific given tasks. It is doubtful that this performance perfectly represents actual real-life creativity. Tasks or problems, in a laboratory setting, are operationalised as divergent or convergent, while the tasks or problems encountered in real natural life are somewhat ambiguous. Consequently, many questions have been raised about the validity of measuring creativity (Said-Metwaly et al., 2017; Zeng et al., 2011). This provides insight about the measurement of creativity and suggests that there is a need to provide a holistic view of creativity.

1.8 Theories of creativity

There are wo important theories regarding the nature of creativity: the controlled attention theory and the associative theory. According to controlled attention theory, creative thought is a top-down process in which executive control plays a critical role in maintaining a strategic focus during problem solving (Beaty et al., 2014). Individuals actively search for novel solutions, maintaining a clear objective through the process. This theory is consistent with the conscious work hypothesis, in which individuals consciously direct their cognitive resources towards a problem (Williams et al., 2018). Associative theory, on the other hand, presents creativity as a more spontaneous, bottom-up activity. It emphasises the need for cognitive flexibility and less hierarchical knowledge (Beaty et al., 2014). In this theory, creativity is seen as a result of spontaneous associations that occur when ideas or concepts in individuals' minds naturally link together, often without conscious control, which aligns with the unconscious work hypothesis. These theories differ in their consistency with the conscious and unconscious work hypotheses, with the controlled attention theory aligning with the conscious work hypothesis, emphasising conscious cognitive control. Conversely, the associative theory aligns with the unconscious work hypothesis, focusing on the spontaneous and uncontrolled cognitive processes.

One prevalent idea about the role of incubation in creativity is based on the conscious work hypothesis. These ideas propose that incubation is a period of relaxation for the conscious mind. Individuals temporarily break from actively working on a problem during the incubation period, which provides for the relief of mental tiredness, the restoration of cognitive resources, and a fresh viewpoint on the problem (Gilhooly, 2016; Williams et al., 2018). Essentially, incubation is viewed as a way to refresh the conscious mind, resulting in improved problem-solving skills when individuals consciously re-engage with the problem.

The unconscious work hypothesis, in contrast to the conscious work hypothesis, offers a distinct mechanism behind the advantage of incubation. Within this perspective, incubation is regarded as a stage during which mental processes continue to function, although unknowingly. One prominent idea is the concept of spreading activation, in which thoughts and ideas freely travel across loosely related concepts or semantic categories during incubation (Sio & Ormerod, 2015). This process might reactivate forgotten or previously inactive memory fragments, which may inspire new approaches to tackling problems. Additionally, the opportunistic assimilation account proposes that during incubation, individuals might unknowingly assimilate external information such as environmental cues or accidental observations (Seifert et al., 1995; Sio & Ormerod, 2015). By incorporating external data, more ideas may be examined, often ones that might not have been taken into account. Both processes contribute to expanding the problem solver’s pool of relevant associates, but through different sources of information. Spreading activation primarily involves the spontaneous activation of related concepts within individuals’ memory, while opportunistic assimilation includes the incorporation of various external cues and information encountered during incubation. It does not rely exclusively on semantic information but accepts all knowledge that might help with problem solving.

These two perspectives on incubation provide diverse insights into the nature of creativity. The restorative part of incubation is emphasised by the conscious work hypothesis, with the conscious mind benefiting from a break and then putting regenerated mental resources to problem-solving. The unconscious work hypothesis, on the other hand, emphasises the continuing operation of cognitive processes during incubation. As a result, the comparison of different theories reveals the complex character of incubation as well as the interaction of conscious and unconscious cognitive systems.

The controlled attention theory and the conscious work hypothesis have one thing in common: they both rely on consciously directed cognitive processes. These two ideas emphasise the idea that creative thinking requires conscious, deliberate, and goal-oriented mental activities. They consider creativity to be the consequence of controlled, goal-oriented processes in which individuals deliberately employ their cognitive resources towards the generation of creative solutions. These concepts essentially stress the importance of executive functions and conscious attention in the creative process, as opposed to spontaneous or unconscious cognitive processes that are emphasised in other theories of creativity, such as associative theory and the unconscious work hypothesis. Both associative theory and the unconscious work hypothesis emphasise that creativity can emerge through spontaneous connections among already-existing brain contents rather than being completely dependent on conscious, deliberate effort. In both situations, individuals let their thoughts wander and establish unforeseen connections, whether in the context of solving creative problems or during the incubation stage (see Table 1.3 for a summary of the similarities and differences among the four theories). It implies an interaction between mind wandering that occurs during the periods of incubation and these theories. That is, mind wandering may support unconscious work, but potentially interfere with conscious work.

Table 1.3 The similarities and differences among the Controlled Attention Theory, Associative Theory, Conscious Work Hypothesis, and Unconscious Work Hypothesis in the context of creativity

Aspect	Controlled Attention Theory	Associative Theory	Conscious Work Hypothesis	Unconscious Work Hypothesis
Creative Process	Top-down, deliberate	Bottom-up, spontaneous	Top-down, deliberate	Bottom-up, spontaneous
Role of Executive Functions	Emphasised	Less emphasised	Emphasised	Less emphasised
Cognitive Flexibility	Less emphasised	Emphasised	Less emphasised	Emphasised
Conscious/Unconscious Processes		More unconscious	Emphasises conscious work	Emphasises unconscious work

Although the conceptual differences between controlled attention and associative theory are apparent, each of these creative cognitions uses a particular combination of the two theories (Benedek & Jauk, 2018). The dual pathway theory proposes that there are two cognitive pathways through which our brain functions when it comes to being creative and solving problems: the flexibility pathway and the persistence pathway (Nijstad et al., 2010). The flexibility pathway allows for the generation of creative insights, problem solutions, or ideas through broad and inclusive cognitive categories, establishing new connections between diverse concepts, and breaking away from old thought patterns. The persistence pathway, on the other hand, emphasises hard work, methodical problem-solving, and resiliency. It implies that deliberate, persistent inquiry may inspire creativity.

Creative thinking processes, including associative and executive thinking, are closely linked to particular brain networks. The aforementioned default network emerges as a critical component, particularly in associative thinking, where it integrates seemingly unconnected ideas and memories (Beaty et al., 2014; Marron et al., 2018). The brain areas in the default network become active while engaged in creative tasks that require unique connections, allowing individuals to tap into their personal ideas and experiences. The executive thinking functions differently from the default network. The involvement of executive functions, such as attention control and working memory, in creative thought helps individuals sustain attention on a problem, shift between closely related and distantly related ideas, and suppress less original and irrelevant thoughts. Thus, it is reasonable that executive thinking is related to decreased default network activity and activated prefrontal areas, such as the left inferior frontal gyrus and dorsal lateral prefrontal cortes (Marron et al., 2018).

These two paths each have their own set of advantages and disadvantages, demonstrating that creativity is a multifaceted process. It is, thus, logical to predict that mind wandering might have a dual impact on the incubation effect of various creative tasks (Yang & Wu, 2022). On the one hand, when thought wandering occurs, it can have a negative impact on creative thinking when it disrupts the controlled aspect of the process. It may undermine the controllability of creative thinking, as executive function might temporarily weaken. This may prevent conscious retrieval and evaluation of potential solutions when completing creative tasks. In this scenario, mind wandering is seen as detrimental to creativity because it hinders the individual's ability to focus on the task at hand and make conscious decisions. On the other hand, mind-wandering can have a positive impact on creativity when it promotes unconscious creative processes. Creative thinking is multifaceted rather than a purely conscious or unconscious activity. It may emerge when individuals allow their thoughts to wander; thus, mind-wandering may facilitate the unconscious creative process by encouraging spontaneous connections between ideas. Basically, the propensity for mind wandering to both hinder controlled, conscious thought and foster spontaneous, unconscious thought is the root of its dual impact on creativity. The effect of mind wandering on creativity is determined by the particular creativity task as well as the balance of these two forms of thought. The research in this thesis investigated these dual impacts by examining how mind wandering might influence creativity across different types of tasks. Specifically, it predicted that in a task that needs focused, controlled thinking (in this case, convergent thinking), increased mind wandering disrupts cognitive processing. Conversely, in a task requiring less-structured thinking (in this case, divergent thinking), increased mind wandering enhances outputs by facilitating spontaneous idea generation.

1.9 The impact of mind wandering in education settings

Mind wandering is common in classrooms. Studies show that students often experience lapses of attention, which tends to decline after 10-18 minutes into a lecture (Johnstone & Percival, 1976). Mind wandering increases over time during a lecture and has been associated poor memory performance. Risko et al. (2012) investigated mind wandering and memory retention during a lecture in a natural classroom setting. In this study, participants watched 60-miutes video-recorded lecture. Mind wandering probes were presented at 2, 20, 35, and 50 minutes into the lecture. After the lecture, participants took memory test corresponding to the material presented just before the probes. Participants reported more mind wandering in the second half of the lecture (49%) compared to the first half (30%), and those who reported more mind wandering performed worse on memory test. The low mind wandering groups (68% correct) outperformance the high mind wandering group (51% correct).

While mind wandering is prevalent in traditional classrooms, it is also a significant issue in online learning environment. Szpunar et al. (2013) showed participants a 21-minute online statistic lecture divided into four segments. After each segment, participants took part in one of three conditions that they were told about in advance: a tested condition (i.e., received a 2-minute memory test on lecture content), a restudy condition (i.e., received a 2-minute restudy phase where they were shown questions and answers related to the lecture content), and a non-tested condition (i.e., completed a 2-minute task unrelated to lecture). The non-test group reported higher rates of mind wandering (41% of the thought probes) during the lecture compared to both the tested group and the restudy group. Mind wandering occurred during 19% of the thought probes in the tested condition, and 39% of the thought probes in the restudy condition. The tested group performed better on questions related to lecture content compared to the other groups. The tested group showed a reduced frequency of mind wandering compared to the other two groups, indicating that interpolated testing helped sustain attention to lecture content and contributed to learning outcomes. This suggests that actively engaging students like with simple tests can help refocus their attention and improve learning.

Unlike the previous studies, which were conducted in a controlled laboratory setting where participants watched video lectures, Wammes et al. (2016) tested the relationship between mind wandering and academic performance in a real-world university lecture setting over a 12-week semester. Mind wandering probes were randomly inserted during lectures. Performance was measured through in-class quizzes which happened at the end of each lecture, midterm, and final term exams. In terms of quiz performance, students who reported intentional mind wandering performed worse on quiz questions, while students who reported unintentional mind wandering also showed a decrease in performance and the difference between the two groups was not statistically significant. For the exam performance, student who reported higher rates of unintentional mind wandering performed worse on exams, while intentional mind wandering did not predict exam performance. Intentional mind wandering potentially was driven by motivation, which primarily affects immediate engagement and short-term learning. Students can compensate for missed content through outside study, reducing its impact on long-term retention. Unintentional mind wandering is spontaneous, which might reflect cognitive limitation (e.g., attention control, work memory), and means it is harder to detect and compensate for missed content, leading to broader performance deficits over time.

Contrary to the work on creativity, all studies show that mind wandering during lectures negatively influences learning outcomes, whether in online or live settings, highlighting the importance of mind wandering in educational contexts, and apparently denying any potential for a positive role. The findings suggest that interpolated test and strategies to increase engagement and motivation may be effective in reducing mind wandering and improving academic performance. Different types of mind wandering have different effects, highlighting the importance of distinguishing between intentional and unintentional mind wandering. Interventions should target both types of mind wandering.

1.10 Summaries and research questions

This literature review revealed that mind wandering is a ubiquitous phenomenon, with a study suggesting that our minds are disengaged from ongoing activities between 25% and 50% of our waking hours (Killingsworth & Gilbert, 2010; Sei et al., 2018). The field of mind wandering is characterised by mixed terminology. This indicates that an updated definition of mind wandering would be beneficial. Measurement of mind wandering has been discussed in section 1.3, along with studies that have examined different hypotheses within the occurrence of mind wandering (i.e., the current concerns, executive failure, decoupling, and meta-awareness hypothesis) and their relationship with WMC, with findings suggesting that WMC may affect mind wandering. Finally, section 1.7 provided a review of research investigating the relationships between mind wandering and creative problem solving, showing that there might be differences in how performance of divergent thinking tasks and convergent thinking tasks are affected by mind wandering. To investigate these effects, two widely used tests were employed: The Unusual Uses Test (i.e., a divergent thinking task requiring participants to generate novel responses to a given item), and the Compound Remote Associate Task (i.e., a convergent thinking task that requires participants to find a single response that forms a compound word or phrase with previously given words).

The overall aim of this research was to explore the relationships between mind wandering, WMC and creative problem solving. Three research questions that were chosen are now explained in detail.

Research question one: Can the concept of mind wandering be consistently defined when considering both internal (e.g., self-awareness) and external (e.g., cultural context) influences?

Research into mind wandering has grown considerably, however, the term 'mind wandering' used as a construct in psychology is relatively new. Various terminologies are used in the field of mind wandering, including the previously discussed TUT, SIT, and spontaneous thought. However, they are by no means the same in terms of concept and activated brain regions as discussed in section 1.1. This suggests that an updated definition of mind wandering is needed to facilitate further research. A key aspect of this definitional clarity involves understanding how external factors, such as culture, might shape mind wandering experiences. For example, cultural differences in individualism versus collectivism might affect how frequently individuals engage in mind wandering or how they perceive its content. To test this, the study employed British and Chinese samples to conduct cultural analysis to explore whether there are cultural differences in mind wandering experiences. It was predicted that if mind wandering is a stable trait, it would be reported with comparable frequencies between

British and Chinese groups. Further detail of a taxonomy study designed to address this is provided in Chapter 2.

Research question two: What is the association between mind wandering and WMC? Previous work has found a role for WMC in mind wandering, but the literature is mixed in terms of what that role is. Some argue that WMC is helpful for suppressing mind wandering (i.e., the executive failure hypothesis), while others maintain that a lack of WMC is beneficial (i.e., the decoupling hypothesis). These apparently contradictory findings have led to suggestions that task demand might moderate the role of WMC. In this study, it was predicted that, in a low-demanding task, individuals with high WMC are prone to mind wandering; but in a high-demanding task, individuals with high WMC are less prone to experience it. To test the assumption, this PhD project employed different demand tasks to test this hypothesis. In addition, examination of the association between mind wandering and WMC provided potential insights into the mechanism underlying the occurrence of mind wandering.

Research question three: Does mind wandering assist problem solving in both divergent thinking and convergent thinking tasks?

Based on findings from recent research, there is speculation about the role of mind wandering in creative problem solving. However, to date, little empirical research that investigates this potentially positive element of mind wandering has been conducted. Research investigating the role of mind wandering in creative problem solving often utilises either tasks of divergent thinking or convergent thinking; here, a more holistic perspective of creativity integrated both types of creative tasks, looking at the effects of mind wandering on these, following a period of incubation. It was predicted that mind wandering during incubation would enhance performance on both divergent thinking tasks and convergent thinking tasks. To test this, an incubation paradigm was employed, providing both repeated and novel problems to separate the general effect resulting from practice and those induced by mind wandering in incubation periods.

2. Chapter two: Defining core characteristics of mind wandering, and cultural variations in these

The literature review chapter has demonstrated the limitations in the existing definitions of mind wandering and potential cultural factors affecting this phenomenon. This chapter reports a study that built on past findings by comparing experiences in two distinct cultures to develop a clearer and more comprehensive taxonomy of mind wandering experiences and explore potential cultural variations in thesis.

2.1 Introduction

The existing definitions of mind wandering, such as task-unrelated thought (TUT), stimulus independent thought (SIT), and spontaneous thought, have been argued to be insufficient in capturing the main characteristics of this phenomenon. While each of these terms captures certain features of mind wandering episodes, they fail to provide an exclusive and comprehensive definition. For example, defining mind wandering solely as TUT or SIT neglects significant aspects such as mind wandering in the absence of a task or the presence of task-related thought.

Consider a scenario where you are sitting quietly, not engaged in any particular task, and your thoughts start to wander. This form of mind wandering cannot fit neatly into the TUT framework, as there is no specific task from which thoughts are deviating. Imagine you are performing a task and your thoughts drift to guessing the purpose of this task. This experience should be considered mind wandering; however, TUT discounts it as mind wandering because it is related to the task, as well as SIT, since these thoughts are directly triggered by the external environment. Despite the connection to the task, it is still a type of mind wandering, as thoughts have deviated from the immediate task to engage in internal, task-related reflection. Although spontaneous thought contains TUT and SIT, it also takes creative thinking into account, which conflicts with the general understanding of mind wandering (Christoff et al., 2016). Moreover, the existing definitions are inadequate for the current thesis since they fail to provide any data on the relative prevalence and perceived significance of mind wandering experiences, limiting the understanding of its overall impact.

Despite the ongoing debate regarding how to define mind wandering, empirical evidence consistently attests to its status as a universal phenomenon that crosses cultural boundaries. Nevertheless, culture is recognized to exert an influence on individuals' cognitive orientation (Nisbett et al., 2001), which might affect more specific characteristics of mind wandering experiences, such as their frequency and content. Collectivism, dominant in Eastern cultures, such as China, emphasises group harmony and relationships, fostering a holistic style that prioritises context. This broader attention focus may lead to fewer instances of mind wandering, as individuals value group performance. On other hand, individualism, dominant in Western cultures, such as the United Kingdom, emphasises personal goals and autonomy, but also the adoption of an analytic cognitive style focused on specific details and objects that may discourage mind wandering for a different reason. These differences are reflected in both behavioural and neural measures, providing insight into various ways in which culture may shape mind wandering.

For example, Chua et al. (2005) used a head-mounted eye-movement tracker to directly record the eye-movement of two groups, European American students (i.e., participants in the United States who have European ancestry) and Chinese students when they participated in an experiment viewing photographs with a focal object on a complex background. Chinese participants spent longer before making their first fixation on the target items when each scene was first presented than did American participants, and focused more on the background. Chinese participants also remained fixed on the focal items for a shorter period than did Americans. A recent study by Cenek et al. (2020) showed that this pattern was also observed in Czech and Taiwanese groups. Two cognitive tasks, a compound figures test and a free-viewing scene perception task were used with both groups, and it was found that participants from Taiwan spent more time on the background than the Czechs did, who tended to focus relatively more on the central objects.

Similarly, there has been some evidence for related effects of culture in other cognition networks. For example, Goh et al. (2013) conducted an fMRI study to test the difference between East Asians and Westerners in cognition in a visuospatial judgment task. The results showed that Westerners had more activation in brain regions associated with visual processing (e.g., frontal, parietal, and occipital areas) and greater suppression in medial frontal, medial temporal, and right middle temporal regions, which are known as the default network. This network is active when an individual is not focused on the outside world and is instead engaged in internal mental processes. These findings align with the idea that Westerners may experience less mind wandering than East Asians when processing visual stimuli due to their narrow focus of attention, while Asians with their broader attentional scope, may be more prone to mind wandering.

However, the content of mind wandering appears to be more consistent across cultures. For instance, Sude (2015) found that while European-heritage participants reported more frequent mind wandering than Asian-heritage participants, the types of thoughts experienced were similar. Both groups reported thoughts about the task, their surroundings, and personal concerns, suggesting that the content of mind wandering may be more universal. This aligns with the findings of Goncalves et al. (2017), who found no significant differences in the content of mind wandering between Portuguese and Brazilian participants. These results indicate that while cultural factors may influence how often individuals mind wander, they may have less impact on the nature of the thoughts themselves.

Despite these insights, the relationship between culture and mind wandering is not always straightforward. Goncalves et al. (2017) failed to find such a relationship between Portuguese and Brazilian participants. The unclear state of the literature may be due to methodological limitations of previous studies. Sude (2015) discussed the relationship between European heritage and Asian heritage samples, which are usually used by most research to examine the impact of cultural variations on psychological phenomena. Comparisons between European and American nations are relatively uncommon, given their close connection and similar cultural values, and it is likely that their cultures are comparable. In line with this, a study conducted by Goncalves et al. (2017) used the Attention Network task and the Resting State questionnaire, which may not capture the same aspects of mind wandering as the task used in others studies.

The present study intentionally selected samples from both Eastern and Western cultures, specifically British and Chinese samples. The primary rationale behind this selection is the geographical distance between the two nations. China, located in East Asia, and the United Kingdom, in Western Europe, are geographically distant from each other. This geographical separation often implies diverse environmental, historical and, sociocultural influences, which can contribute to variations in cognition and behaviour. In addition to the geographically distant culture, China and the United Kingdom are typical examples of relational or collectivist and analytical or individualist cultures respectively, so this study is better placed to uncover the potential influences of cultural factors on the phenomenon under investigation.

This study was designed to achieve two main goals. First, by thoroughly investigating the characteristics of mind wandering experiences, the study aimed to offer a more precise and thorough description of mind wandering. In order to provide sufficient data for a compressive analysis, participants were encouraged to report more mind wandering experiences. To achieve it, an unappealing and easy task was employed, since lowering the task difficulty or decreasing individuals' motivation may result in an increase in the rate of mind wandering (Seli et al., 2016; Unsworth & McMillan, 2013).

Following that, interviews were used in the study to address the triggers and content characteristics of mind wandering. The textual data from transcripts of these interviews were coded at three levels using grounded theory to develop the intended richer taxonomy. Grounded theory is a qualitative research methodology developed by Glaser and Strauss (1967). The original version of grounded theory involved a systematic and iterative process of data collection, coding, and theory development. Over time, different versions and variations of grounded theory have emerged to suit various research contexts and preferences. Unlike classical grounded theory, Strauss and Corbin's version of grounded theory allowed a more flexible approach to data collection and analysis, as it developed theories based on participants' own perspectives and interpretations.

Second, the study sought to investigate and contrast participants' experiences with mind wandering across the UK and China, with an emphasis on figuring out how cultural influences affected mind wandering. It was hoped these twin goals would contribute to a more accurate knowledge of the phenomena itself while shedding insight on individual and cultural variables driving mind wandering.

2.2 Method

2.2.1 Participants

The sample consisted of 49 participants, with an average age of 29.41 (SD=1.53). There were 17 participants from Britain and 32 participants from China. The demographic characteristics of the British and Chinese samples are presented in Table 2.1. To ensure a balanced comparison between the two cultural groups, efforts were made to match the participants as closely as possible in terms of basic demographic characteristics. There were no significant differences found between the two samples in terms of age, t (47) = 1.50, $p>0.05$, and gender, $\chi2(1) = 1.87$, $p>0.05$, indicating sufficient match to allow effective isolation and exploration of cultural differences. Participants received a consent letter and information sheet via electronic contact, primarily via email, in accordance with ethical procedures. These materials clearly stated the study's goals and guaranteed participants' unrestricted right to stop participation at any time if they felt uncomfortable or so desired. Candidates who were interested in the experiment and wanted to learn more about it received these materials. The number of positive responses received to these invitations showed participants' interest in participating in the study. A total of 86 emails were sent, and in the end, 49 individuals who were keen to join the study and met the requirements (i.e., born and brought up in the China or UK and are native Chinese or English speakers respectively) were selected. Due to the coronavirus pandemic, this study was conducted online via WeChat and Zoom.

The sample size for the British group was lower than the Chinese group due to the challenges associated with recruiting participants, especially British individuals. Factors such as time constraints and coronavirus, limited access to potential participants, and perhaps a lower response rate from the British population resulted in the discrepancy in numbers. Despite these challenges, the study was able to achieve a sufficient number of participants for meaningful analysis. The UCL Institute of Education Research Ethics Committee approved the project after carefully reviewing its participant protection guidelines, adherence to ethical standards, and ethical considerations. With the support of this formal approval, the study was carried out with the utmost integrity, protecting the rights of participants and according to ethical standards.

Table 2.1 Gender and Age Mean of the British and Chinese groups

Nationality and gender	N	Mean age (SD)		
British				29.41 (1.53)
Female	15	33.93(12.13)	32.53 (2.93)	
Male	2	22.00(4.24)		
Chinese				
Female	20	27.6(9.07)	27.75(9.77)	
Male	12	28.00(11.32)		

2.2.2 Materials and Procedure

This study was conducted online and employed a straightforward task to investigate participants' mental activities. In this task, participants were instructed to write the numbers from 1 to 400. Due to its simplicity, it was assumed that any errors that appeared in the process of writing were the result of a lapse in concentration, making it an ideal context to explore mind wandering phenomena. Since the mental activity at this moment was the main interest of the study, participants were required to mark the location on the paper where they realized they went wrong. In order to better discuss these mental activities, participants could also choose to jot down their thoughts on a mistake log for later reference during the interview phase. To further probe their thought processes, participants were randomly interrupted by the researcher to answer the question, 'what were you just thinking about?' Each participant was interrupted at least twice to investigate their thoughts. The number of times participants were interrupted varied according to their performance. Participants who had a higher number of errors, for instance, more than 4 errors, or for whom it could be seen on camera that the writing process was not going well with significant pauses or hesitations, were interrupted more often, as it indicated that they were likely to have experienced a higher number of wandering experiences, and so were able to provide richer data for this study. The online nature of the study required careful monitoring and recording of participants' behaviour and responses. During the writing task, participants were asked to position their cameras to focus on their answer sheets. This allowed the researcher to observe their progress in real time, including long pauses, hesitations, and errors, which informed the timing of interruptions.

Immediately after completing the writing task, participants were asked to participate in a semi-structured interview to prevent them from forgetting what they had experienced in terms of mental activities in the writing task. During the interview phase, the camera was repositioned to focus on the participants themselves. This allowed the research to observe their facial expression and body language, providing additional context for their responses. The interview consisted of two parts. First, participants were required to describe in detail what they were thinking when they made a mistake, either by referring to the ideas recorded on the mistake log or the marks they made during the writing process. After that, participants were presented with a series of open-ended questions based on similar experiences in their daily lives: (1) In what circumstances do you tend to experience such mental activity? (2) In what situations do you easily experience such mental activity? (3) How do you think this mental activity will affect the task you are currently doing? (4) Did you know that you were experiencing this mental activity? and if so, did you let this mental activity continue deliberately? In order to reduce bias, the term mind wandering was not used in the questions or instructions. For example, some participants might intentionally be motivated to report more errors and mind wandering experiences to please researchers and suit the purpose of the study. Without guiding participants in any specific direction, the goal of our study was to thoroughly examine the experience of having wandering thoughts. The in-depth interview lasted approximately 30 minutes. Thirty-three participants agreed to video recording and eight participants agreed to the use of a voice recorder for the interviews. For participants who did not agree to electronic records being kept, key points in the interviews were recorded by pencil and paper.

2.2.3 Data analysis

The process of analysing and coding the data obtained from interview responses (i.e., detailed mental activities probed in the task and responses for the four questions based on participants' daily life experience) was based on the grounded theory employed in Strauss and Corbin's research (1990). Given the purpose of the study, grounded theory was an appropriate method as it is widely used to collect data and then systematically create a theory or perception obtained directly from the data rather than developing a theory or perception and then systematically seeking data to validate it. This is in line with the purpose of the study to reflect people's actual experiences (Kaiser & Presmeg, 2019). Grounded theory provides a clear guide to coding data collected by interview. It begins by breaking down the data into small segments and grouping them based on similarities to begin the development of categories. This initial coding process aims for comprehensiveness and authenticity, adhering to an objective and emotion-neutral stance. The primary objective at this stage is to identify and name conceptual categories within the original data. The subsequent phase involves axial coding. Following the principles outlined by Strauss and Corbin (1990), axial coding seeks to establish connections between various conceptual categories. For example, this step may involve determining which categories are primary to the study's focus and which ones are related but not as central. Lastly, selective coding is the stage which focuses on developing a central, core category. This core category serves to integrate and make sense of all the data and categories that have emerged. Based on the general principles of grounded theory, components of the two cultural groups' mind wandering experiences were investigated (see the coding process for the reasons for mind wandering presented in Table 2.2). T-test and correlation analysis were used to examine quantitative differences between groups and relationships between observed variations.

Table 2.2 Coding process for reasons of mind wandering (partial)

Data	Open coding	Axial coding
'I feel so tired, I really do not want to write! When will it end?'	Tired	Physical feelings
'My thighs are so itchy. I want to scratch them so badly.'	Itchy	

2.3 Results

By following the above procedure of grounded theory, four main categories were generated from the interview content, as shown in Table 2.3. The core categories covered four dimensions regarding the structure of mind wandering experiences: reasons, content, meta-awareness, and effect. The reasons of mind wandering included four reported factors, external sound, attitude to task, physical feelings, and emotional states. The content of mind wandering was broken down into two categories based on how it related to the ongoing task: thoughts related to the task and unrelated to the task. For meta-awareness, mind wandering was divided into two categories: mind wandering with and without awareness. Participants' opinions about task performance revealed neutral, positive, and negative mind wandering.

Table 2.3 The coding results of mind wandering (the number in parentheses indicates the number of times the code occurred)

Core categories	Axial coding	Open coding
Reason	External sounds (44)	Noise from streets, conversations in another room, hums of machinery,
	Attitude to task (48)	unappealing task (boring, difficulty, easy, too long, repetitive)
	Physical feelings (21)	Itchy (5), tired (16)
	Emotion state (39)	Nervous (9), careful (14), uncomfortable (2), stressful (11), Worried (2), Perfect (1)
Content	Unrelated to task (141)	Leisure activity (43), work or study (38), personal relationship (31), self issue (5), others (24)
	Related to task (128)	Performance (28), process (36), subsequent task (13), previous task (16), others (35)
Meta-awareness	With awareness (150)	With awareness and let continue (87), with awareness and stop (63)
	Without awareness (48)	Not actively notice this mental shift as it happens
Effect	Negative effect (28)	Impair performance (3), reduce efficiency (18), unconcentrated (3), delay learning (6)
	Positive effect (8)	Refresh mind (4), feel relieved (4)
	Neutral (13)	Neither embrace nor reject mind wandering experiences

The data was examined further to answer the following questions: When and why do people’s minds wander? What happens to their minds during mind wandering? Were they aware of their states of mind wandering? and What do people know about mind wandering?

2.3.1. When and why do people’s minds wander?

The frequency of the participants' mistakes in the task was variable, but the results indicated that the majority of them made mistakes relatively frequently, with an average of 3.94 errors per person (see the distribution of participants who made mistakes in Figure 2.1). Participants were asked about their reasons for mind wandering and particular contexts associated with mind wandering. In terms of why people’s minds wander during a task, reasons reported by the participants included a physical feeling (e.g., tired, itchy), the boredom of the task, external distractions (e.g., the noise of a motorcycle) and personal issues (i.e., emotional state). Among the responses regarding the trigger for mind wandering, a large proportion was induced by internal thoughts (71.05%), which covered three sub-categories (i.e., attitudes to task, physical feelings, and emotional state), while only a small proportion was induced by external factors. Regarding the attitudes of participants, they claimed that when they were engaged in a task that was boring or unappealing, they experienced more mind wandering (31.58%). Participants' minds also wandered more when they felt a negative emotion, such as feeling nervous or stressed (25.66%), and when they felt physically tired or stressed (13.82%; see Figure 2.2 for details).

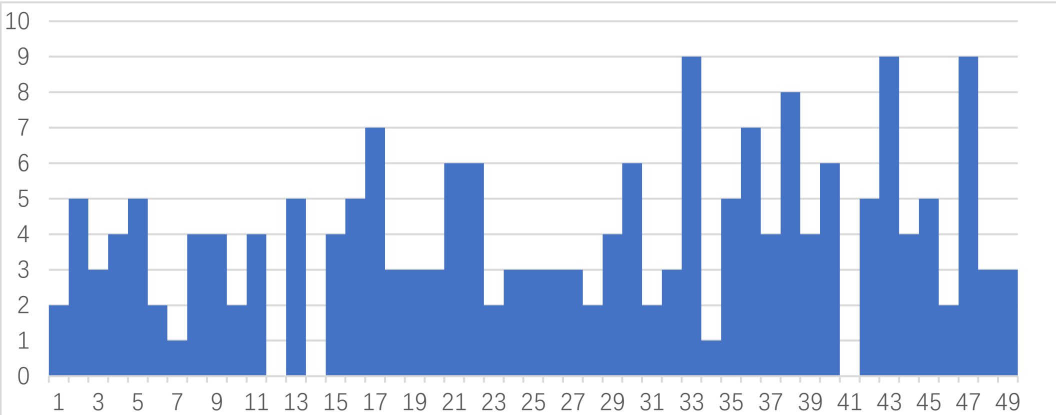

Figure 2.1 Number of times participants made mistakes in the task (The x-axis represents participants, and the y-axis represents the number of errors.)

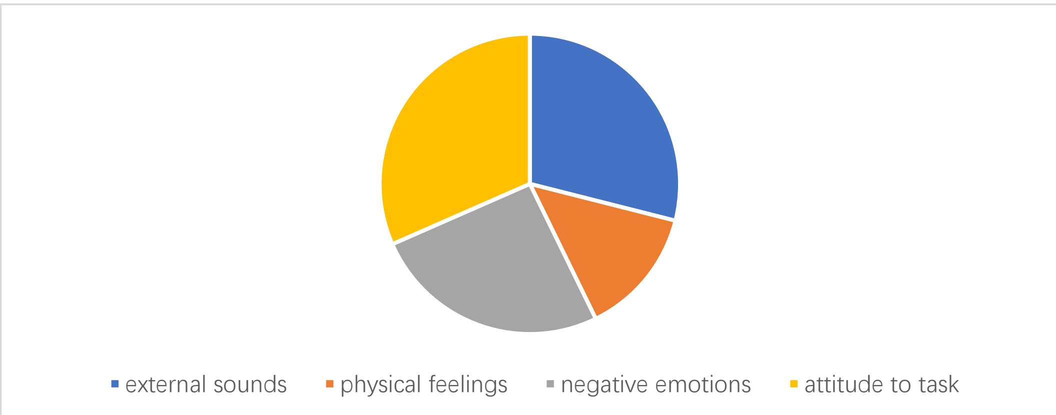

Figure 2.2 Factors related to the occurrence of mind wandering

2.3.2. What happens to their minds during mind wandering?

With regard to the content of mind wandering during a task, the results showed that the content of mind wandering was slightly more often unrelated to the task, and oriented towards the future (i.e., I need to find a new job or wondering what to have for dinner; 63.33%) more frequently than other thoughts (e.g., past oriented). The proportion of thoughts related to the current task (47.58%), including aspects like the previous task, the subsequent task, performance, process, and other task-related issues was reasonably similar to the task-unrelated thoughts. Individuals tended to think about either leisure activities (30.5% of codes) or their work or study (26.95%) when their minds wandered beyond the task itself (see Figure 2.3 for details).

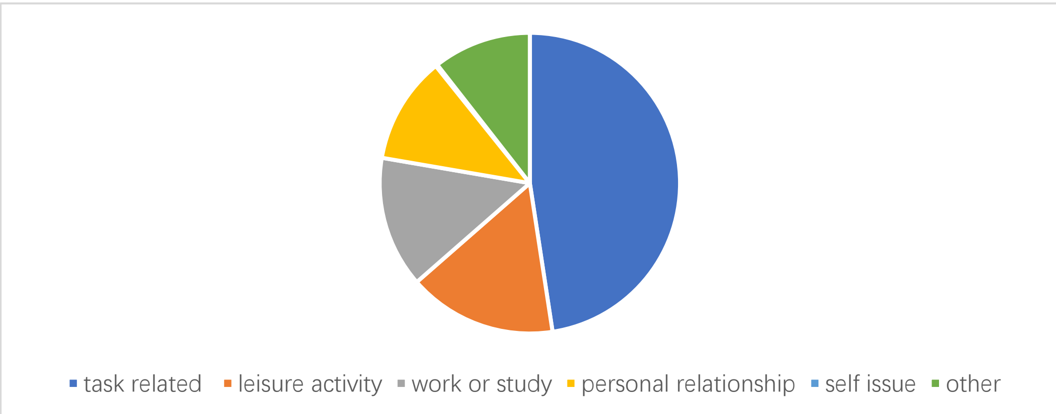

Figure 2.3 The content of mind-wandering experiences

2.3.3. Are participants aware of their states of mind wandering?

With regard to meta-awareness, most of the participants (75.76%) reported that they were aware of their mind wandering during a task, and the vast majority of them (58%) said they would like to let their minds continue to wander. For example, 'When I am attending a lecture and the topic is difficult and boring, I would like to think of something to pass the time.' 'I deliberately recall the game that I played particularly well.' Although they deliberately allowed themselves to wander, most would regret the act, believing it to be a bad influence on the ongoing activity, which is consistent with their perceptions of these experiences.

2.3.4. What do people know about mind wandering?

As for people's understanding of this experience, the majority of responses (51.02%) were focused on the negative effects generated by mind wandering, such as a reduction in efficiency, interference with progress, and hindrance to the learning process. There was also a part of the sample that was unsure of the impact of mind wandering, placing a neutral attitude to this phenomenon. Only a small number mentioned the positive effects, such as a means of mental relaxation, and facilitating enhanced concentration on subsequent tasks.

2.3.5 Cultural differences in mind wandering

The number of errors committed by participants varied, with British participants demonstrating a slightly higher mean error count (M=4.94, SD=2.77) in comparison to Chinese participants (M=3.91 SD=1.51). Exploratory analysis of error rates indicated a large deviation from the assumption of normality, necessitating the use of a nonparametric analysis method. Consequently, A Mann-Whitney was carried out, and no statistically significant difference in error rates between the two national groups was found, $Z= -1.39$, $N_C=32$, $N_B=17$, $p>0.05$. A t-test was then employed to examine whether the frequency of mind wandering was affected by participants' nationality. The means of the frequency of mind wandering show that the Chinese group (M=1.75) reported mind wandering more often than the British group (M = 1.65). However, analysis showed no difference in the frequency of mind wandering between the two groups, $t(48) = -0.25$, $p>0.05$. Correlation between error rate and frequency of mind wandering were not examined, since the former only provided a partial basis for reporting of the latter. In other words, the error rate was an incomplete factor in fully explaining the occurrences of mind wandering. A more comprehensive assessment of mind wandering was employed in the subsequent studies to provide an understanding of its frequency and impact.

Regarding the reasons behind individuals' episodes of mind wandering, external noises, such as motorcycles or footsteps, were the most common causes of errors in both groups, the British (31.82%) and the Chinese (40.58%). A significant number of errors in the British participant group were attributable to their attitude towards the task (i.e., individuals who believed that the task was too boring or easy) and physical feelings (e.g., tiredness), constituting 28.79% and 22.73%, respectively. The emotional state of the participants, which included feelings like nervousness or stress, was responsible for 16.67% of errors. For the Chinese group, attitude towards the task accounted for 28.89% of error causation, whereas physical feelings accounted for 15.94%. Emotional states played only a relatively low impact in error causation among the Chinese group, accounting for 14.49% of the total (see Table 2.4 for further details). To test whether nationality had an impact on the causes of mind wandering, a Mann-Whitney test was employed. The results showed there were no significant differences between the Brtish and Chinese groups in terms of the external noises ($Z= -0.94$, $N_C=32$, $N_B=17$, $p>0.05$), attitude to task ($Z= -1.50$, $N_C=32$, $N_B=17$, $p>0.05$), physical feelings ($Z= -1.89$, $N_C=32$, $N_B=17$, $p>0.05$), and emotional state ($Z= -1.63$, $N_C=32$, $N_B=17$, $p>0.05$).

Table 2.4 Causes of Mind Wandering in British and Chinese Participants

Categories of mid wandering causes	External noises	Attitude to tasks	Physical feelings	Emotional state
British	31.82%	28.79%	22.73%	16.67%
Chinese	40.58%	28.99%	15.94%	14.49%

In terms of the content of task-unrelated thoughts, a considerable portion of the Chinese participants, roughly 20.37%, were engaged with thoughts centred around leisure activities. This was followed by thoughts on work or study, which accounted for 8.64%, and thoughts about family or friends, which accounted for 12.35% of their thoughts content. Conversely, the British participants' thoughts were predominantly focused on work or study, accounting for 20.83% of their mental activity. As a result, thoughts about family or friends accounted for 13.54%, while thoughts about leisure activities accounted for 6.52%. To further test whether nationality affected the contents of mind wandering, a Mann-Whitney test was employed. The results showed there were no significant differences between British and Chinese groups in terms of work or study ($Z= -1.48$, $N_C=32$, $N_B=17$, $p>0.05$), family or friends ($Z= -0.72$, $N_C=32$, $N_B=17$, $p>0.05$), or others categories ($Z= -0.15$, $N_C=32$, $N_B=17$, $p>0.05$). However, there was a significant difference related to leisure activity between two cultural groups, Z=

2.58, N_C=32, N_B=17, p=0.01. In terms of contents of task related thoughts, the Chinese and British groups had the same proportion of task-related information (see Table 2.5 for details) and were found to have no significant difference in task-related mind wandering by t-test, t (48) =-0.11, p>0.05.

Table 2.5 Types of Thought Content in British and Chinese Participants during Mind Wandering

Types of Thought Content	Task related Information	Task unrelated Information			
		Leisure Activity	Work or Study	Family or Friends	Others (e.g., self, daily issues etc.)
British	51.04%	6.52%	20.83%	13.54%	8.33%
Chinese	51.23%	20.37%,	8.64%	12.35%	7.41%

Concerning individuals' perception of mind wandering experiences, it is worth noting that the majority of Chinese groups expressed a belief in the adverse consequences associated with such experiences. Specifically, a sizable 75% of Chinese participants held the view that mind wandering yielded negative effects. Within the Chinese group, a small portion of participants, namely 6.25%, acknowledged experiencing positive effects from mind wandering, while 18.75% expressed a neutral attitude about the effects. In contrast, British participants indicated a more diverse range of opinions about the consequences of mind wandering. Approximately 23.53% recognised positive effects stemming from these experiences, and 17.65% mentioned the concept of negative effects. A big portion, 58.82%, mentioned the concept of neural effects (see Table 2.6 for details). A chi-squared test was used to further examine if there was an association between nationality and participants' beliefs about the effects of mind wandering, revealing a significant association, $\chi 2$ (2) = 15.53, $p < 0.01$.

Table 2.6 Participants' Perceptions of Mind Wandering Effects in British and Chinese Participants

participants' Perceptions	Negative Effects	Positive Effects	Neural Effects
British	17.65%	23.53%	58.82%
Chinese	75%	3.13%	21.87%

Several similarities and differences emerged from these analyses, therefore. A key similarity was the recognition of external stimuli, such as environment sounds, as a significant trigger for mind wandering in both groups. In terms of causes of mind wandering, nationality did not seem to have a significant influence, as there were no significant differences between the British and Chinese groups. However, there were notable differences in the specific content of mind wandering and the participants' perceived effects. British participants were more likely to think about work or study, whereas Chinese participants tended to think about leisure activities during mind wandering, though only the latter difference was significant. In terms of perceived effects, both groups recognised the negative consequences of mind wandering, but British participants also noticed positive and neutral outcomes, while Chinese participants mainly emphasised the negative impact of mind wandering.

2.4 Discussion

In the current study, an in-depth interview following a task designed to stimulate mind wandering was conducted to collect information regarding the content, reasons, meta-awareness of, and impact of mind wandering. It was envisaged that this would provide immediate material for reflection and that the results would be consistent with participants' similar experiences in daily life.

2.4.1 Content of mind-wandering experiences

The results revealed several specific features of mind wandering. Consistent with the findings of Baird et al. (2011), the content of mind wandering had a prospective bias; in other words, there was a tendency for the mind to think about the future (Song & Wang, 2012). Furthermore, the content of mind wandering was closely related to participants’ concerns. The majority of thoughts generated in the task focused on the performance, process, and purpose of the ongoing task since the participants’ main goal was to complete the current task. However, it was also not surprising that one participant was ‘thinking about his girlfriend’s birthday gift and ways to bring them closer’ during the task after ‘having an argument with his girlfriend a couple of days ago’. In daily life, the content of mind wandering was career plans and pensions when a participant was considering changing their job. These findings are consistent with the current concerns hypothesis, which states that mind wandering occurs more frequently when a thought has a “higher incentive value than incoming perceptual information” (Smallwood, 2013, p. 523). When the external stimuli become weaker, the mind tends to focus on the thoughts that are related to individuals’ personal goals and interests.

2.4.2 Reasons for mind-wandering experiences

In terms of the reasons for mind wandering, internal cues played an important role in inducing it. Several participants reported that when they wrote a number that was meaningful to them, they were thinking about their bank number, a clothing band or, their anniversary. Thus, it raises the issue of the fact that research into mind wandering has paid relatively little attention to the kind of mind wandering that is triggered by a task stimulus. In the literature, mind wandering is primarily thought of as reflecting TUT or SIT, both of which are defined according to their lack of relationship to the ongoing task or current perceptual information. Moreover, the SART – which is commonly used in laboratory settings to investigate mind wandering – uses digits that are boring and meaningless as stimuli, which is unlikely to induce thoughts. Therefore, it is reasonable to assume that the mind wandering episodes examined thus far in the research might not have been triggered by task stimuli, and are therefore not representative of wider experiences of mind wandering.

There are points of consistency with past research, however, since the results found that negative emotions were related to the focus of wandering. The participants reported that when they were nervous, they experienced more frequent mind wandering episodes. Additionally, they said that their minds liked to wander when they were in a bad mood in daily life and their thoughts in these mind wandering episodes were past oriented. Consistent with this, empirical evidence has suggested that being in an unhappy mood leads to a retrospective bias in mind wandering in daily life, which easily generates past-oriented thoughts (Killingsworth & Gilbert, 2010;

Smallwood & O'Connor, 2011). In addition to this, when a task was boring or unappealing, the participants were likely to report more mind wandering experiences. It is consistent with the research of mind wandering on motivation that when participants have little motivation to carry out a task, their thoughts may be related to other intentions, which, in turn, could result in intentional engagement in off-task thoughts (Hancock, 2013).

2.4.3 Participants' awareness of their state of mind wandering

An interesting result is that the participants were typically aware of their mind wandering state and let it continue, which confounds the common conceptualisation of mind wandering as reflecting unintentional thoughts. Participants reported that their minds wandered more when they engaged in an unappealing task. As noted above, there is a possibility that participants might have intentionally engaged in mind wandering episodes when they had little motivation. This distinction appears to be important for understanding the subjective experience of mind wandering, as it suggests that not all mind wandering is the same. Mind wandering without awareness may reflect a deeper level of cognitive disengagement, while mind wandering with awareness may reflect goal-directed regulation. A recent study investigated the distinction between spontaneous mind wandering and deliberate mind wandering at a trait level (Seli et al., 2015). The results revealed that spontaneous and deliberate mind wandering were uniquely associated with certain factors of the five-facet mindfulness questionnaire. Spontaneous mind wandering had a negative relationship with the five-facet mindfulness questionnaire's 'Non-Reactivity to Inner Experience' item, whereas deliberate mind wandering seemed to have a positive association with this factor. This finding aligns with the current observations suggesting that different types of mind wandering may have different cognitive and behavioural consequences. Therefore, distinguishing the awareness of mind wandering might shed light on some uncertainties in this field of study.

2.4.4 The taxonomy of mind-wandering

Recognising the findings on mind-wandering experiences and the mixed terminology in the literature indicates that an updated definition of mind wandering is needed. When the mind wanders, attention drifts from the current train of thought to mental content generated by the individual. TUT focuses on the relationship to the current task, where mind wandering reflects a thought that is unrelated to the current task. However, this definition fails to capture thoughts during mind wandering episodes that are task related, for example, worrying about previous performance. Moreover, TUT is defined by a task, meaning that it is easy to neglect resting state mind wandering, a period in which there is no explicit task to complete (Mason et al., 2007). Vanhaudenhuyse et al. (2011) used functional neuroimaging to demonstrate that the occurrence of mind wandering in a resting state was accompanied by the activation of certain areas of the brain known as the default network. In the present study, the participants stated that their minds sometimes wandered in their free time at night.

In contrast, SIT focuses on the independence of the experience from perception, and mind wandering is seen as reflecting thoughts that are decoupled from current sensory information (i.e., they are internally triggered). As previously mentioned, however, the thought triggered by a task stimulus (e.g., the number ‘180’ triggering a thought about a triangle) is inconsistent with the classification of SIT. The definition of spontaneous thought is a broad one, including dreaming and creative thinking, which is beyond the scope of mind wandering (Christoff, 2012). Thus, it can reasonably be claimed that it is not an appropriate definition for mind wandering as such.

Although differences of opinion still exist, there appears to be some agreement that mind wandering refers to a shift in the contents of thoughts away from an ongoing task or events in the external environment to self-generated thoughts or feelings (Smallwood & Schooler, 2015). The self-generated aspect emphasises how a thought arises, which is similar to the key feature of spontaneous thought, rather than relying on a relatively narrow definition of the term task (Christoff et al., 2016). The definition considers the dynamics of thought, which reflects the key feature of mind wandering, that the mind is free to wander hither and thither. To say one's mental state is mind wandering does not necessarily mean that the mental state is task unrelated or stimulus independent, but that the process does arise and can change in focus.

It is easy to tell from the term 'self-generated' that self-generated thoughts emphasise intrinsic changes, just like SIT, though in contrast to SIT they may be cued by stimuli within the task itself. The contents of mind wandering experiences ought to arise from the intrinsic changes that occur within an individual, however, rather than extrinsic changes cued directly from perceptual events occurring in the external environment (Smallwood & Schooler, 2015). Under this definition, being distracted by outdoor noise is not – and should not be – considered as an example of mind wandering. In these circumstances, the mind shifts towards external distraction due to the nature of individuals' attention to novelty and changes in the acoustic environment (Escera et al., 2000); this is known as involuntary attention. However, this kind of attention without conscious control is an automatic response to certain sensory inputs (Angell, 1904). For example, if the door slams while someone is writing, they are seemingly obliged to hear the sound and think about what happened to the door; however, they might prefer not to do so. The commonality between mind wandering and external distraction is that an individual's attention shifts from the current task to processing the content beyond the current task. The difference between the two is that the attention of mind wandering shifts to internal processes, while the attention of distraction is transferred to the stimulus in external situations. In other words, a thought is considered as mind wandering only when external distractions lead to internal processes rather than the focus remaining solely on the external event itself.

Self-generated thought is independent of task relatedness: it can be task related and task unrelated. Tasks such as writing numbers – as the participants did in the experiment – can be performed accompanied by thoughts on the purpose of the research. This is an example of task-related self-generated thought. Self-generated thought can also be task unrelated when a participant has disengaged their attention from the writing task and begun to plan their weekend. There is an example of task-unrelated self-generated thought in Table 2.7.

Table 2.7 The classifications of mind wandering

	Related to task	Unrelated to task
Perceptually guided	Writing the numbers 4, 5, 6 (Task focus)	Noise of motorcycle (Distraction)
Self-generated	What is the point of this task? (Task related reasoning)	Where to go for brunch on the weekend? (Mind wandering)

Based on the thought experiences and these existing definitions, the present study, thus, has proposed a refined understanding of mind wandering, which refers to a shift in the contents of thought away from an ongoing task or events in the external environment to self-generated thoughts or feelings (Smallwood & Schooler, 2015). Unlike many studies investigating mind wandering using specific task paradigms, this study observed it in a more holistic way, capturing mind wandering as it naturally occurred. It provides fresh insights into awareness of mind wandering, challenging the traditional view that focuses on its unconscious aspect. Given the finding of the existence of regulated mind wandering, it is plainly important to distinguish between mind wandering with awareness and without awareness. The distinct forms of mind wandering will be adopted and examined further in the following studies to test its relationship with other cognitive characteristics.

2.4.5 Cultural differences in mind wandering

The research, which included participants from the United Kingdom and China, examined mind wandering experiences and unveiled several key findings.

While no statistically significant difference in the frequency of errors during writing task or occurrence of mind wandering were found between the British and Chinese groups, a careful inspection of the means for some aspects of mind wandering revealed differences. Specifically, British participants had a slightly higher incidence of errors and a lower frequency of mind wandering, and the content of their thoughts during these tasks indicated that approximately half of their thoughts were concerned with task-related interference information that hampered writing performance. This observation is consistent with the findings of a previous study conducted by Sude (2015), which found that people of European heritage reported being mostly involved in task-related interference thinking. Despite the similarities between the British and Chinese samples in the results, then, the proportion of contents of mind wandering differed to some extent for each group. In line with this, a recent study by Goncalves et al. (2017) researched the relationship between the types of thoughts (i.e., on task, task-related interference thoughts, eternal distractions, and stimulus independent and task unrelated thoughts) and the three components of the attention network system (i.e., alerting, orienting, executive) as assessed by a Thought Identification Task. The results demonstrated that during the task, individuals were mostly engaged in task-related interference thoughts and external distractions, which dramatically reduced their performance accuracy. Interestingly, the study findings deviated from the conventional notion that mind wandering, characterised by stimulus independent and task unrelated thoughts, significantly impaired task performance, such as reading comprehension (Unsworth & McMillan, 2013) and driving (Yanko & Spalek, 2014).

Surprisingly, while there were limited differences in the content of mind-wandering, there were variances in the perceived quality of mind wandering between cultures. Both groups acknowledged the negative effects of mind wandering, but the British participants also noted positive and uncertain effects, whereas the Chinese participants mostly emphasised the negative impact. It is difficult to explain this result, but it might be related to Chinese learning beliefs and styles. Confucian values are at the heart of Chinese education. According to Confucian tradition, individuals should take opportunities to cultivate effort, endurance, and focus (Tweed & Lehman, 2002). Learning is closely tied to hard work, and effort is much more valuable than ability. Effortful learning is fundamental to attaining success.

These Confucian values are also closely aligned with collectivist cultural orientations, which emphasize group harmony, social responsibility, and the importance of fulfilling one's role within the collective. In collectivist cultures, such as China, individuals are often motivated by a desire to meet societal and familial expectations, which can lead to a strong emphasis on self-discipline and attentiveness. Mistakes or lapses in attention, such as those caused by mind wandering, may be perceived not only as personal failures but also as failures to meet the expectations of the group or family. This could explain why the Chinese participants in the experiment viewed mind wandering primarily in a negative light, as it conflicts with their cultural values of effort and focus. It seems to be this dimension of cultural difference that matters most.

Indeed, Peter (2002) found that Asian heritage students (i.e., Hong Kong students) put great effort into academic pursuits and believed in the usefulness of effort. It is therefore understandable that the Chinese sample in the experiment made slightly fewer errors because they were willing to put in the effort for the experiment despite the fact that it was too boring to concentrate, and thus satisfied their own inner quest. If mistakes are made for their own reasons, such as a lack of attention, it will lead to self-blame because these errors are evidence of inattentiveness, which goes against their belief in effort. Thereby, the occurrence of mind wandering is associated with negative outcomes.

Another potential factor explaining cultural variation in the perception of mind wandering might be cultural values. Almost a third of the British respondents stated something along the lines that "the effect of mind wandering is uncertain because they could actively choose to experience mind wandering when performing a simple and unimportant task and give their full attention to the important task." An individualistic culture, like the United Kingdom, compared to those from a collectivist culture (e.g., China; Sun, Horn & Merritt, 2004) places a greater emphasis on personal autonomy and independence (Welzel & Inglehart, 2010). The British sample seems to have a greater sense of control over their own mental processes and may be more likely to prioritize their own goals or interests over social expectations, which reflects some aspects of individualistic culture. This is consistent with the meta-awareness account of mind wandering, which holds that self-monitoring allows for the adjustment of mind wandering events.

Furthermore, based on the results that British participants showed more frequent task related thought, it is suggested that individuals' perception of task performance may be influenced by their cultural tendencies towards individualism and collectivism. That is, if individuals have a more individualistic orientation, they may interpret their agreement to participate in the study as a personal choice, and they may prioritise the task because they consider it as a direct commitment they made, reflecting their decision-making. In this case, the emphasis is on their own responsibilities and personal choices, and they do not stray far from a task focus. If individuals have a more collectivist orientation, they might view their participation in the study as a commitment to a social contract. Their focus on task performance – but not task characteristics - may stem from their desire to fulfill their obligations to the group. Reichle, Reineberg, and Schooler (2010), researching eye movements during mindless reading (i.e., mindless reading occurs when the eyes continue moving across the page even though the mind is thinking about something unrelated to the text) showed that self-caught mind wandering had longer fixations than probe-caught mind wandering, suggesting that these particularly extended reading durations may indicate the recognition that the mind had drifted. The notion of meta-awareness enriches our understanding of how individuals, affected by cultural tendencies, regulate mind wandering experiences. Following the findings of mindless reading, individuals from cultures emphasising social obligations (collectivism) may demonstrate longer fixation on tasks as a demonstration of collectivist responsibilities, even when the mind has wandered. It may be feasible to comprehend the function of meta-awareness in the way that individuals manage their mind wandering experiences.

To sum up, this research offers a valuable understanding of the individual and cultural factors that impact mind wandering, defined as self-generated thought. It reveals the complicated nature of mind wandering by demonstrating that, although the frequency of mind wandering may not differ greatly between different groups, the content, and perception of mind wandering might vary depending on cultural values and beliefs.

3. Chapter three: Examining the relationship between mind wandering and working memory capacity

This chapter investigates the relationship between working memory capacity and task demand in relation to mind wandering. The study employs both the 0-back task and 2-back task, representing varying task demands, along with two complex span tasks (operation and symmetry span task), measuring individual working memory capacity, to examine how different levels of task demand influence the occurrence of mind wandering, particularly in individuals with varying working memory capacity.

3.1 Introduction

Several hypotheses have been developed to clarify how mind wandering arises. For instance, the current concerns hypothesis suggests that mind wandering is driven by individual concerns; the meta-awareness hypothesis states that it happens when meta-awareness is absent. The executive failure hypothesis proposes that mind wandering happens once executive control over external information fails, contrary to the decoupling hypothesis, which suggests that it reflects a shift of executive attention from the external environment to internal processes. The exploration of mind wandering has resulted in the development of two competing hypotheses about working memory capacity (WMC). On the one hand, empirical research has shown that high WMC individuals tend to be less likely to mind wandering than low WMC individuals (McVay & Kane, 2009), which is consistent with the executive failure hypothesis. On the other hand, individuals with high WMC are better compared those that have low WMC at sustaining the mind wandering state, consistent with the decoupling hypothesis (Krawietz et al., 2012).

It is important to recognise that both executive failure and decoupling hypotheses may be concurrently correct, depending on the particular demands of the work at hand. Central to the present research is that varying task demands may influence how WMC relates to mind wandering. Under low demands tasks, individuals with high WMC may sustain the mind wandering state, as the executive resources are not heavily stressed. Contrastingly, high demands tasks may lead to executive control failure in individuals with low WMC. The demand for executive control is considerable, necessitating resources to maintain attention on the task and inhibit mind wandering. The present study was therefore aimed to vary task demands to determine their moderating role in the relationship between WMC and mind wandering.

An investigation by Rummel and Boywitt (2014) provided preliminary evidence that task demand predicts the adaptation of mind wandering WMC. In this study, participants were asked to perform the N-back tasks, such as the 1-back (representing a less-demanding task) and the 3-back task (representing a more demanding task). The findings revealed a positive link between WMC and mind wandering when task demands were low and a negative relationship when task demands were high. Similarly, Zavagnin, Borella, & De Beni (2014) exposed participants to two versions of SART, the perceptual and semantic versions, to manipulate the task demand. Findings indicated that participants with high WMC report more mind wandering experiences in the perceptual SART, which is considered a less complex and less demanding task, though they provide no evidence for the negative connection between them in the semantic SART.

In another recent study, Randall, Oswald, and Beier (2014) used a meta-analysis to test whether task demand moderates the association between WMC and mind wandering. Tasks were classified as less complex or more complex based on three types of complexity identified by Wood (1986): the total number of distinct acts and information required to complete the task, the dimensions of information that needed to be organised, and whether the relationship between inputs and outputs is divergent or not. Thus, the SART, Choice Reaction Time Task, and Stroop Task were considered less complex tasks (i.e., low demand tasks), and a reading comprehension task, math task, working memory task, visual search task with high load, or other tasks assessing complex cognitive abilities were considered as more complex tasks (i.e., high demand tasks). Their results revealed that those with high WMC are more likely to resist mind wandering in general, but they found no direct evidence to support their assumption that increasing task complexity might exaggerate the negative connection between WMC and mind wandering. Given the contradictory results of previous research, the present study attempted to measure mind wandering among high and low WMC groups during relatively demanding tasks at the level of the semantic SART (but less demanding than the 3-back task used by Rummel and Boywitt, 2014), and to compare the impact of these to low demand tasks.

As the results from Study 1 showed the function of meta-awareness in managing mind wandering, suggesting that individuals who are more conscious of their mind wandering may be better at adjusting their attention, the present study further explores mind wandering by dividing it into two types: mind wandering with awareness and mind wandering without awareness. Mind wandering with awareness refers to a mental state in which individuals' thoughts deviate from their current task or immediate surroundings, but they are fully aware of this deviation. In other words, individuals consciously allow their thoughts to wander. Mind wandering without awareness, on the other hand, describes a mental state in which individuals' thoughts drift away from the ongoing task or the present moment without them consciously realising it (Smallwood et al., 2007).

Meta-awareness is a special form of metacognition which is an awareness of one's own thought process and an awareness of tendencies underlying it (Chin & Schooler, 2010). It is described as 'intermittent' since it functions as a monitoring system that intermittently evaluates mental contents and processes. That is, it does not continuously and actively monitor mental thoughts but rather has moments when individuals are aware of their current mental contents. It is also 'propositional', as it requires awareness and inner evaluations of awareness. This intermittent and propositional process is essential for self-reflection and self-regulation (Dunne et al. 2019; Konjedi & Maleeh, 2021). Schooler (2002) stated that meta-awareness helps individuals notice when their minds are wandering and allows them to refocus on primary tasks. Schooler and colleagues (2011) believed that meta-awareness works in a gentle way rather than a direct way. It allows individuals to make changes to stay on track with what they are supposed to be thinking about. From the perspective of Wegner (2002), meta-awareness functions in a different manner. For example, when you notice that your mind is wandering, it feels like you have taken control and caught your mind wandering, but the truth is that your focus might have come back on its own, and you are realising it after the fact.

Komori (2016) investigated the impact of WMC on metacognitive monitoring processes by examining the confidence judgments provided by participants. This study involved a multitasking condition, specifically a Japanese listening span test, one form of working memory test, that asked participants to listen to a series of spoken items, such as sentences, and report them in the correct order, alongside listening comprehension test. The difficulty of the test was increased by presenting longer sequences of items, with four levels: two, three, four, and five sentences. Participants were asked to assess their confidence in their answers' accuracy on a scale of 0 to 100%. The results showed substantial disparities regarding tracking accuracy between high and low WMC groups, despite the increasing cognitive load. High WMC groups demonstrated superior confidence judgments, both in regards to total precision and discrimination, which implies that individuals with high WMC are more effective at accurately assessing their own cognitive processes. It additionally indicates that those with high WMC can inhibit task-unrelated distractors and maintain attention on retrieval cues or task related information while performing multitasking. This monitoring ability enables high WMC individuals to be more in control of their mental states compared to those with low WMC, including during periods of mind wandering. It is reasonable to conjecture that high WMC individuals might therefore exhibit more mind wandering with awareness than low WMC individuals.

The present study tried to resolve prior inconsistencies by manipulating task demand within participants and measuring the two types of mind wandering under both conditions. The N-back tasks was chosen over the SART because it allows for the manipulation of cognitive demand through varying level of task difficulty (e.g., 0-back and 2-back tasks), while keeping other task characteristics constant. This flexibility enables this study to examine how different levels of cognitive demand influence mind wandering and task performance. The present study utilised 2-back rather than 3-back tasks due to considerations of cognitive load. A 3-back task might have imposed excessive cognitive demands, potentially overshadowing the nuances of mind wandering; conversely, a 2-back task might provide a balance between cognitive challenge and participant engagement. Selecting the two versions of N-back is sufficient to provide a clear distinction in the cognitive load between conditions. Unlike the measures of WMC used in the above studies, the study employed the complex span task to provide two dimensions of working memory; the visuospatial and verbal. Moreover, based on the results of working memory tests, participants were selected from the top and bottom of the sample pool to give a clear distinction between groups. Given the observation in Study 1 that there was little difference between the British and Chinese groups in terms of frequencies of mind wandering, and the comparable patterns in mind wandering episodes, it indicates that the behaviours or responses under investigation are not markedly different across these populations. As such, it is reasonable to use a Chinese sample in the current study, as the results are likely to reflect patterns that could be observed in other cultural contexts. While Chinese sample showed slightly higher frequencies of mind wandering, the key point is that the overall patterns consistent across both samples, supporting the validity of using the Chinese sample for this research. In line with the findings from Study 1, this study distinguishes between mind wandering with awareness and without awareness. This distinction may have implications for task performance and working memory, and provide a more nuanced understanding of how mind wandering influences cognitive processes.

The primary objective of the study was to evaluate the link between WMC and the occurrence of mind wandering, and to test whether task demand works as a moderator to adjust this relationship. Individuals with high WMC were predicted to be more prone to mind wandering than those with low WMC under low demand settings, whereas those with high WMC were expected to be less inclined to mind wandering under high demand conditions. The high WMC group would also be better equipped to maintain awareness of their thoughts during mind wandering than the low WMC group.

3.2 Method

3.2.1 Design and Participants

All participants completed initial tests of working memory capacity and then performed N-back task to assess the degree of mind wandering. For the purpose of analysis, participants were then divided into two groups based on their performance on the initial test. To detect significant effects, the power analysis indicated that the minimum sample size was 34 (i.e., 17 in each group) which is sufficient to identify medium effects with power set at 0.8. More participants than this were recruited to improve the stability of the group differences following the tests of WMC by permitting sampling from the tails of the distribution of performance. A total of 47 participants were recruited via advertisements from a high school located in the eastern part of China and they included teachers and staff members from various departments with the school. The age range of the participants was between 18 and 60 years old, ensuring a diverse representation of age groups (M=38.09, SD=15.27). Among the participants, there were 28 male and 19 female individuals. Before being included in the study, all participants received detailed information about the study's the purposes and procedures, and informed consent emphasising the voluntary nature of their involvement and the assurance of confidentiality. The UCL Institute of Education Research Ethics Committee provided permission for the study.

3.2.2 Materials

Complex span tasks

Complex span tasks, operation and symmetry span tasks, are commonly used measures of working memory (Redick et al., 2012; Unsworth et al., 2005). Based on Baddeley's multicomponent model, it is commonly accepted that there are two types of working memory: verbal and visuospatial. To obtain a comprehensive assessment of individuals' working memory capacity across these domains, two different types of complex span tasks were employed, one focused on verbal information and the other on visuospatial information. The complex span task has two key components, memory and processing. During the memory phase, participants are presented with a series of stimuli, such as words or spatial locations, and asked to both remember the stimuli and perform a cognitive processing task. For instance, the operation span task involves a simple math problem that focuses on verbal information, while the symmetry span task involves evaluating an image as symmetrical or non-symmetrical, which focuses on visuospatial information.

These demands enable the tasks to provide a measure of working memory capacity (i.e., accuracy in the face of competing load). For both tasks, items are scored in terms of whether they are correctly remembered in the right serial position, thereby, partial credit scoring is used. For example, in the operation span task (OSPAN), a participant is given a list of number to remember and recall in order. The list is: ‘19’, ‘3’, ‘27’, ‘32’. If the participant correctly recalls the first two figures in order (‘19’ and ‘3’) but then incorrectly recalls ‘3’ instead of ‘27’, they would receive partial credit for the first two items but not for the third item. The score is based on the number of items correctly recalled in the appropriate serial position. In the OSPAN task, list length was in a sequential order, from the two to seven items, there were three trials of each length for a total possible score of 81. Each stimulus appeared on the screen for 2500ms. The last memory test did not have a time restriction. It typically took approximately 15 minutes to complete (see the Figure 3.1).

In the symmetry span task (SSPAN), participants were presented with a matrix containing a blue square and memorized positions of blue squares while performing a processing task, in which they were shown an image that was an 8 x 8 matrix with some squares filled in black. Following their assessment of the image's symmetry along its vertical axis, participants clicked on the cells in an empty matrix to recall the order in which the blue squares were located (see Figure 3.2). There were three lists of each length, ranging in length from two to seven items, for a total potential score of 81. The scoring procedure and the time length of the SSPAN was similar to the one used in the OPSAN.

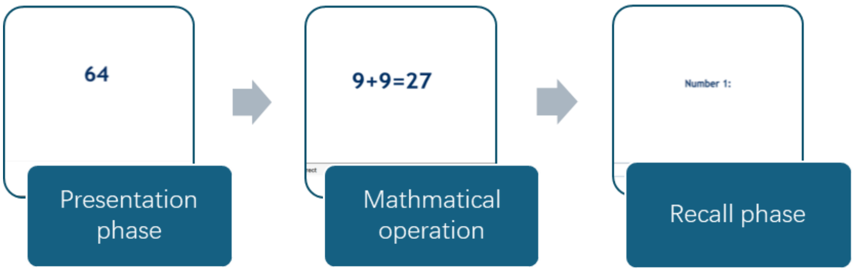

Figure 3.1 Schematic representation of the operation span task

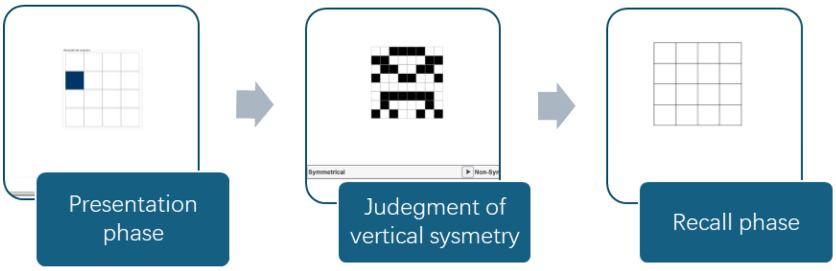

Figure 3.2 Schematic representation of the symmetry span task

N-back tasks

N-back is a cognitive task that was originally introduced by Kirchner (1958) that has been widely employed in research on working memory. The N-back task involves the presentation of words on a computer screen, and participants are required to decide whether the current word matches a previously shown word. By varying the N value, researchers can assess how much information individuals can hold in their work memory. The N-back task has been extensively used in the study of mind wandering, since its structure with varying cognitive load allows the investigation to be done within a consistent format (Miller et al., 2009; Murray et al., 2021). Research has shown that mind wandering tends to decrease as task demands increase, with 2-back tasks reducing the likelihood of mind wandering compared to 0-back tasks (Smallwood, 2009). Neuroimaging studies using the N-back task have also identified brain regions associated with mind wandering. These findings highlight the utility of the N-back task in understanding the interplay between cognitive load and mind wandering.

For present purposes, 0-back and 2-back tasks were used. In the 0-back task, participants are asked to decide whether the presented word is matched with a pre-specified word. This is considered a low demand task since the participant only needs to focus on the current word and compare it with a single reference point. In the 2-back task, participants are asked to decide whether the presented word is matched with a word presented two trials prior. This considered a higher demand task since the participant needs to hold the previous words in their working memory and compare it to the current word. Each word stimulus appears for 2000 milliseconds (ms). If the current word matches the pre-specified word (0-back) or the word presented two trials prior (2-back), participants need to press a button; if there is no match, they need to withhold their response (See the Figure 3.1 for the schematic of the task). The task consists of 15 blocks, and each block contains 16 trials, resulting in a total of 240 trials. Target stimuli were randomly inserted in a block. The ratio of non-target to target item was 8 (1 target per 8 trials). In all, these two versions of N-back tasks took approximately 15 minutes each, but the task duration varied slightly depending on participants' response time and the pace through the trials. Two performance measures were used in this task, accuracy and reaction time. Each correct response to a stimulus was awarded one point, while incorrect responses resulted in zero points for that trial. The total number of correct responses across all trials was tallied to calculate the proportional overall accuracy rate. Thus, the possible maximum score was 1.

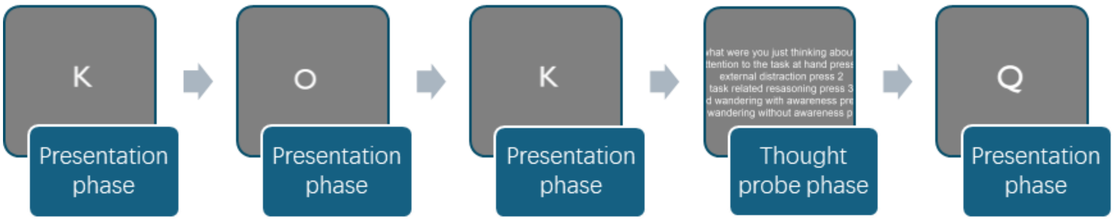

Figure 3.3 Schematic representation of the N-back task with thought probes included.

To further investigate the performance of participants, the study also employed two indicators, hit rate, and false alarm rate, to observe participants' positive responses. That is, situations when participants thought current letters matched with target letters were indicated by these positive responses. Hit rate referred to the situation when target letters appeared and were detected and judged to be matched with previous letters and was calculated as hit rate= (number of correct matches to target letter)/ (total number of target letters presented). False alarm rate referred to the situation when the non-target letters appeared and were incorrectly identified as matching previous letters, which was calculated as: false alarm rate= (number of incorrect match to non-target letters)/ (total number of non-target letters presented).

The two indicators offer a more thorough assessment of how well participants performed in identifying matched and mismatched tasks. The reaction time was recorded for each trial, measuring the average time taken by the participants to respond to each stimulus.

Thought probes

Participants were presented with a thought probe to assess the extent of mind wandering during the N-back tasks. The probe trial was presented once in a block. That is, there were 15 probe trials per task. These probes inquired about what participants were thinking about just prior to the probe, and there were five response options to choose from: (1) attention to the task at hand; (2) external distraction; (3) task-related reasoning (i.e., it is related to the ongoing task but not the current stimuli, such as, recalling the purpose of the task); (4) mind wandering without awareness (i.e., when your mind wanders but you are unaware of it until a probe or you catch it) and (5) mind wandering with awareness (i.e., when your mind wanders and you know and let it continue). Option 1 was recorded as on task, option 2 as external distractors, option 3 as task related interference, option 4 and 5 as mind wandering, in line with the definition of self-generated thought proposed above after Study 1. Mind wandering was calculated as: mind wandering frequency = (number of options 4 and 5)/ (total number of probe trials, i.e., 15). Mind wandering with awareness frequency = (number of option 5)/15. Mind wandering without awareness frequency = (number of option 4)/15.

3.2.3 Procedure

Participants in the study first completed the pre-experimental complex span tasks, which included the operation span task and symmetry span task in counterbalanced order, to measure their working memory capacity. Half the participants started with the operation span task, followed by the symmetry span task, while the other half took them in the reverse order. The SSPAN scores were normally distributed (Mean=26.79, SD=14.03, Median=19, Min=6, Max=71, see Figure 3.1) based on Kolmogorov-Smirnov and Shapiro-Wilk tests ($p>0.05$). From the participant pool, low and high visuospatial working memory capacity groups were formed from the tails of the distribution, each consisting of 17 participants (M low = 13.65, M high = 41.65). An independent t-test revealed a significant difference between the two groups $t(32) = 9.88$, $p<0.001$. Participants also completed the Operation Span Task (OSPAN) to assess verbal working memory capacity (WMC), and low and high groups were formed in the same way.

OSPAN scores were normally distributed (Mean = 29, SD = 11.55, Median = 25, Min = 8, Max = 48, see Figure 2.2) according to Kolmogorov-Smirnov and Shapiro-Wilk tests ($p>0.05$) for the high verbal WMC group. However, the low verbal WMC group's scores were non-normally distributed ($p<0.05$), necessitating a non-parametric test (Mann-Whitney) due to small sample size (N < 30). The difference in OSPAN scores between low and high WMC groups was significant (M low = 16.12, M high = 40.65, U=289, $p<0.001$). The visuospatial and verbal working memory capacity (WMC) groups were identical for participants in the low working memory groups and only one person was different between the high working memory groups. This participant was excluded to ensure consistency across both memory tasks. Ultimately, then, 33 participants from the high and low WMC groups, representing approximately 35% each of the initial participant pool, were chosen to take part in the experiment, with ages from 18 to 60 years (M=39, SD=15.66). While the ultimate sample size of 33 participants deviated slightly from the initially suggested 34 participants based on power analysis, this adjustment was expected to have minimal impact on statistical analysis. Prioritising cohesive groups across both verbal and visuospatial WMC aspects simplifies the analysis and improves the interpretability of this study.

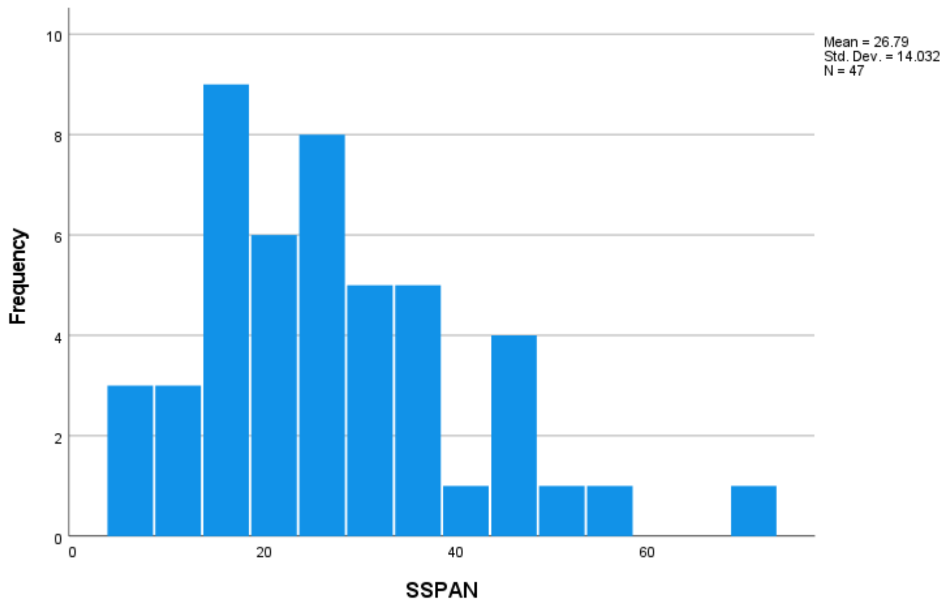

Figure 3.4 The distribution of SSPAN scores (The x-axis represents the SSPAN score, ranging from 6 to 71, and the y-axis represents the frequency of participant)

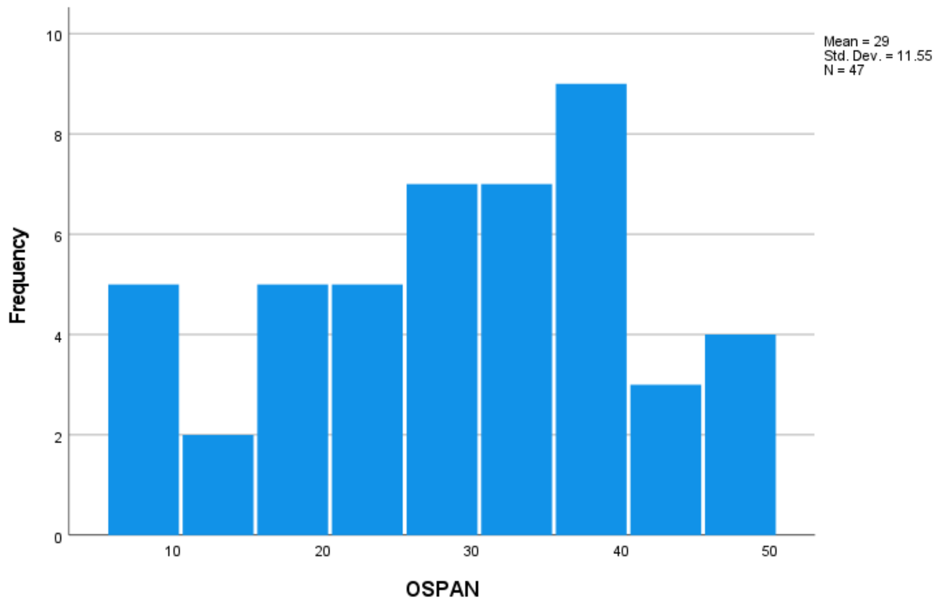

Figure 3.5 The distribution of OSPAN scores (The x-axis represents the OSPAN score, ranging from 6 to 71, and the y-axis represents the frequency of participant)

After this initial assessment, participants then completed two versions of the n-back task (0-back and 2-back). Counterbalancing (i.e., splitting the participant sample in each group in half and having one half carry out the 0-back task followed by the 2-back task and the other half do the 2-back task followed by the 0-back task) was used to account for potential order effects. Random thought probes were utilised on both versions of the test to measure mind wandering during the n-back tasks.

3.2.4 Analysis plan

Examining WMC's function in mind wandering was the main goal of this investigation. That is, the study aimed to explore how individual differences in WMC influenced mind wandering under different task demand conditions. As noted above, a specific prediction was made about how the WMC group and task demand would interact with regard to mind wandering. It was expected that high WMC participants would exhibit higher levels of mind wandering during the 0-back task compared to low WMC participants. Conversely, during the more challenging 2-back task, high WMC participants would show lower levels of mind wandering in comparison to those with low WMC. To analyse and test the predicted interaction, a mixed design analysis of variance (ANOVA) was used, with WMC as a between-subject variable and task demand as a within-subject variable. Prior to this, task demands were also assessed in terms of whether accuracy rates and reaction time differed according to the type of task and WMC. Furthermore, the impact of task type and WMC on hit rate and false alarm rates was explored to understand how these factors contribute to participants' ability to correctly identify relevant stimuli and avoid false identification. The impact of task demands and WMC on different types of mind wandering were considered, based on the characteristics of awareness defined earlier. A 3-way mixed design ANOVA was used to examine the main effects of task type, WMC, and mind wandering types, as well as to explore potential interactions between these factors.

3.3 Results

3.3.1 Does task performance reflect differences in demand? Were those differences affected by WMC?

A two-way mixed ANOVA was conducted to investigate whether there were differences in reaction time between the two types of tasks (as the within-participant factor; 0-back, 2-back), and whether reaction time varied based on WMC group (as the between-participant factor; low, high). The ANOVA revealed a significant main effect of task type, $F (1, 31) = 54.85$, $P < 0.01$, partial $\eta 2 = 0.64$, indicating that participants took longer to respond to the 2-back task (1259.09 ms) than to the 0-back task (691.94 ms, see Table 3.1 for details). However, the main effect of the working memory capacity group was not significant, $F (1, 31) = 136$, $P = 0.25$, partial $\eta 2 = 0.04$. Additionally, the interaction between task type and WMC was not significant, $F (1, 32) = 1.99$, $P = 0.17$, partial $\eta 2 = 0.06$, though there was some indication that the impact of greater demand was more for the low WMC group (see Figure 3.3).

Table 3.1 Reaction time mean for low and high WMC groups on the 0-back and 2-back tasks

	WMC	Mean (SD)	N
0backRT	Low	678.52(190.31)	17
	High	685.58(176.91)	16
2backRT	Low	1361.54(553.55)	17
	High	1150.24(261.96)	16

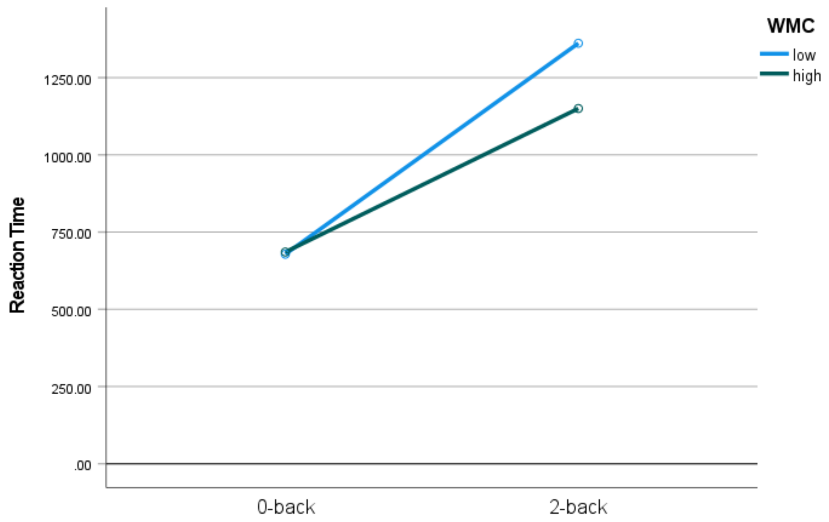

Figure 3.6 The relationship of task type and WMC to reaction time (The x-axis represents the task type, the y-axis represents reaction time, and the WMC group is represented by different colours)

Whether the accuracy rate differed with respect to the type of task and WMC was also examined. The first independent variable was the type of task (with subject), with two levels: 0-back and 2-back tasks. The second independent variable was the WMC group (between subjects), with two levels: low and high. The dependent variable was the accuracy rate, out of 1. The ANOVA revealed a significant main effect of task type, $F(1, 31) = 77.65$, $P < 0.01$, partial $\eta 2 = 0.72$, indicating that participants had a higher accuracy rate in the 0-back task (0.98) than in the 2-back task (0.90, see Table 3.2 for details). However, the main effect of the WMC group was not significant, $F(1, 31) = 0$, $P = 0.98$, partial $\eta 2 = 0$. Additionally, the interaction between task type and WMC was not significant, $F(1, 31) = 0.53$, $P = 0.47$, partial $\eta 2 = 0.02$.

Table 3.2 Accuracy rate mean for low and high WMC groups on the 0-back and 2-back tasks

	WMC	Mean (SD)	N
0backAR	Low	0.98(0.05)	17
	High	0.99(0.03)	16
2backAR	Low	0.90(0.06)	17
	High	0.89(0.06)	16

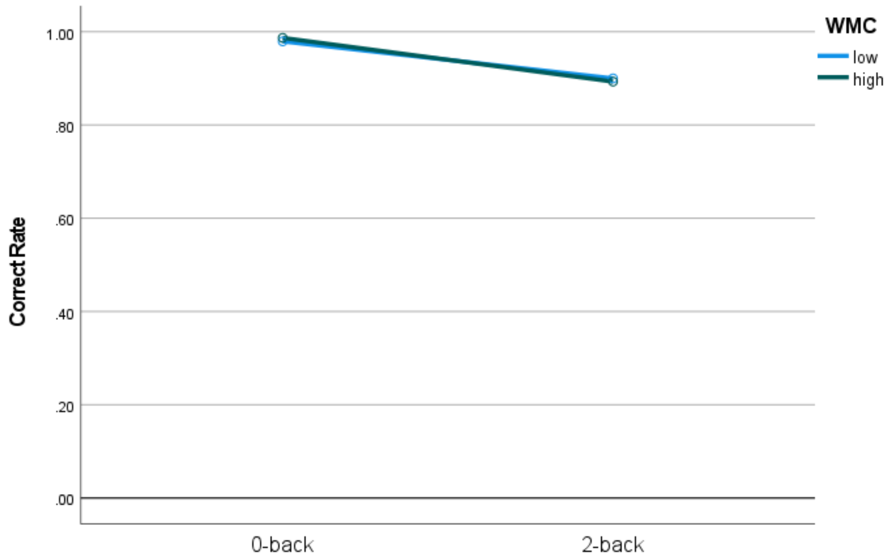

Figure 3.7 The relationship of task type and WMC to accuracy rate (The x-axis represents the task type, the y-axis represents correct rate, and the WMC group is represented by different colours)

The two ANOVA tests suggest that compared to the 0-back task, participants have longer reaction times and lower accuracy rate in the 2-back task, which indicates that there is a difference in task demanding conditions and that the contrast in demands between the two versions of the task was as expected – and crucially was the same for both groups.

A mixed measures ANOVA was also conducted to assess the impact of task type and its interaction with WMC on the hit rate (see Table 3.3 for details). A significant main effect of task type was evident, $F(1,31) = 118.06$, $p<0.001$, partial $\eta^2 = 0.79$, but the main effect of WMC was not significant, $F(1,31) = 2.31$, $p = 0.14$, partial $\eta^2 = 0.07$. The interaction effect between task type and WMC approached significance, $F(1,31) = 3.92$, $p = 0.057$, partial $\eta^2 = 0.11$, suggesting a potential interplay. A significant main effect of task type on the false alarm rate (see Table 3.4 for details) was evident, $F(1,31) = 29.73$, $p < 0.001$, partial $\eta^2 = 0.49$, however the main effect of WMC, $F(1,31) = 0.30$, $p = 0.59$, partial $\eta^2 = 0.01$, and the interaction effect between task type and WMC, $F(1,31) = 0.18$, $p = 0.67$, partial $\eta^2 = 0.01$, did not reach statistical significance. These results confirmed the impact of the two tasks in terms of demand, giving little indication that the differences in demand varied according WMC group.

Table 3.3 Hit rate mean for low and high WMC groups on the 0-back and 2-back tasks

	WMC	Mean (SD)	N
0backHR	Low	0.93(0.07)	17
	High	0.93(0.07)	16
2backHR	Low	0.64(0.14)	17
	High	0.51(0.24)	16

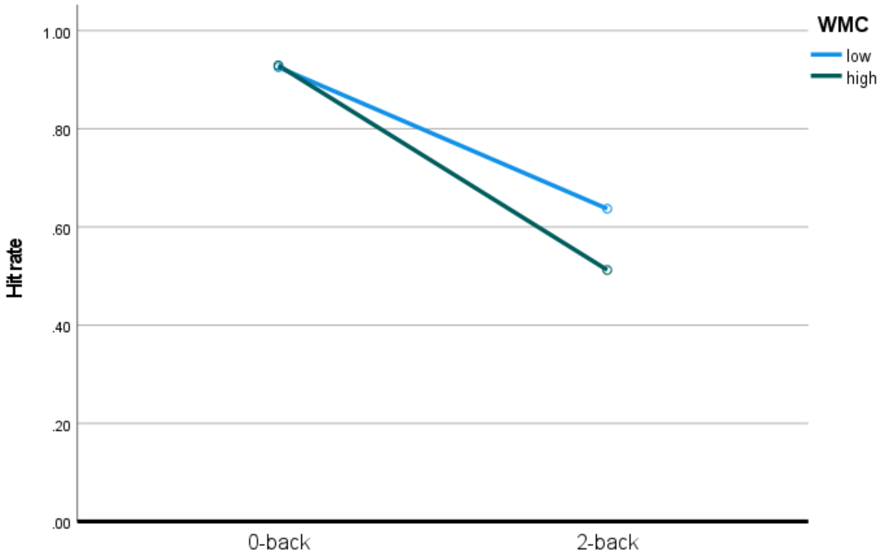

Figure 3.8 The relationship of task type and WMC to hit rate (The x-axis represents the task type, the y-axis represents hit rate, and the WMC group is represented by different colours)

Table 3.4 False alarm rate mean for low and high WMC groups on the 0-back and 2-back tasks

	WMC	Mean (SD)	N
0backFR	Low	0.002(0.004)	17
	High	0.001(0.002)	16
2backFR	Low	0.061(0.056)	17
	High	0.051(0.060)	16

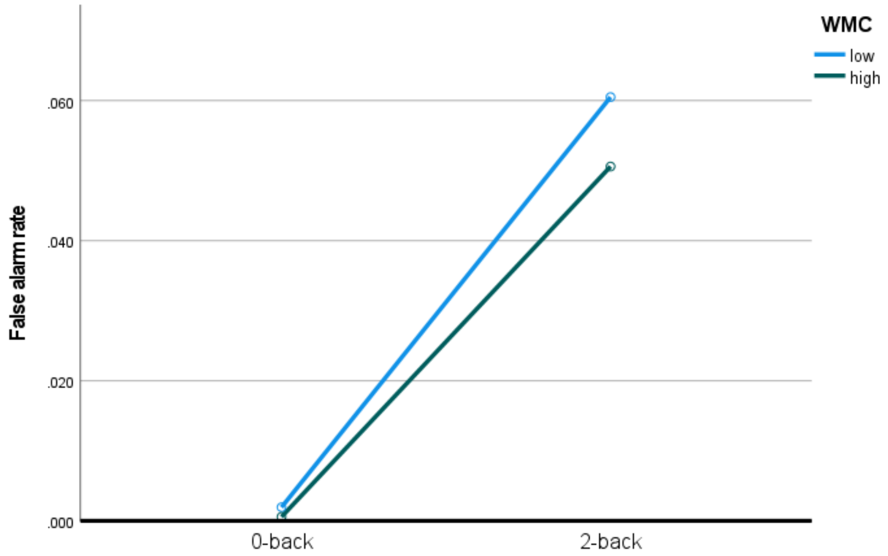

Figure 3.9 The graph of the relationship of task type and WMC in false alarm rate (The x-axis represents the task type, the y-axis represents false alarm rate, and the WMC group is represented by different colours)

3.3.2 The rate of mind wandering in two task conditions

On the descriptive level, the average number of responses for mind wandering experiences (i.e., average for options 4 and 5, see Table 3.5) was 2.12 and 2.06, respectively, in the 0-back task and the 2-back task. Among the sample, 12 participants reported mind wandering experiences, and 11 participants did not have such experiences. The rate of mind wandering was slightly higher in the 2-back task (0.148) than in the 0-back task (0.144, see Table 3.6). A T-test showed that, regardless of the rate of mind wandering, there was no difference between the two conditions, $t(32) = -0.12$, $p = 0.91$, $d = 0.02$. A two-way mixed model ANOVA was conducted to examine whether the rate of mind wandering was affected by working memory capacity and type of task. The ANOVA included a within-subject factor of task type (0-back, 2-back) and a between-subject factor of WMC (low, high). The dependent variable was the rate of mind wandering, out of 1. The operational definition for the mind wandering rate used in this study was calculated as the ratio of the number of mind wanderings probed to the total number of probes conducted during the task. For the type of task, there was no significant effect, with $F(1,31) = 0.02$, $P = 0.91$, partial $\eta^2 = 0$. Similarly, the main effect of the WMC group was not significant, with $F(1,31) = 0.04$, $P = 0.85$, and partial $\eta^2 = 0.001$. Additionally, the interaction between task type and WMC group was not significant, with $F(1,31) = 0.02$, $P = 0.91$, and partial $\eta^2 = 0.001$.

Table 3.5 The average of the probe responses on the 0-back and 2-back tasks

				Mind wandering	
	attention to the task at hand (numbers of option 1)	external distraction (numbers of option 2)	task-related reasoning (numbers of option 3)	Mind wandering with awareness (numbers of option 5)	Mind wandering without awareness (numbers of option 4)
0-back	8.61	2	2.27	2.09	0.03
2-back	8.39	1.26	3.24	1.91	0.15

Table 3.6 Mind Wandering Frequency Mean for Low and High WMC groups on the 0-back and 2-back tasks

	WMC	Mean (SD)	N
0backMW	Low	0.137(0.26)	17
	High	0.151(0.28)	16
2backMW	Low	0.137(0.24)	17
	High	0.159(0.31)	16

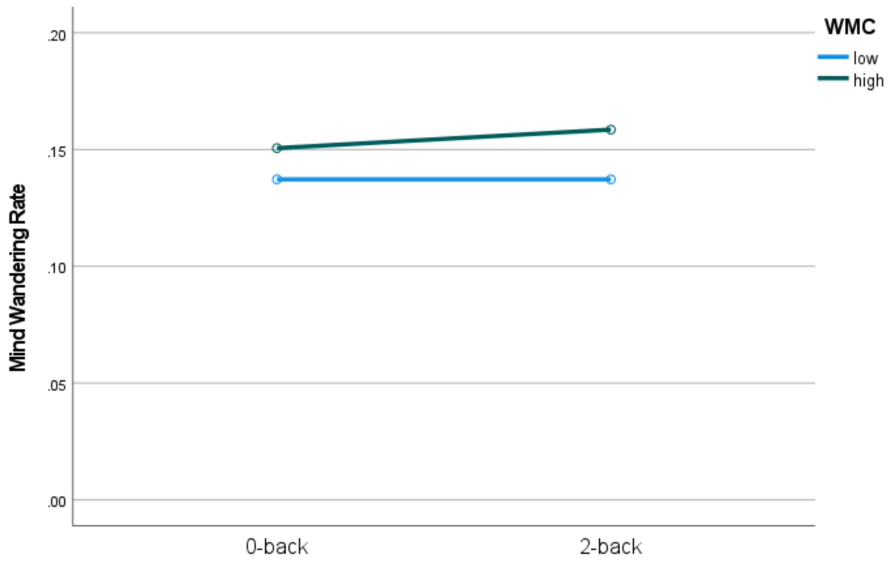

Figure 3.10 The relationship of task type and WMC to mind wandering (The x-axis represents the task type, the y-axis represents mind wandering rate, and the WMC group is represented by different colours)

To look at the different form of mind-wandering episodes, a 3-way mixed design ANOVA was conducted to examine the effects of task type, WMC, and mind-wandering types, and interactions between these factors, on the rate of mind wandering. The analysis suggested that there was a significant main effect of mind wandering types $F(1,31) = 12.41$, $p<0.001$, partial $\eta^2 = 0.29$, but none of the other main effects (task type, $F(1,31) = 0.713$, $p=0.41$, partial $\eta^2 = 0.22$; WMC, $F(1,31) = 0.02$, $p = 0.90$, partial $\eta^2 = 0$) were statistically significant. In addition, none of the interaction effects (task*WMC, $F(1,31) = 0.03$, $p = 0.86$, partial $\eta^2 = 0.001$; MW*WMC, $F(1,31) = 0.10$, $p = 0.77$, partial $\eta^2 = 0.003$; Task*MW, $F(1,31) = 1.81$, $p = 0.19$, partial $\eta^2 = 0.06$; Task*MW*WMC, $F(1,31) = 0.16$, $p = 0.69$, partial $\eta^2 = 0.005$) reached statistical significance.

The rate of mind wandering with awareness was higher in the 0-back task (0.180) than in the 2-back task (0.140), however, based on a t-test result, there was no difference between the two tasks, $t(32) = 1.12$, $p=0.27$, $d=.20$. For the rate of mind wandering with awareness, a two-way mixed ANOVAs was used to analyse the data, with task type (0-back, 2-back) as a within-subject factor and with working memory group (low, high) as a between-participant factor. For the type of task, there was no significant effect, with $F(1,31) = 1.21$, $P = 0.28$, and partial $\eta^2 = 0.04$. Similarly, the main effect of the working memory capacity group was not significant, with $F(1,31) = 0.04$, $P = 0.85$, and partial $\eta^2 = 0.001$. Additionally, the interaction between task type and working memory capacity group was not significant, with $F(1,31) = 0.09$, $P = 0.77$, partial $\eta^2 =$

0.003, with any difference there was between the two groups on the 2-back task in the opposite direction to that predicted.

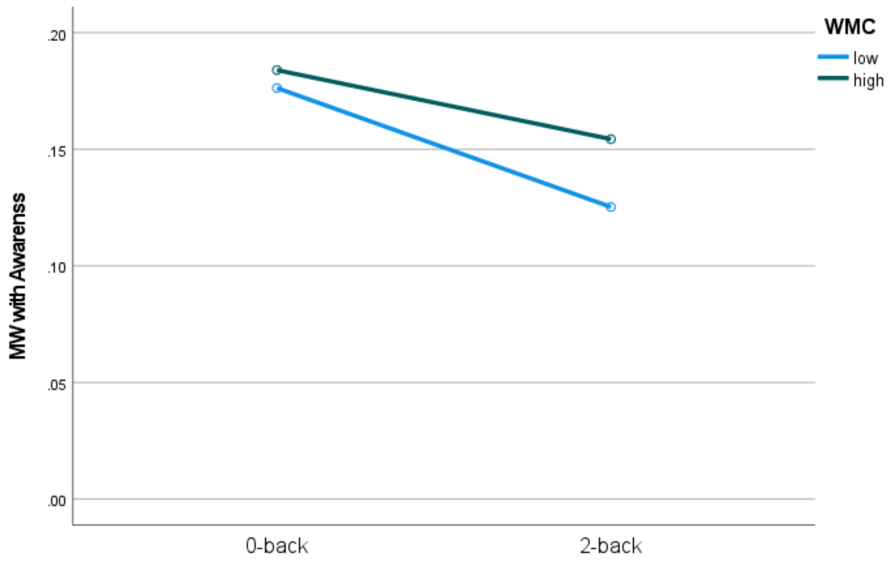

Figure 3.11 The relationship of task type and WMC to mind wandering with awareness (The x-axis represents the task type, the y-axis represents mind wandering with awareness rate, and the WMC group is represented by different colours)

For the rate of mind wandering without awareness, this was higher in 2-back task (0.010) compared to 0-back task (0.002), but the difference between two tasks was not significant, t (32) =-1.42, p=0.17, d=-0.247. The data were analysed using two-way mixed ANOVAs, with task type (0-back, 2-back) as a within-subject factor and working memory group (low, high) as a between-participant factor. Results revealed that neither task type nor working memory group had a significant effect, with F (1,31) =

1.92, P = 0.18, partial η2 = 0.06 and F (1,31) = 2.18, P = 0.15, partial η2 = 0.07, respectively. Moreover, the interaction between task type and working memory group was not significant, with F (1,31) = 0.42, P = 0.52, partial η2 = 0.01, with any difference between the two groups now in the opposite direction to that predicted for the 0-back task.

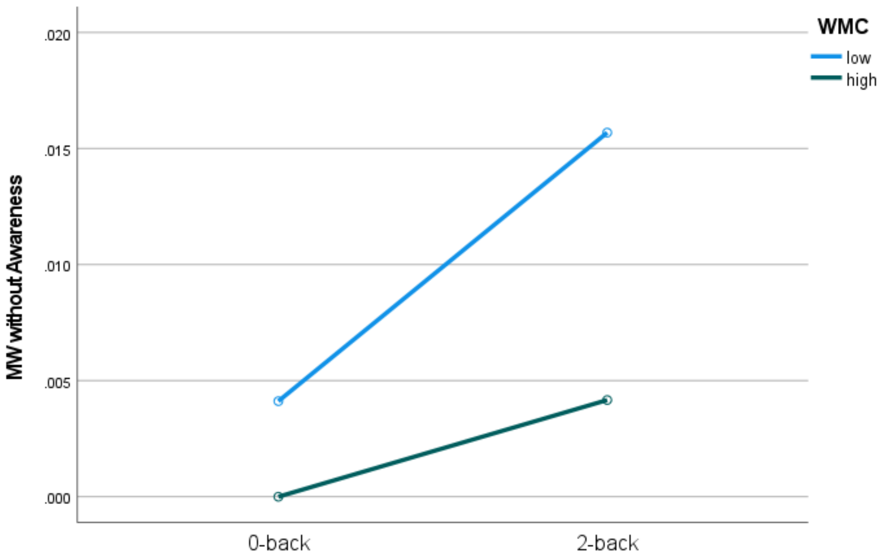

Figure 3.12 The relationship of task type and WMC to mind wandering without awareness (The x-axis represents the task type, the y-axis represents mind wandering without awareness rate, and the WMC group is represented by different colours)

3.4 Discussion

This research investigated the connections between mind wandering and WMC, with a specific focus on testing the hypothesis that an interaction between WMC groups and task demand might influence the reported amount of mind wandering. The results, as anticipated, failed to support this theory. The study found a significant difference in demand between two tasks, 0-back and 2-back tasks, with substantial effect sizes for reaction time and accuracy rate. This indicated that the setting of tasks was sufficient to create additional demand as anticipated. While task demands did vary in expected fashion, however, the rate of mind wandering was found to be low, and task accuracy was high in comparison to previous research on the N-back task by Miller and colleagues (2009). Specially, in their study, the accuracy for the 0-back task was 0.97, and for the 2-back task, it was 0.84. These findings suggest that in the present study, participants' attentional system was focused to a greater extent on processing relevant information and ignoring distractions. If so, this would lead to the suppression of extraneous ideas and the reduction of mind wandering, potentially enhancing performance.

Despite the differences in task demand, the predicted interaction between WMC and task demand also did not appear. Not only was there no significant difference between task demand conditions in the overall occurrence of mind wandering, but high WMC participants did not exhibit more mind wandering in the 0-back task or less in the 2-

back task compared to low WMC participants. This lack of interaction necessitates a closer examination of the relationship between mind wandering and WMC.

There are at least two possible reasons for the lack of effects. First, it is plausible that the expected interaction does not actually exist or does so only intermittently. The past inconsistency in evidence about the association between mind wandering and WMC raises the possibility that the impact under consideration is not very strong or that it depends on certain environmental circumstances. The idea that the predicted interaction might not be a phenomenon that applies to all situations is supported by the observation that there was no difference in mind wandering between different task demands in the 0-back and 2-back tasks. The alternative explanation is that, there is some kind of robust effect, but the design employed here failed to capture it. This could be due to the insensitivity of tasks and inserted probes. The 0-back and 2-back tasks differed significantly in terms of accuracy rate and response time, but it is possible that the tasks chosen weren't sensitive enough for identifying up on slight differences in mind wandering, and the limited number of probes did not allow for knowledge of the state of minds of all participants in real time. It is possible that more demanding tasks or more frequent probes might be required to detect effects. The relationship between mind wandering, WMC and task demands therefore remains a complex area that requires further exploration.

3.4.1 Mind wandering and task demands

The manipulation of task demand or difficulty is often achieved through cognitive load in various task paradigms, including sustained attention tasks, working memory tasks, and reading tasks. However, the link between mind wandering and task demand may not be obvious. On the one hand, an easy task or less demanding may offer more opportunities for mind wandering compared to a difficult or resources demanding task, as unused executive resources become available (Smallwood & Schooler, 2006). In contrast, other research shows that challenging tasks are more favourable to mind wandering (Feng et al. 2013; Levinson et al., 2012). In Feng et al. study (2013) on text difficulty in mind wandering, participants were provided two text conditions, easy and difficult, with results indicating a higher frequency of mind wandering in difficult conditions.

To better understand the complex relationships, it may be helpful to return to the concept of individuals' region of proximal learning (RPL), that task difficulty influences cognitive engagement. Based on the RPL model, moderate tasks located in the middle of the U-shaped curve appear to be optimal for engagement and learning, falling within individuals' optimal difficulty range. In this case, attention and effort are expected to have a more obvious effect on task performance, resulting in fewer mind-wandering experiences. According to the RPL interpretation, when the difficulty of the task is within individuals' 'sweet spot', the rate of mind wandering is less likely to show a significant change. In this case, the difficulty of the task is likely to match the participants' existing expertise. In the present context, it may be that both the 0-back and 2-back tasks were within the optimal level of difficulty and so led to lower and equal amounts of mind wandering. In other words, the difference in demand may not have been sufficient to produce a significant contrast in the rate of mind wandering. If the tasks fell within the range that individuals could cope with, participants would have been able to pay more attention to the task, hence the relatively low rate of mind wandering and high accuracy rate in both tasks.

This explanation is also compatible with the notion that the balance between difficulty and mind wandering is complex and varies according to an individual's present degree of knowledge. Therefore, it is essential to take individual differences into account when using the RPL model. Xu and Metcalfe (2016) mentioned that when mind wandering increased with task difficulty, it indicated that individuals might have little or no mastery of the task. Tasks get more challenging as they get farther from the learners' 'sweet spot', which results in more mind wandering experiences. On the other hand, if mind wandering decreased with task difficulty, it could be because the task was nevertheless still relatively easy, falling into the RPL range, which limits the possibility of mind wandering. However, it is important to acknowledge that the RPL model is not the only possible explanation for the findings. Motivation and competition for resources could also account for the observed patterns of mind wandering, as is discussed in detail below.

3.4.2 Mind wandering and awareness

The occurrence of mind wandering with awareness and without awareness was significantly different, which is consistent with previous studies that the two states are dissociable (Smallwood et al., 2007), leading to different patterns of cognitive processing in specific brain regions. Christoff et al. (2009) revealed distinct neural patterns associated with mind wandering depending on the absence of awareness. There was significant activation in regions such as the rostromedial prefrontal cortex, rostrolateral prefrontal cortex, dorsal anterior cingulate cortex, posterior cingulate/precuneus, superior temporal gyrus, middle frontal gyrus, fusiform gyrus, lingual gyrus, cerebellum when individuals experienced mind wandering without awareness. Notably, the default network, represented by the medial prefrontal cortex, is strongly engaged during mind wandering without awareness. Conversely, the anterior prefrontal cortex showed increased activity when individuals were aware of their mind wandering.

The brain regions activated during mind wandering without awareness may result in difficulty in noticing its occurrence. For instance, the elements of the medial prefrontal cortex are involved in mental state attribution. When this region is highly active during mind wandering without awareness, it may result in reduced resources for external monitoring, which hinders the occurrence of self-awareness, making it less available for recognising thought processes. Brain regions responsible for the cognitive control process, such as the dorsal anterior cingulate cortex and anterior prefrontal cortex, are also activated during mind wandering without awareness, which might make them less effective at realising that the mind has started to wander. That is, the brain regions needed to monitor our minds are occupied when our minds are drifting, making it hard to redirect attention to the ongoing mental state, resulting in the difficulty in noticing mind wandering without awareness (Schooler et al., 2011). Sayette et al. (2009) manipulated alcohol consumption, with one group consuming alcohol (0.82/kg), and one placebo group, and they found that the alcohol group was more engaged in mind wandering without awareness compared to the placebo group. Therefore, while it is less likely that one will be aware of a mind wandering, it is also more likely to occur when manipulations that lower meta-awareness occur.

It is important to note that despite the relatively greater incidence of mind wandering without awareness in the 2-back, the occurrence of mind wandering with awareness was more frequent in both the 0-back and 2-back tasks than mind wandering without awareness. This is consistent with past findings that participants frequently engaged in mind wandering with awareness in both versions of the SART: one with a high target frequency of 40% and the other with a low target frequency of 20% (Smallwood et al., 2007). Moreover, there was a similar pattern in the rate of mind wandering in a daily-life setting. That is, participants reported mind wandering with awareness at 60.4% of the overall mind wandering rate and mind wandering without awareness at 39.6% of the overall rate (Kane et al., 2017). It is plausible that a higher frequency of mind wandering with awareness arises when participants feel that the task is simple enough that they may afford to engage mind wandering without impairing performance. In a comparable manner, manipulations of task difficulty might have an opposing effect on mind wandering with and without awareness. Seli et al. (2016) presented participants with two different difficult versions of SART to measure rates of the two types of mind wandering. The findings demonstrated that individuals reported more intentional mind wandering in an easy SART task than in a difficult task, and vice versa, more frequent unintentional mind wandering in a difficult task than in an easy one. It is worth noting that there was no difference in the overall rate of mind wandering in Seli et al.'s study (2016), which shows a possibility that the null hypothesis in previous studies regarding mind wandering and task difficulty may not necessarily mean there is no effect. There are indications that the findings might need to be reconsidered by focusing on a specified type of mind wandering. The absence of significantly greater mind wandering in the present study in the 2-back task is of course consistent with the suggestion that this remained within participants' optimal levels of difficulty, as discussed above.

Another possible reason for the higher rate of mind wandering with awareness is that participants felt an incentive to engage in the tasks. An increase in incentive might result in heightened meta-awareness to regulate mental states. Zedelius et al. (2015) provided two forms of incentives to encourage participants to self-catch their mind wandering experiences: one directly providing financial incentives to stimulate participant engagement, and another using bogus statements to convince them that their mind wandering experience states were monitored via a physiological device to ensure the accuracy of their self-report. The results confirmed the hypothesis, showing that direct or indirect incentives led to more frequent self-catching. It is worth noting that the increase in meta-awareness did not result in an improvement in performance, which aligns with our findings that WMC was not associated with type of mind wandering.

The discrepancy between the findings and predicted results suggests: that the monitoring system involved in assessing individuals' meta-awareness of mind wandering states is independent of WMC. This conjecture does not directly contradict the meta-awareness hypothesis (i.e., individuals possess the ability to self-monitor and regulate their thoughts; Schooler, 2002), since both contribute to regulation and control of thoughts; and it acknowledges the importance of a monitoring or meta-awareness mechanism in the occurrence of mind wandering. According to the meta-awareness hypothesis, however, recognising thoughts that stray from a desirable aim state requires a representation of consciousness, and this hypothesis takes a broader viewpoint on controlling general mind wandering based on current goals. In fact, the monitoring system appears to be more concerned with putting a stop to mind-wandering experiences; it assesses people's awareness of the event and may potentially bring it to a close. It may be more associated with the monitoring and interruption of cognitive processes in real time. The study by Zedelius et al. (2015) might explain the adjustment role of the monitoring system. Although participants reported more self-catching experiences under the incentive conditions, the performance did not vary compared to the control condition because those experiences served primarily to keep performance on track.

A study by Voss et al. (2018) examining the impact of WMC on individuals' ability to remain on task and the continuation of mind wandering once it occurs, showed similar results. Participants in the study were required to complete both probe-caught (i.e., in which participants were interrupted by probes to state their mental condition) and self-caught (i.e., in which participants reported when their minds were wandered) sessions and measured the amount of time they spent on the task before their minds started to wander, as well as the duration from the start of the wandering to the finish of it. The length of time spent on the activity rose with higher WMC, according to the results, indicating that those with higher WMC can concentrate better. There was no obvious association between WMC and the duration of mind wandering from the start to the finish. This implies that the ability to continue or end mind-wandering episodes is not impacted by WMC. It is important to acknowledge that these interpretations are conjectural and predicated on the facts at hand. There might be variations in the other variables between the studies that affect the observed outcomes. To draw stronger conclusions, further study is required.

3.4.3 Mind wandering and motivation

There was of course no incentive in the present study of the kind provided by Zedelius et al. (2015) that might have heightened awareness. However, based on the RPL account, the difficulty of the present task was appropriate to the participants' state of knowledge, so it is reasonable to assume that it was able to stimulate their interests or motivations, which in turn explains the present finding of a lower rate of mind wandering compared to previous research (Miller et al., 2009). Furthermore, as a result of the failure to observe the effect of WMC on mind wandering, it might be proposed that the change in rates of mind wandering by motivation is not influenced by WMC. One study that provides indirect evidence in favour of this theory indicates that higher levels of motivation are linked to lower rates of daydreaming (Unsworth & McMillan, 2013). In order to determine how these factors affect mind wandering while reading, participants in this study completed three working memory span tasks (such as operation span, symmetry span, and reading span tasks), a reading task with a comprehensive test, and multiple questionnaires about their motivation and interest in the topic at hand. The findings indicated that reading comprehension and mind wandering were positively impacted by WMC and motivation in a comparable manner. More specifically, participants with low WMC experienced mind wandering more frequently than those with high WMC, while participants who were driven to read or who were interested in the topic material reported mind wandering less frequently than those who were not motivated or did not find the topic material interesting. High levels of motivation, in turn, induced high levels of interest, again resulting in low rates of mind wandering. WMC did not have an impact on either topic interest and motivation.

There might be several reasons for the influence of motivation on the frequency of mind wandering. A potential explanation is that highly motivated individuals can focus their attention on information relevant to the work at hand, which reduces the chance of mind wandering. An investigation by Seli et al. (2019) provides evidence explaining the influence of motivation on both unintentional and intentional instances of mind wandering. In this study, two distinct sets of instructions were given to participants during a metronome response task in order to manipulate motivation. Participants in this assignment had to keep their focus on a series of tones and respond by pressing keys in time with the rhythms. The normal motivation condition provided standard task completion instructions. The high motivation condition included an alternate instruction: participants might end the experiment early by achieving a predefined performance level. The results showed that participants that were given higher motivation had significantly better performance than those in the group that received normal motivation. Crucially, participants in the high motivation group also showed lower rates of mind wandering, both unintentional and intentional. These findings provide support to the hypothesis that more motivation is correlated with less mind wandering.

Alternatively, motivated individuals might be better at inhibiting mind wandering. The anterior cingulate cortex is an area related to motivation and cognitive regulation, and it is important in mistake detection and reward loss. According to a study by Sarter et al. (2006), increased motivation led to an increase in cingulate brain activity. This suggests that those who are more motivated are more likely to pay attention to task-relevant information, minimising the conflict of shifting from the ongoing event to irrelevant information. This study also highlighted the potential role of mesolimbic regulation of prefrontal acetylcholine efflux, linking motivation and attentional effort. Motivated individuals may have an increase in acetylcholine efflux, which adds to increased attention and acts as a positive way to correct mind wandering. These results support the idea that motivation is closely tied to the identification and suppression of mind wandering experiences.

The RPL model of Xu and Metcalfe (2016) suggests that motivation does not increase as difficulty increases. There may come a point at which individuals have lower motivation to perform a task and disengage their attention, since difficulty at this point is beyond their mastered levels and hard to overcome. The RPL model allows, however, for individual differences in subjective perceptions of difficulty. Forrin et al. (2021)

presented two experimental conditions for participants: one short text section with one sentence per screen and an alternative long text section with 2–6 sentences per screen. They observed that participants frequently reported mind wandering in long compared to short text sections with similar levels of difficulty, and they had poorer comprehension in long than short text sections. Forrin et la. argued that the potential reason for this observation is that participants utilised section length as a clue for evaluating the difficulties of reading a given text. The evaluation of difficulty offers insights into the level of effort or engagement required for a task, as well as the extent of mind wandering that occurs while working on it. If individuals expect a task to require effort, and if they are more motivated to perform a task, then their attention will be allocated to it, resulting in a lower rate of mind wandering; if perceived effort does not increase motivation, the opposite occurs.

Barrington and Miller (2023) support the idea of an interplay between difficulty and motivation. They assessed participants' perceived difficulty and motivation in relation to standard and modified SART activities. The adjustment entailed altering the target digit during the task. Participants found the modified task more difficult than the normal one. The results show that despite the task being more difficult, participants were more driven to complete it. Higher participant motivation was connected with fewer the mind wanderings. This again suggests that the perceived difficulty of work may influence motivation, which in turn influences people's capacity to focus attention and avoid mind wandering. Motivation and difficulty may interact in a dynamic manner. For example, a seemingly tough job can keep someone's attention if they are motivated to do it. However, low motivation may make it tough to engage.

3.4.4 Conclusion

The adjustment of task complexity, as investigated through SART, reading tasks, and N-back tasks, produces inconsistent results in terms of its influence on mind wandering. The RPL model provides insight into this complexity, arguing that activities within the optimum difficulty range, just beyond mastery, reduce attention wandering. The U-shaped link between task demands and mind wandering highlights the significance of a task's position in the RPL. Distinct brain regions characterise the types of mind wandering, mind wandering with and without awareness. The nonsignificant relationship between WMC and the type of mind wandering implies that the monitoring system assessing individuals' meta-awareness of mind wandering is independent of WMC. However, it cannot rule out the involvement of WMC in mind wandering, since the tasks used in this study may not be sufficient to engender enough mind wandering experiences to detect any differences of that kind. It is critical to investigate the actual effect of deliberately selecting tasks outside the RPL. Nevertheless, given the RPL model's emphasis on individual variances, this is not a straightforward undertaking. The RPL model proposes that participants' optimum difficulty range drives motivation, resulting in decreased rates of mind wandering. Motivated people show increased attention, less mind wandering, and higher quality performance. However, the relationship between difficulty and motivation is dynamic, and subjective perceptions of difficulty influence motivation and attention allocation. In brief, understanding the complex interaction of task demands, awareness, and WMC is necessary when investigating mind wandering. It appears that task difficulty and individual motivation are more closely correlated with the frequency of mind-wandering episodes than WMC is.

4. Chapter four: Examining the role of mind wandering in divergent thinking

In this chapter, the influence of mind wandering on divergent thinking, one type of creative thinking, is under investigation. There is a particular focus on how subtypes of mind wandering episodes influence this cognitive phenomenon, given the findings from Study 1 of differences between mind wandering with and without awareness. The exploration of mind wandering in the context of divergent thinking was carried out by an empirical experiment conducted with 85 adults in China. Using thought probes, a comprehensive profile of mind wandering was captured, encompassing variables such as mind wandering frequency, and types of mind wandering thoughts, along with any impact of these on incubation effects and divergent thinking.

4.1 Introduction

The exploration of the relationship between mind wandering and creativity has been overshaded by the predominant emphasis on mind wandering as a disruptive and undesirable phenomenon. While there has been a substantial body of research on adverse effects of mind wandering, there is a gap in the literature with regard to the potentially positive aspects of this mental process, particular its role in facilitating creativity. Nevertheless, this study is grounded in the findings of the limited past research testing the connection between mind wandering and creativity, especially in terms of divergent thinking. Divergent thinking involves creatively generating diverse responses to open-ended questions, while convergent thinking focuses on a single correct solution to well-defined problems (Cortes et al., 2019). However, researchers often utilise either divergent thinking or convergent thinking to investigate creativity, which is problematic because each only shows one aspects of creativity. It is crucial to provide a holistic view, that is, employing both types of creative thinking. Therefore, this study and the next chapter focus divergent and convergent thinking respectively to give a fuller picture of the influence of mind wandering on creativity.

4.1.1 Empirical research between mind wandering and divergent thinking

Baird et al. (2012), addressing the relationship between mind wandering and divergent thinking, used the interpolated activity method (Ritter & Dijksterhuis, 2014), in which participants were given a problem to solve within a specific period, and provided with an incubation period, that is, an intervening break, following which they returned to the task. Participants' after-break performance was compared with their performance before-break. The incubation paradigm is well used in other studies on creativity. However, Baird et al. used four distinct types of incubation, including a relatively demanding task (i.e., 1-back task), an undemanding task (i.e., 0-back), a rest condition in which participants were required to sit quietly, and a no break condition. Participants during the undemanding task were required to determine whether a presented coloured target number was even or odd. In the demanding task, participants needed to determine whether the number preceding the target was even or odd. Although the procedure of these two tasks is not classic N-back in format, they were held to be equivalent in demand. The object was to manipulate demand loads during the incubation period. Importantly, the results revealed that the only improved performance was observed in an undemanding task. This suggests not only that tasks used during the incubation period might influence the incubation effect, but that conditions conducive to mind wandering might be particularly productive. One aspect of the region of proximal learning (RPL) model is its argument about the impact of task difficulty on mind wandering (Xu & Metcalfe, 2016). When tasks are too easy, individuals can complete them rapidly with minimal effort. The condition of relative ease frees up cognitive resources for mind wandering, which, it is argued, allows them to explore alternative ideas and generate novel solution to problems. In other words, consistent with the findings of Baird et al. (2012), easy tasks may beneficially influence creative performance by promoting mind wandering.

However, unlike Baird et al., Smeekens and Kane (2016) failed to find an incubation effect. They utilised thought probes to measure mind wandering and adopted four versions of the N-back task, a 0-back task resembling that of Baird et al. (2012), a 1-back task, a 2-back and 3-back task, and also a reading task. Despite variations in the demand of incubation tasks and the resulting mind wandering rates, the correlations between mind wandering during incubation and performance on divergent thinking were consistently null across all conditions. That is, there were no observed incubation effects. In a study conducted by Steindorf et al. (2021), the primary goal was to investigate the impact of different incubation intervals on divergent thinking. Participants were provided three types of incubation interval, those without any probes interrupting the task, those interrupted by thought probes, and those interrupted by trivia probes, in which participants received the same thought probes, but were also required to answer general knowledge questions. They hypothesised that incubation benefits, as observed in Baird et al.'s study, would be evident in the first incubation interval, while there would be no incubation effect in the second and third interval, given results in Smeekens and Kane's study. However, the results showed no advantage in post-incubation divergent thinking performance for any of the three incubation intervals. This finding challenged the argument that different types of incubation intervals would produce varied creative outcomes.

The inconsistency of these findings on the relationship between divergent thinking and mind wandering highlights the need for an improved approach. To address conflicting findings, it is better to bring the classification of types of mind wandering experiences into consideration. The definition of mind wandering used in the above studies emphasizes the spontaneous aspect of mind wandering, but as noted in Studies 1 and 2, mind wandering also has a deliberate aspect, suggesting a tighter definition may help draw a firmer association than existing empirical studies. This distinction is consistent with work by Seli et al. (2015), who observed different correlations between spontaneous and deliberate mind wandering on the five-facet mindfulness questionnaire, specifically one factor of the five-facet mindfulness, non-reactivity to inner experiences, which had a negative association with spontaneous mind wandering and, conversely, a positive association with deliberate mind wandering.

In line with this, a study by Teng and Lien (2022) investigated the influence of diversity in mind wandering content and different types of mind wandering, with three contrasting incubation conditions, a 0-back task (mind wandering-prone condition), focused-breathing practice (mindfulness-induced condition) and no incubation (control group). Creative performance was measured using the divergent thinking task, Unusual Uses Test (UUT). Regarding incubation effects, the findings revealed that the mindfulness-induced group outperformed the mind wandering-prone group, and there was no incubation effect observed in the group prone to mind wandering, which challenges the account that mind wandering facilitates creativity. However, it also showed that mindfulness-induced group reported fewer but more diverse mind wandering experiences, such as intentional or unintentional and aware or unaware mind wandering, than the mind wandering-prone group. Mindfulness induced tasks often involve breath-counting meditation (Ren et al., 2011) and a body scan practice (Rummel et al, 2021) to promote a state of relaxation and reduce cognitive load. Mindfulness practices typically train participants to control their attention and focus on the present moment, which may help them maintain a level of awareness that prevents their thoughts from drifting into unproductive or distracting avenues during the incubation period. This heightened awareness and more selective diversity in the mind wandering experiences that do occur may allow for a wider range of ideas to emerge, together contributing to creative thinking.

A study by Agnoli et al. (2018) exploring the role of mind wandering on creative performance and creative achievement supports the findings of Teng and Lien (2022) that the intentionality of mind wandering thoughts is important for facilitating creative performance. A divergent thinking test, an Alternative Use Task, was used to assess creative performance. The creative achievement questionnaire was used to assess creative achievement. Mind wandering was assessed by two instruments, the mind wandering-deliberate and mind wandering-spontaneous questionnaires created by Carriere et al. (2013), to capture the tendency towards mind wandering at deliberate or spontaneous levels. The results demonstrated a beneficial relationship between deliberate mind wandering and both creative performance and achievement, but no association was observed with spontaneous mind wandering. However, though the research revealed a significant effect of this specific type of mind wandering on divergent thinking, investigation of mind wandering at the trait level, solely relying on self-report questionnaires, limits the ability to confirm the consistency of mind wandering across various contexts and relies heavily on retrospective memory. Thus, integrating thought probes into a cognitive task like the 0-back task could potentially effectively capture participants' ongoing thoughts while engaged in a task and maintain the ecological validity of the experimental setup, allowing for real-time assessment of mind wandering. The present study used such an approach.

4.1.2 Theories of incubation effects

Turning to the underlying mechanism of incubation, there are three main hypotheses. The first is the intermittent work hypothesis, which proposes that participants might consciously think of original problems despite being involved in an interpolated task during the incubation period to gradually find a possible solution. According to this hypothesis, if participants were intermittently working on the previous problems during incubation, their performance on the interpolated task should be impaired due to the distraction. Gilhooly et al. (2012) used a divergent task with two groups, one having delayed incubation periods and the other having immediate incubation periods. In the delayed incubation condition, participants initially worked on divergent tasks, were interrupted to do the incubation task, then returned to work on the divergent task. In the immediate incubation condition, participants were given instructions on the divergent task, then immediately took the same incubation task during the incubation period, and then worked on the divergent task. The duration of task work of both conditions was same, except the sequence of tasks. Results showed no significant differences in performance on either the rotation or anagram tasks (i.e., interpolated tasks) during incubation periods compared to the control group (i.e., the group having immediate incubation periods), suggesting that the intermittent work did not cause the impairment of interpolated tasks. The absence of impairments contradicts the expectations of the intermittent work hypothesis.

A second hypothesis, beneficial forgetting, was initially observed in the study of Smith (1995), suggesting that participants were more likely to solve problems when they forgot misleading cues. The argument is that forgetting misleading information during the incubation period facilitates problem-solving, in turn contributing to the incubation effect. Segal (2004) claimed that the break offered participants a new opportunity to reorganise their thoughts about problems. In Segal's study (2004), results further indicated that no matter how short (4 minutes) or long (12 minutes) the break, both improved performance on creative problems. The finding contradicts the predictions of beneficial forgetting. Since the more time is provided, the more opportunities participants should have to forget the misleading information.

A third hypothesis is the unconscious work hypothesis, in which the incubation effect occurs due to unconscious work during incubation periods. Dijksterhuis and Meurs (2006) offered two conditions for participants to create as many new pasta names as possible: one immediate condition in which they completed the task immediately in one minute after reading the instruction, and the other unconscious condition in which, after reading the instruction, they were initially asked to complete a distractor task for three minutes, then were given one minute to list the names. Results showed that participants in the unconscious condition reported more names compared to those in the immediate condition; thus, Dijksterhuis and Meurs revealed the beneficial role of unconscious thought in novel idea generation.

Gilhooly et al. (2012) employed the same experimental structure, offering three conditions: delayed condition (i.e., participants worked on creative task before giving an incubation task, then returned to the creative task), immediate condition (i.e., participants completed the incubation task immediately after giving the instructions on creative task, followed by uninterrupted work on the creative task), and control condition (i.e., participants in this condition worked on creative task without incubation period). However, they failed to find similar findings. The results showed that participants creative performances in both immediate and delayed conditions outperformed those in the control condition, and the immediate condition produced better performance than the delayed condition. It is noted that providing instructions in an immediate condition means letting participants know the requirements of tasks rather than doing tasks, so it is unclear if they had a task-relevant goal or attempted to be creative. Neither the beneficial forgetting hypothesis nor the intermittent work hypothesis seems to be applicable in the results of the immediate condition. In this case, the misleading information did not exist, and there was no impaired performance on the incubation task either. The possible explanation for the performances in immediate conditions only lies in the unconscious work hypothesis.

In essence, the study aimed to empirically explore the relationship between mind wandering, its subtypes, and their different effects on divergent thinking. Investigating specific types of mind wandering may help explain discrepancies in results between previous studies and provide a better understanding of when and how mind wandering enhances creativity. The present study, therefore, measured the relationship between incubation and the subtypes of mind wandering rather than simple mind wandering per se. To better understand the complex nature of mind wandering and its function in the creative process, this study explored these effects within the context of an ostensibly easy cognitive task. To observe the same incubation benefits as in the study of Baird et al. (2012), the 0-back task was employed rather than complicated tasks requiring intensive attention.

The choice to continue employing the 0-back task in this study was influenced by several factors. Firstly, low demanding tasks, such as 0-back tasks are more likely to promote creative thoughts (Sio & Ormerod, 2009). The 0-back task is well-established cognitive task for its low cognitive load, and its prevalence provides comparability across studies. Secondly, although the 0-back may have matched participants optimal knowledge level in Study 2, resulting in a low incidence of mind wandering, some individuals nonetheless experienced mind wandering while completing the task. Furthermore, in Study 2, the combination of the 0-back and 2-back tasks with complex span tasks may have led to its perceived difficulty being greater, despite its essentially simple nature. However, in this study, there was no such context to colour perceptions. This lack of additional tasks may have allowed participants to perceive the 0-back task as less challenging, potentially influencing their engagement differently compared to Study 2. This disparity between task complexity and perceived difficulty may have significance for the incidence of mind wandering and its influence on creative problem-solving, therefore allowing the 0-back task's ongoing use in this study.

The incubation length was set to last approximately 15 minutes. Several reasons contributed to the selection of this time period. First, it was consistent with the duration of the 0-back task, which occupied the entire incubation period. This ensured that participants were focused on the tasks during the incubation period, reducing possible distractions from the experimental condition. Second, the decision to choose this setting was based on two reviews: a review by Dodds et al. (2003) and a meta-analytic review by Sio and Ormerod (2009). These two reviews both acknowledge the relevance of the duration of the incubation period in incubation effects, which indicates that there are various observable trends when considering the impact of time length. Studies that use incubation periods of less than 15 minutes show minimal change in performance that can be attributed to the duration. Furthermore, these reviews suggested that when the incubation period has gone on for more than 15 minutes, a clear pattern emerges: performance tends to get better with time up to the

30-minute point, after which it starts to become worse until the hour point. The study attempted to capture the point at which performance was expected to stabilise by sticking to the 15-minute interval. Instead of using questionnaires to assess the trait level of mind wandering, thought probes were employed to measure frequency of the two dimensions of mind wandering: mind wandering with awareness and mind wandering without awareness. This distinction is important because it reflects different levels of cognitive engagement and has been shown to influence task performance in distinct way. Study 2 demonstrated that mind wandering with awareness was more frequent than mind wandering without awareness during the N-back task. For the creativity test, the UUT was chosen as a divergent thinking task since it is a classical task involving the development of ideas.

The underlying expectation was that mind wandering in general hinders the generation of creative ideas while engaging in 0-back tasks. As the research noted above suggests, though, mind wandering with awareness might be helpful in creative problem solving; conversely, mind wandering without awareness does not contribute positively to this process. The two types of mind wandering episodes seem to work in opposite directions, implying a potential cancelling out of effects. However, since the findings in Study 2 showed that mind wandering with awareness was more common than mind wandering without awareness, the positive impact of the more frequent mind wandering with awareness was expected to outweigh the neutral impact of mind wandering without awareness, leading to an overall positive but diluted effect. This was our primary hypothesis. The secondary prediction was that there would therefore be a stronger positive relationship between creative performance and mind wandering accompanied by increased awareness, and conversely, a zero or negative, if it disrupted productive reflection – relationship between mind wandering without awareness and creative performance. This idea stems from the perception that divergent thinking requires focused attention and cognitive engagement. When the mind wanders without awareness, an individual may become disorientated and disengaged from the task being undertaken. This disengagement from the problem-solving process might hinder the ability to generate original solutions.

4.2 Method

4.2.1 Participants

A power analysis was performed to ascertain an appropriate sample size, which revealed that with 84 individuals it would be possible to detect medium-sized effects with the required statistical power of 0.8, assuring robustness and dependability in the study's conclusions. Eight-five participants (Mean age = 33.68; SD = 12.69), of whom 40 were females were recruited from two different institutions located in the east of China. One of the institutions was a renowned university, where participants were recruited through advertisements via student groups, who shown a keen interest in taking part in research projects. The second institution was an enterprise that provided training in the preparation of fruit and vegetable juices, from which participants were recruited through their network of staff who also showed a willingness to engage in research studies. Participants’ eligibility was determined based on their willingness to participate in the tasks and the lack of any history of cognitive impairments or neurological illness. This criterion-based selection process aimed to minimise potential confounding factors by ensuring that the recruited participants possessed the necessary cognitive capacity and health status for the successful completion of the study’s tasks. This recruitment produced a sample not only from varied work units, but also from diverse backgrounds and experiences, which improved the generalizability of the study. Prior to their enrolment in the research, every individual was provided with detailed particulars regarding the objectives and methodologies of the investigation, along with informed consent that highlighted their choice regarding participation and guaranteed anonymity. The study was approved by the UCL Institute of Education Research Ethics Committee.

4.2.2. Design

This study was paired with Study 4, which is detailed in Chapter 5. Both studies shared similar structure and employed the same group of participants. To prevent the risk of practice effects systematically influencing the results of Study 4, the order in which participants engaged in the two studies was counterbalanced. This involved having half of the participants complete the current study first and the other half complete Study 4, thereby ensuring that any practice effects would be evenly distributed across both studies.

4.2.3 Materials

Divergent thinking: UUT

In the original UUT task, participants were presented with a set of everyday objects, such as bricks, newspapers, spoon and were encouraged to generate as many potential non-standard uses as possible for each item within a specified time limit (Guilford, 1967). In this instance, they were given six minutes to complete the baseline task, encompassing two UUT items: a brick and a plastic bottle. The post-incubation task contained the two UUT items presented in the baseline task and two new UUT items (newspapers and a pair of chopsticks) with twelve minutes to complete the task. Employing both novel and repeated items facilitated the separation of general effects resulting from task practice or familiarity from the specific effects potentially induced by mind wandering occurrences during the incubation period. Improved performance on novel items compared to the baseline would suggest practice effects, while improvement on repeated items only would suggest incubation effects.

In terms of scoring, the majority of the research described above used the originality grading system. There are two ways to assess originality, including an objective and a subjective method. The objective technique is based on the statistical probability of each response in the research sample. Researchers utilise statistical methods to find responses that are particularly unusual by looking at how frequently responses occur within the set of participants. Since they deviate from the regular replies provided by research participants, these less frequent responses are seen as being more unique.

Studies have employed continuous frequency-based scores (Forthmann et al. 2017) or those responses given by less than 5%, 10%, or 20% of the study sample (Plucker et al., 2014). Subjective scoring involves expert or rater evaluation of the quality and creativity of the generated ideas. It depends on the judgment of persons who evaluate responses in accordance with particular standards, occasionally using a Likert-type scale (Silvia et al. 2008). Subjective scoring is frequently more time-consuming since experienced raters who understand the scoring standards are required. Based on the circumstances of this study, the objective scoring method is a suitable choice for measuring divergent thinking because of its advantages in terms of objectivity, consistency, and efficiency. By using predetermined criteria, objective scoring ensures that judgments are consistent and less prone to personal prejudice. Furthermore, Plucker et al. (2014) did a comparison of objective and subjective scoring methods in the assessment of divergent thinking, and the results showed that the objective method (i.e., counting the number of responses provided by less than 20% of the sample) performed well in terms of reliability and validity (convergent and predictive).

This study replicated the scoring method used in Plucker et al.'s study to measure the UUT performance. In this case, the threshold for what constituted an uncommon or rare response was set at a response provided by less than 20% of the total sample of participants. For each idea generated by a participant, a count was made of the number of participants in the entire sample who provided same idea. If the number of participants who generated a particular idea was less than 20% of the total sample size, that idea was considered an uncommon or rare response, and the person was awarded one point for it; they got no points for any other responses. The total number of ideas that met the requirements of being uncommon or rare responses was then calculated. A higher count of original ideas indicated that a participant had produced a greater number of rare and less commonly generated responses, and they thus got higher scores. A separate measure of the overall number of responses produced – that is, fluency – was also used to check whether incubation affected fluency as well as or instead of originality.

Most of the aforementioned studies used an improvement in the scoring index as their measure of improving UUT. Improvement on UUT in repeat exposure items was calculated as (score across post-incubation repeated UUT items – score of baseline UUT)/ score of baseline UUT). Although this gives an index of proportional improvement, the formula is problematic in suppressing variance, particularly at the top end of the scale. For instance, if a participant starts with a score of 5 and another with a score of 20, and they both improve by 5, it might appear that the participant who started with 5 and doubled their score performed better than the person who started with 20, and proportional improvement scores reflect this, at the expense of progressively compressing variance in improvement as the baseline gets higher. However, from another perspective, it might be argued that in both these cases participants improved the same amount if baseline and improvement scores are unrelated. Furthermore, proportional improvement scores cannot be calculated in the situation where the baseline score is zero, since dividing by zero is not possible. In order to avoid this, a small nonzero value can be added to the baseline score, but this is arbitrary and therefore still problematic. To address these issues, it was decided to look at the values that simply represented the raw improvement in performance for both originality and fluency. That is, the study examined the degree to which participants' scores improved over their starting point.

0-back task

The 0-back task used in this study was identical to the one used in Study 2. Participants were instructed to respond when current stimulus matched a predefined target stimulus and their behavioural indices were monitored, including reaction time and accuracy rate. This task took approximately 15 minutes.

Thought probes

The thought probes were identical to those used in Study 2. Participants were given a thought probe during the 0-back task to determine the nature of their mind wandering. The probes were presented 15 times at variable intervals, so participants could not anticipate when they were actually going to happen. They were then given five options to choose from as most relevant to their current condition: (1) attention to the task at hand, (2) external distraction, (3) task-related reasoning, (4) mind wandering without awareness, and (5) mind wandering with awareness. Option 1 was marked as being on task, option 2 as having external distractors, option 3 as having task related interference, and option 4 and 5 as having mind wandering.

4.2.4 Procedure

The study was conducted in person. Participants were first asked to complete two UUT problems, as a baseline, in which they were requested to list as many unusual uses as possible for two problems within 6 minutes. The two problems were presented in a fixed order, and participants had the option of allocating a different length of time to each problem. This baseline measure worked as a reference point for evaluating creative performance. After completing the baseline tasks, there was an incubation period during which they were engaged in the 0-back task with thought probes. Participants then completed four UUT problems, including those previously encountered during the baseline phase (repeated exposure) and two novel problems presented for the first time (new exposure). They were given 12 minutes to generate as many as possible ideas as they could for the four items. That is, participants had a block of time allocated, with 6 minutes each for a repeated block (i.e., two repeated problem) and a novel block (i.e., two new problems). Within these blocks, participants had the flexibility to divided this time as they preferred between the two types of problems. Instructions and examples were written on a sheet of paper, with two versions, digital and paper. As some participants were not confident with their typing skill, they were allowed to choose one of the two versions to write their responses in order to avoid compromising their performance in the limited time available. To control for potential order effects, counterbalancing of problem types was employed.

4.2.5 Analysis plan

This study investigated the relationship between mind wandering and divergent thinking, in particular the UUT task. First of all, measures of improvement from baseline to post-incubation were examined for the repeated and novel items using the approach outlined in the materials section. The improvement differences between repeated and novel conditions were then compared using the t-test to explore the role of incubation effects. T-tests were also used to compare the performance on the 0-back task and incidence of mind wandering between the present study and Study 2, in order to check how far these were similar. Correlational analyses were then conducted to explore the association between mind wandering and various indicators of UUT performance, including originality scores, fluency scores, and improvement over baseline. These analyses were grouped by different exposure conditions (repeated and new exposure) and types of mind wandering. In this study, multiple t-tests were used to examine changes in performance relative to baseline for repeated and novel items, as well as to compare the improvement between these conditions. The use of ANOVA was not feasible for this purpose because the baseline values were identical for both repeated and novel items. Analysing both conditions simultaneously in an ANOVA would have effectively duplicated the baseline data, rendering the analysis invalid.

Similarly, there was no reasonable alternative to use of multiple bivariate correlations to examine the relationships of interest. The use of Bonferroni corrections for these analyses was inappropriate. First of all, the risk of inflated Type 1 error is usually taken only to apply to tests within a family, and it is debatable how far the reported tests are actually part of the same family, since they rarely share an error term. Beyond this, there is a substantial literature from various scientific fields supporting the notion that multiple comparisons without corrections are appropriate for exploratory studies – as here – since they help avoid the risk of missing potentially important findings through Type 2 statistical errors (e.g. Bender & Lange, 2001; Li et al., 2017; Roback & Askins, 2005; Rubin, 2017). Therefore, t-tests and correlations without corrections were the most appropriate method for examining changes within each items types separately and for comparing the extent of change between them.

4.3 Results

4.3.1 Preliminary analyses

Since participants were split between occupation (students vs. others) and response mode (digital vs. paper-pencil), preliminary checks were conducted to determine whether these factors influenced performance. It was necessary to assess each other factor independently, since both response mode and occupation were unevenly distributed across participants groups (see Table 4.1 for details).

Table 4.1 Response mode by occupation of participants

Format	Digital	Paper-pencil
Student	22	3
Others	39	21

There was no significant difference between the two response modes in baseline divergent thinking performance, including both fluency ($U = 668.5$, $p > 0.05$) and originality ($U = 647.5$, $p > 0.05$; Mann-Whitney was used because of non-normality). Similarly, no significant differences were found in post-incubation performance, with fluency ($t\ (83) = -0.33$, $p > 0.05$) and originality ($t\ (83) = -0.90$, $p > 0.05$). A t-test on mind wandering also showed no differences between response modes ($t\ (83) = 0.85$, $p > 0.05$, $d = 0.21$). Furthermore, correlational analyses revealed no difference in relationship between mind wandering and post-incubation divergent thinking performance between digital (fluency: $r = 0.07$, $p > 0.05$; originality: $r = -0.07$, $p > 0.05$) and paper-pencil (fluency: $r = 0.14$, $p > 0.05$; originality: $r = -0.07$, $p > 0.05$) response formats.

Similarly, no significant differences were found between students and other workers in baseline divergent thinking performance (fluency: $t(83) = -0.31$, $p > 0.05$; originality: $t(83) = -0.55$, $p > 0.05$) or post-incubation performance (fluency: $t(83) = -0.33$, $p > 0.05$; originality: $t(83) = -0.90$, $p > 0.05$). Mind wandering also did not differ between these groups ($U = 831.50$, $p > 0.05$). Correlational analyses indicated no difference in association between mind wandering and post-incubation divergent thinking performance for either students (fluency: $r = 0.003$, $p > 0.05$; originality: $r = 0.02$, $p > 0.05$) or other workers (fluency: $r = -0.20$, $p > 0.05$; originality: $r = -0.19$, $p > 0.05$). Since neither response mode nor occupation influenced overall outcomes, these factors were discounted from further consideration in subsequent analyses.

4.3.2 UUT performance

UUT performance was measured using two indicators: fluency scores - the total number of responses and originality scores (see Table 4.2 and Table 4.3 for details). In terms of fluency, there was significant increase between baseline and post-incubation in fluency scores under repeated exposure condition, $t(84) = -9.53$, $p = 0.001$, $d = 1.33$. Similarly, there was a significant increase between the two variables for the new items, $t(84) = -4.35$, $p = 0.001$, $d = 1.67$. A correlation was conducted to examine the relationship between baseline scores and raw improvement scores. The results did not show a correlation between baseline and raw improvement scores in repeated and new exposure condition ($r(83) = 0.03$, $p = 0.81$; $r(83) = -0.12$, $p = 0.27$, respectively). Raw improvement on UUT in repeat exposure items was significantly different from improvement in new exposure items ($t(84) = 2.79$, $p = 0.06$, $d = 3.88$). The improvement in the new exposure condition ($M = 1.58$, $SD = 3.34$), was lower than in the repeated exposure condition ($M = 2.75$, $SD = 2.66$).

In terms of originality, the scores differed significantly between baseline and post-incubation for the repeated items, $t(84) = -10.16$, $p = 0.001$, $d = 0.82$, and for the new items, $t(84) = -4.73$, $p = 0.001$, $d = 1.30$. A correlation was also conducted for the associations between baseline scores and improvement scores, and it showed nonsignificant corelations between them in both repeated and new exposure conditions, $r(83) = -0.08$, $p = 0.48$; $r(83) = -0.20$, $p = 0.07$, respectively. Compared to the baseline scores, the improvement in originality scores for the repeated exposure problems ($M = 1.81$, $SD = 1.64$) did not differ significantly from the improvement scores for the new exposure problems ($M = 1.33$, $SD = 2.59$), $t(84) = 1.59$, $p = 0.12$, $d = 2.81$.

The correlation between the baseline and improvement scores supported the decision to use raw change scores as the index of improvement, since a nonsignificant correlation suggests that the amount of improvement was not related to the baseline score. Thereby, the use of raw improvement scores reflects pure change without being influenced by initial performance levels to avoid the potential biases introduced by proportional calculations, especially when baseline scores vary widely. The results indicated that creative performance improved in both repeated and new exposure items. However, the degree of progress varied across the two conditions, particularly in terms of fluency scores. There was a significant difference in fluency scores at baseline and after incubation for repeated and novel exposure items. The improvement in fluency scores was greater with repeat exposure items compared to new exposure items, and the relationship is close enough to suggest a potential trend, consistent with an incubation effect. The originality scores of the repeat and new questions differed considerably between baseline and post-initiation, as did the fluency scores, but there was no significant difference in the improvement in originality scores between the two types of items, indicating that effects here more in keeping with the impact of prior exposure to the task.

Table 4.2 The fluency scores at baseline and post-incubation stages

Baseline fluency scores	Post-incubation fluency scores	
	Repeated exposure	New exposure
7.71	10.46**	9.28**

Footnote: **p<0.001.

Table 4.3 The originality scores at baseline and post-incubation stages

Baseline originality scores	Post-incubation originality scores	
	Repeated exposure	New exposure
6.55	8.36**	7.88**

Footnote: **p<0.001.

4.3.2 0-back task performance

Compared to Study 2 (M = 0.98 SD = 0.04), the accuracy rate on the 0-back task was slightly lower (M = 0.96 SD = 0.08), but there was no significant difference between the two, t (116) =-1.43, p = 0.16, d = 0.07. Participants in the present 0-back task (M = 625.43 SD = 298.01) showed slightly faster reaction time than the previous Study 2 (M = 681.94 SD = 181.09). However, there was again no significant difference between the two, t (116) = -1.68, p = 0.10, d = 193.49. The hit rate in the present task (M = 0.87, SD = 0.14), differed significantly from that in Study 2 (M = 0.93, SD = 0.07), t (116) = 2.10, p = 0.04, d = 0.58. The false alarm rate in the present task (M = 0.026, SD = 0.09) did not differ from that in Study 2 (M = 0.001, SD = 0.003), t (116) = -1.58, p = 0.12, d =

0.07. The results suggest that participants in the present task had lower sensitivity to relevant stimuli compared to those in Study 2, but they also had a similar tendency to respond to irrelevant stimuli. That is, the group in the present study had a more cautious approach to responding to stimuli. Conversely, the group in Study 2 was better at correctly identifying target stimuli.

4.3.3 Mind wandering

Participants in the present 0-back task reported slightly fewer mind wandering episodes (M = 0.13 SD = 0.19) than did participants in Study 2 (M = 0.14 SD = 0.26). However, there was no significant difference between the two studies, t (116) = -0.42, p = 0.67, d = 0.21. For the subtypes of mind wandering, participants in the present study reported significantly less mind wandering with awareness (M = 0.09 SD = 0.14) than did participants in study 2 (M = 0.18 SD = 0.26), t (116) = -2.38, p = 0.02, d = 0.19. Participants also exhibited greater mind wandering without awareness (M = 0.04 SD = 0.09) compared to those in Study 2 (M = 0.002 SD = 0.01), t (116) = 2.26, p = 0.03, d = 0.07. Mind wandering with awareness was nevertheless more common than mind wandering without awareness.

4.3.4 The correlation of UUT performance and different mind wandering types

Repeated exposure condition

There were no statistically significant associations found between mind wandering and overall originality scores in repeated exposure items ($r = -0.15$, $p = 0.17$; see Table 4.3 for details), regardless of whether it was with awareness ($r = -0.09$, $p = 0.39$), or without awareness ($r = -0.17$, $p = 0.12$). Similarly, there were no significant correlations between mind wandering and improvement in originality scores for repeated exposure items, regardless of type of mind wandering: overall mind wandering ($r = -0.02$, $p = 0.85$); with awareness ($r = 0.02$, $p = 0.89$); or without awareness ($r = -0.07$, $p = 0.53$).

Additionally, no statistically significant associations were observed between mind wandering and overall fluency scores for repeated exposure items (overall mind wandering: $r = -0.11$, $p = 0.29$; with awareness: $r = -0.08$, $p = 0.47$; without awareness: $r = -0.12$, $p = 0.29$). Lastly, regardless of mind wandering types, there were no significant correlations found between mind wandering and the improvement in fluency scores in repeated exposure items: for the 0-back task, mind wandering overall ($r = -0.02$, $p = 0.87$), with awareness ($r = 0.002$, $p = 0.98$), or without awareness ($r = -0.04$, $p = 0.69$).

New exposure condition

There was no statistically significant association between originality scores for new exposure items and mind wandering types, regardless of whether it was overall mind wandering ($r = -0.06$, $p = 0.56$), with awareness ($r = -0.03$, $p = 0.79$), or without awareness ($r = -0.09$, $p = 0.40$). Likewise, no significant relationships were observed between mind wandering and improvement in originality scores for new exposure items ($r = 0.06$, $p = 0.58$), with awareness ($r = 0.07$, $p = 0.53$), or without awareness ($r = 0.02$, $p = 0.88$).

There was no statistically significant association ($r = -0.003$, $p = 0.98$) between fluency scores for new exposure items and mind wandering. The association between fluency scores and mind wandering with awareness was similarly not significant ($r = 0.03$, $p = 0.76$). Similarly, there was no significant association between fluency scores and mind wandering without awareness during the 0-back task ($r = -0.06$, $p = 0.57$). Additionally, regardless of mind wandering types, there was no statistically significant association between improvement in fluency scores in new exposure items and mind wandering overall ($r = 0.12$, $p = 0.29$), with awareness ($r = 0.14$, $p = 0.21$), or without awareness

($r = 0.02$, $p = 0.83$), during the 0-back task.

There was therefore no significant association between mind wandering and any aspect of UUT task performance. Specifically, the occurrence of mind wandering or types of it did not influence participants' originality performance or its improvement under either exposure conditions. Similarly, mind wandering did not influence fluency scores or their improvement under either exposure conditions. The results imply that, at least within the context of the study, mind wandering may not be a reliable predictor of the effectiveness of incubation in promoting creative problem-solving.

Table 4.4 The results of UUT performance and different mind wandering types

		Mind wandering	Mind wandering with awareness	Mind wandering without awareness
Repeated exposure condition	Originality scores	r=-0.15, p=0.17	r=-0.09, p=0.39	r=-0.17, p=0.12
	Improvement of originality scores over baseline	r=0.02, p = 0.85	r=0.02, p = 0.89	r=-0.07, p= 0.53
	Fluency score	r=-0.11, p=0.29	r=-0.08, p=0.47	r=-0.12, p=0.29
	Improvement of fluency scores over baseline	r=-0.02, p= 0.87	r=0.002, p=0.98	r=-0.04, p= 0.69
New exposure condition	Originality scores	r=-0.06, p=0.56	r=-0.03, p=0.79	r=-0.09, p=0.40
	Improvement of originality scores over baseline	r=0.06, p = 0.58	r=0.07, p = 0.53	r=0.02, p = 0.88
	Fluency scores	r=-0.003, p=0.98	r=0.03, p=0.76	r=-0.06, p=0.57
	Improvement of fluency scores over baseline	r=0.12, p = 0.29	r=0.14, p = 0.21	r=0.02, p = 0.83

4.4 Discussion

This study investigated the incubation effects under a low-demanding setting to clarify the inconsistent link between mind wandering and incubation effects on divergent creativity. It also investigated how various elements of mind wandering during incubation might predict the incubation effects. The study also contrasted participants' performance in a prior 0-back task (Study 2) and assessed the impact on performance of various factors, such as filler task performance (e.g., response time and accuracy rate), mind wandering frequency, and mind wandering subtypes.

The accuracy rate in the 0-back task was slightly lower in the present study, however this difference was not statistically significant, according to the comparison of filler task performance between Study 2 and the present investigation. Additionally, participants in the current research showed somewhat quicker reaction times than those in Study 2, but once more, this difference failed to achieve statistical significance. These results imply that individuals' fundamental cognitive performances in the 0-back task were consistent between the two investigations. This is a side indication that the frequency of mind wandering should not change (Thomson at al., 2014). In terms of frequency of mind wandering, the results showed that participants in the current study reported somewhat less mind wandering than those in Study 2, however this difference was not statistically significant. This finding implies that the total occurrence of mind wandering during the 0-back task was comparable in both experiments.

The analysis of originality scores for repeated exposure problems and new exposure problems did not reveal a significant difference between them. This suggests that, in this particular experimental context, the incubation effects may not play a substantial role in divergent creativity, and that what was observed was primarily the effects of practice. In line with this, there was no significant correlation between mind wandering frequency and subsequent creative problem-solving. It should be noted, though, that the subtypes of mind wandering varied during the 0-back task. In comparison to Study 2, participants in this study reported considerably fewer mind wandering with awareness but significantly greater mind wandering without awareness.

4.4.1 Factors contributing to lack of effects

The present study on incubation effects had similar procedures to those of Baird et al. (2012). Use was made of incubation periods, during which participants worked on the 0-back task, serving as offering a relatively undemanding condition. Although the incubation tasks were very similar across studies, a discrepancy emerged in participants' behaviour and performance during the incubation periods. Specifically, the accuracy of the 0-back task in the present study was markedly higher, at 0.96, whereas Baird et al. had a lower accuracy of 0.87, which might potentially suggest that participants in this study were more focused on performing the task compared to those in Baird et al.'s study. Those studies that failed to find that the incubation effect had similar or better performance in the incubation tasks to the present task. Steindorf et al. (2021) and Murray et al. (2021) also used the 0-back task as the incubation interval, and their reported accuracies were approximately 0.93 and 0.91, respectively. The similarity in accuracy rate across these studies was taken to indicate that participants were able to sustain their attention on the 0-back task even engaging in mind wandering episodes. Following the sustained task performance during incubation intervals, it is noteworthy that none of these studies demonstrated a subsequent enhancement in performance on creative tasks.

If participants were highly engaged in the incubation task, it is conceivable that a significant portion of their cognitive resources would be allocated to this task, potentially leaving limited resources available for engaging in creative thinking during the incubation period. This limits the potential for creative problem-solving strategies to emerge, which might result in the absence of incubation effects. Furthermore, if participants perceived the incubation task as requiring their full attention, they might be less inclined to engage in mind wandering, even if it is possible to associate it with creative thinking. This observation suggests a potential competition between mind wandering associated with creative processing and the cognitive resources required for sustained engagement with the incubation task. Such competition might explain why participants in studies like the present and Murray et al. (2021) showed high accuracy on the 0-back task but did not show evidence of increased creativity.

Extending this argument, the incubation task used in the present study was the 0-back task, where stimuli were a series of letter rather than spatial locations and participants were instructed to respond to particular target stimuli instead of those in a specific location. Due to the types of stimuli and criterion for target response, the present incubation task therefore focused on verbal processing. Since the present divergent task required participants to list the different functions of given object, the creative task was also verbal. The similarity in processing resources between the incubation and the creative tasks could potentially be significant when considering the role of mind wandering in creative cognition. If the assumption that mind wandering or creative processing and the incubation task are competing for the same cognitive resources is right, it is worth considering the possibility that participants may be able to engage in both activities simultaneously without direct interference while creative processing and the incubation task are drawing on different cognitive domains. Specifically, participants would allocate verbal resources to engage in creative processing, such as verbalising thoughts, while allocating spatial resources to perform the incubation task. In this conceptualization, creative processing and incubation tasks may interact collaboratively, with each process benefiting from the involvement of the other rather than competing for resources. For example, engaging in a spatial incubation task may facilitate verbalising creative ideas.

Further support for this assumption is provided by the findings of Gilhooly, Georgiou, and Devery (2013), who conducted a study investigating the impact of varying incubation tasks, with verbal (i.e., working on anagrams solving) and spatial (i.e., working in mental rotations) versions on creative tasks. There were two types of creative tasks: the verbal alternative use task and the spatial mental synthesis task. The results revealed an interaction between the incubation task type and the creative task type. Specifically, a spatial incubation task was found to enhance performance on a verbal creative task more than a spatial creative task, whereas a verbal incubation task had a positive effect on performance on a spatial creative task compared to a verbal creative task. These results are consistent with the assumption about the relationship between incubation tasks and creative tasks. When incubation tasks (e.g., verbal processing) and creative tasks (e.g., spatial processing) utilise different resources, the two activities could be performed with minimal interference. However, if both tasks utilise the same cognitive resources (e.g., verbal processing in both tasks), interference and competition for resources are more likely to occur. In this case, participants may have difficulty allocating resources efficiently to both tasks, resulting in decreased performance in incubation tasks or impaired creative outcomes. It is possible that the most efficient condition for observing incubation effects is to use non-overlapping resources in both incubation tasks and creative tasks.

Given that the incubation task in these aforementioned studies lacking incubation effects appears to consume lower cognitive resources, overall, one could also speculate that participants had high motivation for performing well in the incubation task. Studies have indicated that motivation and mind wandering during a task are significantly associated (Kawagoe, Onoda, & Yamaguchi, 2020; Seli et al., 2019). Participants with a higher level of motivation towards the ongoing task experience less mind wandering and better performance. Nevertheless, Brosowsky et al. (2020)

offered another perspective on the relationship between motivation and mind wandering in a study during which participants were given the metronome response task and responded to thought probes into the depth of mind wandering. In the metronome response task, participants were asked to press buttons each time an auditory stimulus appeared. Participants were also required to rate their current state on a sliding scale ranging from 0 (indicating not at all mind wandering) to 100 (indicating fully mind wandering), as well as their motivation level by selecting one of five options ranging from non-motivated to highly motivated. The results revealed an interaction between motivation and the depth of mind wandering in influencing task performance. Specifically, when participants were highly motivated, the depth of mind wandering did not impact task performance. Conversely, when motivation was low, the depth of mind wandering was negatively associated with task performance.

However, motivation levels may be of little consequence when attention is fully engaged in a task for other reasons, and its additional impact on performance may be limited. Based on the results, the accuracy of the 0-back task in the present study was not significantly different from that in Study 2, where it was concluded that participants felt an obligation to take the task seriously. Participants in the present study seemed to deeply engage in the task, possibly for the same reason. Consequentially, there might be little room for additional performance enhancement from heightened motivation.

4.4.2 Conclusion

The study investigated the incubation effect using the 0-back task as an incubation interval and found high engagement among participants, as observed from their accuracy rate on the task. Perhaps as a result of this engagement, there was no observable function for mind wandering or incubation in creativity, suggesting that the cognitive resources allocated to the incubation task may have limited creative processing. The task primarily focused on verbal processing, potentially influencing creative processes, which also involved verbal processing. Previous research suggests that drawing on different cognitive resources for incubation tasks and creative tasks may result in a stronger incubation effect mediated by mind wandering. Furthermore, motivation may play a role in the relationship between mind wandering and divergent thinking where engagement is not naturally high, with higher motivation possibly reducing the impact of mind wandering.

5. Chapter five: Examining the role of mind wandering in convergent thinking

In this chapter, the influence of mind wandering on convergent thinking is under investigation. Building on the same experimental structure and sample employed in Study 3, there is a comparison analysis between convergent thinking and divergent thinking. The used convergent thinking task – compound remote associates test, with items dividing into vary difficulty levels, identifies the appropriate context for the incubation effect.

5.1 Introduction

Early research found that convergent thinking, particularly in the Remote Associates Test (RAT), corresponds with intelligence (Kaufman et al., 2011; Lee & Therriault, 2013). The ability to establish remote associations between presented words and find an identified single word as a solution to a problem is required for this test. For example, in the RAT, if the three words are 'cottage','swiss' and ‘cake’, the correct answer would be ‘cheese’ since it forms common associations with all three words (cottage cheese, swiss cheese, cheesecake). It has been assumed that the ability to do well in RAT is related to cognitive skills such as logical thinking, pattern identification, and the ability to focus attention on pertinent information (Cushen & Wiley, 2018; Ellis et al., 2021). Apart from this, the cognitive skills involved in RAT performance may include executive functions in decision making and maintaining attention to relevant information (Ricks et al. 2006; Ellis et al., 2021).

There may be more involved, however. The incubation effect, a phenomenon in which a time of rest or distraction leads to enhanced problem-solving after returning to the activity (Sio & Ormerod, 2009), has been studied to some extent within the field of convergent thinking. Segal (2004) found that working continuously for a given time frame was less efficient than taking a distracting break during the process of solving convergent thinking problems. In this study, participants were given a mathematics problem to solve within 20 minutes, then they divided into break and no-break groups. The employed mathematics problems had specific correct answers and involved well-defined rules, making them a type of convergent thinking test. In the break condition, participants worked on a crossword puzzle or reading newspapers. In the no-break condition, they continued to work on the problem. The results showed that the break group outperformed the no-break group in the problem-solving. Segal further proposed that the break functioned as a possibility for participants for reorganise their thoughts.

Another existing test for convergent problem solving research is based on the RAT. Kohn (2007) used the digit monitoring task to manipulate the attention levels engaged during the incubation to investigate the optimal condition for the incubation effect on RAT problems. In the Digit Monitoring Task, participants were required to monitor and count occurrences of odd numbers in sequences of specific lengths. For example, a sequence of numbers was presented, 4, 3, 5, 2, 7, 3, 5, 8, 6. In the low condition, participants needed to count the occurrence of two odd numbers that appeared together, in this case, the count was three (i.e., 3, 5 first occurrence, 7, 3 second occurrence, and 3, 5 three occurrence). In the medium condition, they counted the number of the occurrences in which three odd numbers appeared together, in this case, the count was one (i.e., 7, 3, 5 first occurrence). Participants in the high condition counted the times where five odd numbers appeared together. The control group was not required to respond to the digit monitoring task, but only to watch it. Results showed that among the three conditions, participants in the medium condition had best performance on the RAT problems (i.e., this yielded the largest incubation effect), along with the control group. This implies that the cognitive level of task during the incubation relates to the incubation effect, and a lower cognitive demand incubation task might more benefit the occurrence of incubation relating to convergent thinking (Sio & Ormerod, 2009).

Jarosz, Colflesh, and Wiley (2012) examined other helpful factors affecting participants' performance on RAT problems, finding that reduced executive control led to improved performance. By manipulating alcohol consumption, participants had a blood alcohol content (BAC) of approximately 0.075%, placing them in a state of reduced ability to control their attention. Then, both intoxicated and sober participants were instructed to complete RAT problems. Results showed that intoxicated group had higher accuracy rate and faster reaction time than sober group during the RAT. The findings suggest that moderate alcohol use may result in less attention control or a more diffused attentional state, which might improve problem-solving ability. As a result, it is plausible to believe that in the case of convergent problem solving, mind wandering caused by executive control failure (McVay & Kane, 2010) may be advantageous to the solution. This seems to be contrary to the argument, outlined in Chapter1, that convergent thinking relies on executive control, as mind wandering would be expected to be disruptive in this situation.

5.1.1 Mind wandering and convergent thinking

Despite the growing interest in cognitive processes such as incubation and mind wandering, the majority of existing research has primarily focused on divergent thinking, leaving a gap in understanding how these factors influence convergent thinking. The studies discussed here are among the few that directly address this interplay. Tan et al. (2015) used the Number Reduction Task (NRT) to assess participants' convergent thinking. The NRT is a task in which participants are presented with a series of three digits and are required to follow specific rules to generate responses based on the digits they see. In Tan et al.'s study, three digits, like 1, 4, and 9, were given to participants. At the beginning of each trial, two digits were shown on the screen. If the two digits were the same, for example, both were 4, they had to provide the same digit as the answer; thus, the correct answer was 4 in this situation. If the two digits were different, for example, one was 1 and the other was 9, they had to provide the third remaining digit; thus, the correct answer was also 4 in this situation, but for a different reason. A new digit then appeared (e.g., one of the three digits, like 1), and participants needed to compare it to their previous answer and follow the same rules to produce the answer. This process was repeated until seven responses had been made. Each trial was completed once the final (i.e., seventh) response was submitted. There was a hidden rule in each trial: the final response was the same as the second response. That is, the final answer was the same as the second answer. There were 90 trials of the NRT before an incubation period, during which mind wandering was measured via thought probes, and 300 trials of the NRT after the incubation period. At the end of the experiment, participants were asked to describe the rules used, and those who identified the hidden rules after the incubation period were considered to have gained insights. This method straightforwardly showed whether insight was involved or not compared to other convergent thinking tasks. The results showed that participants who gained insights into the hidden rules reported more mind wandering experiences compared to those who failed to find the hidden rules during the incubation period, which suggests not only that insight was involved but that mind-wandering might play a role in convergent thinking as well as divergent thinking.

Leszczynski et al. (2017) further confirmed the positive effect of mind wandering on this form of creativity by using an alternative convergent thinking task, the Compound Remote Associate (CRA) task (Bowden & Jung-Beeman, 2003). Participants in this task were presented with sets of three words and were required to find a fourth word that could combine with each of the three given words to form a compound word or phrase. For example, in the task, if the three words are 'cream’, ‘skate’, and 'water', the fourth might be ‘ice’ because it forms compound words with all three words (ice cream, ice skate, ice water). In this study, participants were required to complete the CRA test, then performed the Sustained Attention to Response Task (SART), during which thought probes were inserted to measure mind wandering. After the SART, they continued solving the unsolved CRA problems from the first attempt. The results showed a significant positive correlation between mind wandering and post-incubation creative performance and no correlation between mind wandering and pre-incubation creative performance. It suggests that the benefits have appeared after a period of incubation, highlighting the importance of a break that permits mind wandering for subsequent creative processing.

However, Smeekens (2013) failed to find the beneficial role of mind wandering in convergent thinking. In this study, two different convergent tasks were employed, the coins problems (i.e., there are 8 coins in a picture, and participants need to identify movements to 2 coins to make sure they meet the requirement that each coin touches 3 other coins), and the pigpen task (i.e., there are nine pigs locked in a square fence, and participants need to build two further square fences to ensure that each pig is in a separate fence). In this study, participants were given one of the two convergent problems to work on for 3 minutes. Regardless of whether they solved the problem, they then completed an N-back task during which participants identified if the current item was matched with previously presented item, working as the incubation period. If participants solved the problem before the incubation period, they provided their solution after completing the N-back task. If they had not solved the problem before the incubation period, they returned to the original problem for an additional 5 minutes after the N-back task. The order of the convergent problems was counterbalanced. Half of participants solved the coins problem first, and then the pigpen problem, while the other half completed the task in reverse order. Mind wandering was measured during the N-back task using inserted thoughts probes. Results showed that there was no correlation between mind wandering frequencies and post incubation problems solution rates. This suggests that the problem type might influence incubation effects, and mind wandering may not be universally beneficial across all convergent task types. Tasks involving hidden rules (e.g., the NRT) or linguistic convergent thinking (e.g., the CRA) may benefit from mind wandering compared to spatial arrangement convergent task (e.g., coins problem and pigpen tasks).

5.1.2 The possible benefits of mind wandering

As argued in Chapter 1, it is possible that the advantage of mind wandering in creative performance results from its diffused attention-focus characteristic. A study by Kounios et al. (2008) investigated different neural activities involved in solving problems through insight (i.e., a sudden solution that solvers might be unable to report) or an analytic strategy (i.e., a strategic processing where each step gradually moves closer to the solution) through electroencephalograms (EEG) (Brown et al., 2007; Wegbreit et al., 2012). Participants who solved problems via an analytic strategy showed increased beta (13–18 Hz) frequency in their occipital lobe, reflecting increased neural activity in specific visual pathways. This indicates that they focused more narrowly on specific visual details and inhibit other information. In contrast, participants using the insight strategy had a decreased alpha (10–13 Hz) frequency, reflecting less inhibition. This suggests that under these circumstances the brain allows a broader range of information to be processed. These findings imply that individual differences in brain activity are a reflection of attentional focuses. Mind wandering is often associated with a broader attention focus, similar to the insight strategy. Meanwhile, the decreased alpha frequency in insight strategy, reflecting less inhibition, parallels the decreased inhibition seen during mind wandering. Thus, the study's findings suggest how the beneficial role of mind wandering in convergent tasks might come about.

Zedelius and Schooler (2015) provided empirical support for the relevance of mind wandering through directly examining its role with a specific focus on convergent thinking using different problem-solving strategies. In order to induce an insight strategy, before starting the CRA task, participants were instructed to emphasise intuition and avoid deliberately making mental list of words associated with words presented in the task. In contrast, in terms of analytic strategy, participants were required to systematically search for the right answer. For instance, they needed to make mental lists of words associated with the first word, attempting to list all relevant words, then moving to the second and third words. Following these specific instructions, participants were guided to adopt either an insight or analytic strategy to solve the CRA problems. Half the participants were given instruction on analytic strategy in the first block before completing the CRA task, and then they were required to use an insight strategy to solve the same number of CRA problems in the second block. The other half used the two strategies in the opposite order. The tendency to mind wander was measured by the mindful awareness and attention scale, which was a 15-item questionnaire created by Brown and Ryan (2003). The results showed that the tendency towards mind wandering was higher when participants used an insight method compared to an analytic strategy, and this tendency was positively associated with performance. However, this propensity for mind wandering was detrimental to creative performance when using an analytic strategy. Kounios et al. (2008) and Zedelius and Schooler (2015) both indicate that mind wandering supports convergent thinking, particularly for CRA problems, by promoting a broader attention focus and reduced neural inhibition, resulting in creative solutions.

5.1.3 The relationship between convergent and divergent thinking

With regard to the interplay between convergent and divergent thinking, it is hard to say whether both types of creativity work independently or together. Divergent thinking explores multiple potential ideas, while convergent thinking involves narrowing down possibilities to find a single correct solution. Despite their distinct roles, though, both offer avenues for creative exploration. Several studies have attempted to explore the interaction of divergent and convergent thinking in different settings, but none have examined the correlation between them directly. Duan et al. (2020) used the Trier Social Stress Test to investigate the effect of stress on both divergent thinking and convergent thinking. The increased stress had an effect on both divergent and convergent tasks, although in varying ways. While stress was associated with reduced flexibility in divergent thinking tasks, an indicator that shows the variety of types of response, it resulted in lower accuracy and faster reaction time in convergent thinking tasks. These findings suggest that stress can impact two types of thinking concurrently, though as the implication is that they are separable if not separate processes.

Similarly, de Vink et al. (2022) used two types of mathematical tasks: Single Solution Tasks (SST), a task that requires one solution, and Multiple Solution Tasks (MST), requiring multiple solutions, to examine the interaction between divergent and convergent thinking on mathematics problems. The results showed varying patterns in the two tasks. In the SST, participants who had low divergent thinking scores but high convergent thinking scores had the highest performance. However, the highest performance in MST was seen in participants with high levels of both divergent and convergent thinking. The patterns observed in the SST and MST suggest that the relationship between divergent and convergent thinking might vary depending on the specific task or conditions. For optimal performance, sometimes a combination of both types of thinking is required, while in other situations, the absence of one type of thinking can be advantageous – again implying they are separable.

Cropley (2006) proposed the summation model to explain the interaction of divergent and convergent thinking, which emphasised the compensatory relationship between them. That is, strengths in one type of thinking may compensate for weakness in the other, which explains the results of de Vink et al.'s study (2022) on performances of SST and MSTs: participants who were good at convergent thinking but not at divergent thinking performed well in SSTs because their ability to narrow down to a single correct solution compensate for their low ability to generate multiple ideas. Conversely, in the MSTs, participants with high levels of both divergent and convergent performed best, suggesting that the combination of generating multiple ideas and finding single correct solution led to optimal performance. Based on the above empirical results and theoretical model, it appears that the interaction between divergent and convergent thinking is not fixed but rather dynamic based on the specific context. Meanwhile, the apparent separability of convergent and divergent thinking suggests that it is at least possible that they are supported by mind wandering in different ways.

5.1.4 Structural equivalence of compounds in Chinese and English

The main goal of the current study was to investigate the connection between mind wandering and convergent thinking, with the aim of validating findings from convergent thinking research and enhancing the understanding of incubation effects. Given the use of a Chinese sample in the present research, there are key considerations regarding the nature of convergent tasks that come to the fore. Success in RAT or CRA requires making connections between words and identifying the correct remote associations. The content of the task may be more familiar to some individuals based on their cultural and linguistic backgrounds, and that culture may influence participants' performance. Indeed, several studies have attempted to translate RAT/CRA items across languages to establish comparability (German version of T, Landman et al., 2014; Japanese version of RAT, Orita et al., 2018; Italian version of T, Salvi et al., 2016, etc.); nevertheless, the same RAT/CRA items might not be equally challenging in other languages even if they could be translated (Behrens & Olteţeanu, 2020). Different languages have different semantic structures and associations, which may not directly translate to another language. RAT or CRA may work differently in different contexts as the compounding of words is different, not just in terms of actual compounds but also in terms of how commonly compound construction are used.

It is, thus, crucial to ensure the appropriateness of using RAT or CRA, which was initially developed in the English context, in the Chinese context. Compounds, as the combination of two words, can be described according to the components' form types. The compound noun category is frequently seen in both Chinese and English. For instance, compound nouns can be noun + noun (e.g., in Chinese, 火车 equals fire-vehicle, which means train; in English, spaceman), adjective + noun (e.g., 长城 equals long-wall, which means the Great Wall; superman), verb + noun (e.g., 跑道 equals run-path, which means runway; playground), and proposition + noun (e.g., 后台 equals behind-stage, which means backstage; overnight). The compound verb category is also common in both languages, including verb + verb (e.g., 听说 equals to listen-to speak, which means to hear about; breakdance), adjective + verb (e.g., 慢跑 equals slow-to run, which means to jog; highlight), noun + verb (e.g., 心跳 equals heart-to jump, which means heartbeat; babysit), and proposition + verb (e.g., 进行 equals enter-to proceed, which means to conduct; overcome). The compound adjective category can be adjective + adjective (e.g., 矮小 equals short-small, which means short and small; bittersweet), proposition + adjective (e.g., 过敏 equals over-sensitive, which means allergic; overconfident), and noun + adjective (e.g., 困难 equals difficulty-hard, which means challenging; waterproof; Christianto, 2020). Chinese and English therefore share similarities in the structure of compounds, especially the noun-to-noun structure that is common in both languages (Zhang et al., 2012).

Compounds also differ in terms of productivity (i.e., how easily new words can be formed) and transparency (i.e., how clearly the meaning of a word can be understood). English shows higher productivity and transparency in certain compound forms, such as affixation by adding the suffix or prefix. However, English compounds, excluding those combined with affixation, are less productive and transparent than Chinese compounds (Zhang et al., 2010; 2012). While there are differences in productivity and transparency in both languages, these differences do not impact the overall structural equivalence. Both languages require the integration of component meaning to understand compounds, thus maintaining the CRA task's relevance and ensuring its appropriateness for use with Chinese samples.

5.1.5 Experimental design and hypotheses

The experimental structure employed on Study 4 closely mirrored that of the Study 3 on divergent thinking to facilitate a comparative analysis between divergent and convergent thinking. Thus, participants in both studies completed a first pass at the relevant creative task; then completed the 0-back task in an incubation period, lasting 15 minutes, during which they were probed for mind wandering; and finally completed a second pass at the creative task, with both repeated and novel items. They had a similar time interval to complete the creative task, which was 6 minutes. The study used the Chinese version of CRA validated by Wu and Chen (2017). These CRA items were divided into three levels of difficulty based on the passing rate observed in Wu and Chen' study. The study, thus, set a specific threshold for difficulty, attempting to identify the level at which incubation effects are apparent.

The underlying hypothesis was that mind wandering facilitates convergent creative thinking. Individuals reporting higher instances of mind wandering would have better performance in CRA post-incubation than those with fewer mind wandering experiences. It was also expected that there would be a semi-positive relationship between difficulty levels and incubation effects, with the benefits of mind wandering during incubation being highest at moderate level of difficulty. An inverted U-shaped effect was predicted, since moderate difficulty provides the optimal balance, engaging cognitive processes without overwhelming them. This hypothesis stems from the findings discussed in Chapter 3 (Study 2) that low difficulty CRA problems do not benefit from incubation or mind wandering, while high difficulty problems may be too complex for incubation or mind wandering alone to provided substantial help. Therefore, moderate difficulty problems are likely to benefit the most by mind wandering during incubation periods. Specifically, participants would show significant improvement across the three difficulty levels: low, moderate, and high, with the greatest improvement at the moderate difficulty level. Participants' abilities in convergent and divergent thinking would vary. That is, it was hypothesised that there would be a modest correlation between participants' performance on convergent and divergent thinking tasks. Given that different cognitive processes are involved in each type of creative thinking, it is likely that individuals' abilities in one type of thinking do not strongly predict their abilities in the other types.

5.2 Method

5.2.1 Participants

The participants for this study were the same as those employed in Study 3, reported in Chapter 4. As noted there, half of the participants completed the current study first, while the other half completed Study 3 first. This served to reduce the variability caused by order effects and allow a direct comparison to be made between divergent and convergent thinking, within the same group.

5.2.2 Materials

Chinese compound remote associates test (CRA)

In this task, participants were presented with three words and asked to make a remote association with a fourth word that formed meaningful word phrases with the initial three words. In the baseline task, participants were given eight CRA problems, with six minutes to complete the entire task. The CRA problems were chosen from Wu and Chen (2017), based on the pass rate reported there, with three levels: 0.5–0.8 (low difficulty, comprising 2 items), 0.3–0.5 (moderate difficulty, comprising 3 items), and

0.1–0.3 (high difficulty, comprising 3 items). The post-incubation task involved the same CRA items presented in the baseline task and eight new items sharing the same variation in level of difficulty, with twelve minutes to complete the task. Instructions and examples were written on a sheet of paper, with the task being presented in one of two versions, digital or paper. Participants were given the option of selecting a format that suited their needs. Participants were given 1 point when they produced the correct answer, so the maximum total score of the baseline was 8. The scoring method used to measure improvement of post-incubation was the same as that used in the divergent study (i.e., the raw differences from baseline performance).

0-back task

The 0-back task used in the present study to occupy the incubation period was identical to that used in Study 3. Participants were instructed to respond to the current stimulus when it was matched with a predefined target stimulus. The task duration was about 15 minutes. Reaction time and accuracy rate were recorded to compare participants' performances.

Thought probes

The thought probes were also identical to those used in Study 3, distinguishing between mind wandering with awareness and mind wandering without awareness. Based on participants' responses, their mental states were divided into five categories: being on task, external distractors, task-related interference, and mind wandering with awareness and mind wandering without awareness.

5.2.3 Procedure

Participants were asked to complete eight problems as a baseline measure. This baseline served as a reference point for evaluating creative performance. Following the baseline tasks, participants were provided with an incubation period involving engagement in the 0-back task, along with thought probes. Finally, participants were presented with sixteen problems in a fixed order, including both the eight items encountered during the baseline phase (repeated exposure) and eight new problems presented for the first time (new exposure). To control for potential order effects, counterbalancing was employed. That is, the participant sample was divided in half, with one half completing repeated problems (repeated exposure) followed by novel problems (new exposure), while the other group followed the reverse order, completing the novel problems (new exposure) followed by repeated problems (repeated exposure). This experimental design enabled a comparison of creative performance variations between pre- and post-incubation periods. As in Study 3, it made it easier to distinguish between general effects caused by task practice or familiarity and particular effects caused by mind wandering during the incubation phase.

5.2.4 Analysis plan

This study examined the relationship between mind wandering and convergent thinking, with a specific focus on CRA. Initially, the pre-incubation to post-incubation improvement scores from both repeated and novel conditions were analysed, both overall and broken down by item difficulty level. T-tests were then used to compare the improvement differences between the two conditions, thereby assessing the specific effects of incubation versus practice. In order to investigate the relationship between mind wandering and CRA performance, Pearson correlation analyses were performed. Additionally, to compare the effects of divergent and convergent thinking on task performance, t-tests and correlation analyses were conducted to compare the performance on creative performance (the UUT and CRA tasks), the 0-back task, and the incidence of mind wandering between this study and Study 3. The rationale for using multiple t-tests without applying Bonferroni corrections in this study is consistent with that outlined in Study 3. Briefly, the tests addressing distinct research questions did not share a common error term, meaning they could not be considered part of the same family. The exploratory nature of the study and the need to avoid Type II errors supported the decision to forgo corrections of multiple comparisons.

5.3 Results

5.3.1 Preliminary analyses

As in discussed in Study 3, participant occupation group (students vs. other workers) and response mode (digital vs. paper-pencil) were examined separately to determine whether they influenced convergent thinking performance.

A significant difference was found between the two response modes in baseline convergent thinking performance, with the paper-pencil group outperforming the digital group, $U=1045.5$, $N_{digital}=61$, $N_{paper\text{-}pencil}=24$, $p=0.002$. Similarly, there was a significant difference found in post-incubation performance, $U=989.00$, $N_{digital}=61$, $N_{paper\text{-}pencil}=24$, $p=0.01$. Despite these differences, there was no significant difference in change scores from baseline to post-incubation on convergent performance (i.e., post-incubation score minus the baseline score), t (83) =1.38, $p>0.05$, indicating that both groups improved by the same amount. This suggests that the difference in post-incubation performance was simply a reflection of their initial baseline differences, rather than an effect of the incubation period. Age might have contributed to these baseline differences, as a positive correlation between age and convergent thinking baseline score was found, r=0.26, p=0.02, indicating that older participants tended to perform better in baseline convergent thinking. However, the age difference between digital (M=32.33, SD=12.32) and paper-pencil (M=37.13, SD=13.48) groups was not significant, t (83) =-1.57, $p>0.05$, d=-0.38. This suggests that while age is correlated with convergent thinking performance, it does not fully explain the difference between the digital and paper-pencil groups. Instead, format plays an important factor. The paper-pencil format may enhance focus and reduce distractions, initially benefiting tasks that require goal-directed and structured problem solving, like convergent thinking.

Further analyses showed no significant difference in mind wandering between the digital and paper-pencil groups in convergent thinking, U=705.00, Ndigital=61, Npaperpencil=24, $p>0.05$. Correlational analyses revealed no difference in relationship between mind wandering and post-incubation convergent thinking performance between digital ($r=0.10$, $p>0.05$) and paper-pencil ($r=-0.06$, $p>0.05$) groups. Similarly, no significant differences were found between students and other workers in baseline convergent thinking performance ($U=943.50$, Nstudent=25, Nothers=60, $p>0.05$) or post-incubation performance ($t(83)=-1.54$, $P>0.05$). Mind wandering did not differ between these groups ($U=787.50$, Nstudent=25, Nothers=60, $p>0.05$). Correlational analyses indicated no difference in association between mind wandering and post-incubation divergent thinking performance between students ($r=0.30$, $p>0.05$) and other workers ($r = -0.09$, $p > 0.05$). Given the lack of effects on the key outcomes and the absence of participants group effects, both response mode and participants group were discounted from further consideration in subsequent analysis.

5.3.2 Scores on the CRA problems

A 2-way repeated ANOVA (exposure type: repeated vs. novel x difficulty level) was used to look at the effects of exposure type and difficulty level on proportional improvement scores. However, calculating proportional improvement becomes problematic when the baseline is zero, which can distort the results. To avoid this, raw change scores were divided by the maximum possible change (i.e., 2 for low difficulty, 3 for moderate, 3 for high). This creates a normalised proportional measure, which allows for fair comparisons across difficulty levels. The main effect of exposure was not significant, $F(1, 84) = 0.56$, $P>0.05$, partial $\eta^2 = 0.01$, indicating that there was no difference between repeated and new exposure conditions in term of proportional improvement. The main effect of difficulty was significant, $F(2, 84) = 20.30$, $p = 0.01$, partial $\eta^2 = 0.20$, indicating that performance varies significantly across difficulty levels. There was a significant interaction between exposure types and difficulty level, $F(2, 84) = 15.43$, $p = 0.01$, partial $\eta^2 = 0.16$. As the interaction between exposure types and difficulty level was significant, the main effect of exposure for each level of difficulty (3 paired sample t-tests) was examined. Low and moderate difficulty levels showed significant effect of exposure type (low: $t(84) = 3.15$, $p = 0.002$, $d = 0.34$; moderate: $t(84) = -3.78$, $p= 0.001$, $d = -0.41$). No difference was found between repeated and new exposure at high difficulty, $t(84) = 0.96$, $p>0.05$, $d = 0.10$.

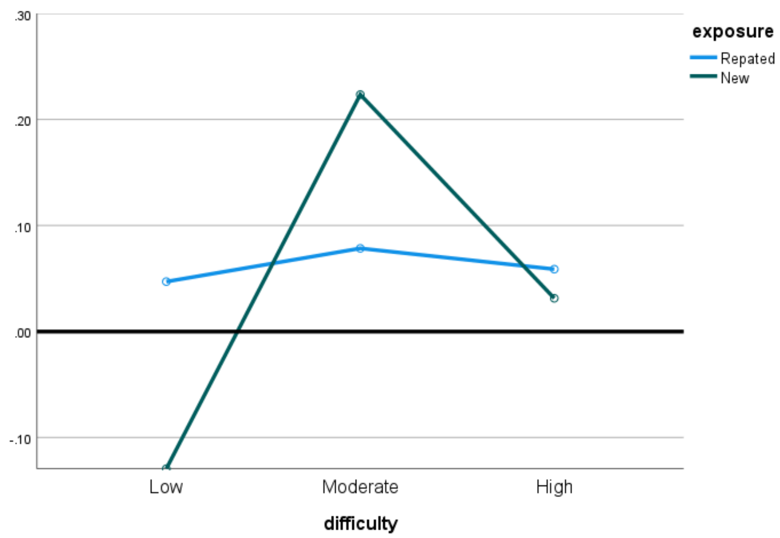

Figure 5.1Performance changes across difficulty levels for each exposure condition (The x-axis represents difficulty level, low, moderate, high; the y-axis represents performance score; and the repeated and new exposure condition is represented by different colours)

In order to examine these variations more carefully, t-tests on the raw scores were carried out. There was a significant increase between baseline (M = 1.61, SD = 1.22) and post-incubation (M = 2.13, SD = 1.56; see Table 5.1 for details) in the scores of problems under the repeated exposure condition, t (84) = 5.59, p= 0.001, d= 0.37. Similarly, there was a significant increase between baseline and post-incubation (M = 2.06, SD = 1.49) in the problems under new exposure condition t (84) = 2.58, p= 0.01, d= 0.33. A correlation was computed to examine the relationship between baseline scores and improvement scores. The analysis did not reveal a correlation between baseline scores and raw change scores in the repeated exposure condition, r (83) = 0.12, p = 0.29. However, in the new exposure condition, the analysis showed a negative correlation between baseline and raw change scores, r (83) = -0.47, p<0.001, indicating that there may have been a practice effect for those who performed more poorly to start with. The improvement in repeated exposure condition (M = 0.52, SD = 0.85) was slightly higher than in new exposure condition (M = 0.45, SD = 1.60), but the difference was not significant, t (84) =0.35, p = 0.72, d = 0.04.

In terms of task difficulty, there was a significant difference for the low difficulty items between baseline scores (M = 0.84, SD = 0.72; see Table 5.1 for details) and post-incubation score for the repeated problems (M = 0.93, SD = 0.74), t (84) =2.62, p = 0.01, d = 0.12. However, there were significant decreases in the scores for the low difficulty condition between baseline and post-incubation (M = 0.58, SD = 0.70) for the new exposure problems, t (84) = -2.33, p = 0.02, d = 0.37. The repeated exposure condition showed a slight improvement (M = 0.09, SD = 0.33), whereas the new exposure condition showed a decrease (M = -0.26, SD = 1.03), and the difference between these opposing effects was significant, t (84) = -3.15, p = 0.002, d = 0.46.

For the moderate difficulty items, the differences between baseline scores ($M = 0.62$, $SD = 0.72$; see Table 5.1 for details) and post-incubation scores ($M = 0.86$, $SD = 0.90$) for repeated problems were significant, $t(84) = 4.31$, $p < 0.001$, $d = 0.30$. Similarly, the difference for the new exposure condition (i.e., new problems, $M = 1.29$, $SD = 0.92$) was significant, $t(84) = 6.64$, $p < 0.01$, $d = 0.81$. The improvement in repeated exposure condition ($M = 0.24$, $SD = 0.50$) was considerably lower than in new exposure condition ($M = 0.67$, $SD = 0.93$), and the difference was significant, $t(84) = -3.78$, $p < 0.001$, $d = -0.57$.

For the high difficulty items, the mean difference between baseline score ($M = 0.15$, $SD = 0.36$; see Table 5.1 for details) and post-incubation score was significant under the repeated exposure condition ($M = 0.33$, $SD = 0.56$), $t(84) = 3.94$, $p < 0.001$, $d = 0.38$. However, the difference under the new exposure condition ($M = 0.25$, $SD = 0.55$) was not significant, $t(84) = 1.38$, $p = 0.17$, $d = 0.22$. The improvement in repeated exposure condition ($M = 0.18$, $SD = 0.41$) was slightly higher than in new exposure condition ($M = 0.09$, $SD = 0.63$), but the difference was not significant, $t(84) = 0.96$, $p = 0.34$, $d = 0.17$.

Table 5.1 Performance on the CRA task

Difficulty level	Baseline scores	Post-incubation scores		improvement	
		Repeated exposure	New exposure	Repeated exposure	New exposure
Overall	1.61	2.13	2.06	0.52	0.45
Low difficulty	0.84	0.93	0.58	0.09	-0.26
Moderate difficulty	0.62	0.86	1.29	0.24	0.67
High difficulty	0.15	0.33	0.25	0.18	0.09

Participants showed significant overall performance improvement from baseline to post-incubation in both repeated and new exposure conditions. This indicates incubation can enhance performance on both repeated and new exposure problems. No correlation was observed between baseline scores and improvement raw change score for repeated items, indicating that no matter whether participants' initial performances were good or not, they showed similar improvement after the incubation period. However, for new exposure condition, it suggests that participants who initially struggled with problems benefited more from the incubation period. For all the difficulty conditions, there was significant improvement over baseline scores for the repeated exposure items. The greater improvements for repeated items compared to new items suggest incubation effects were present in both low and high difficulty levels conditions. Practice effects were present to a greater extent in the moderate difficulty condition, with bigger improvements in new exposure problem. This suggests that practice or repetition is not helpful for more challenging problems, perhaps because items at this level of difficulty level are beyond participants' knowledge level. The reason for the regression on the low difficulty new items is less clear, but this might be due simply to differences between the items involved, with the new post-incubation items proving more difficult than the baseline ones.

5.3.3 Comparisons between Studies 3 and 4

With regards to the relationship between convergent and divergent performances, the correlation analysis showed that there was no significant association between convergent and divergent task (see Table 5.2 for details) at baseline scores, r (83) = 0.05, p = 0.63. For post-incubation performance, there was no significant relationship between convergent and divergent scores on repeated exposure problems, r (83) = -0.04, p = 0.74. Similarly, no significant correlation was found between the two studies on new exposure problems, r (83) = -0.03, p = 0.76. For the improvement scores, the analysis showed a null correlation between convergent and divergent tasks in the repeated exposure condition, r (83) = -0.14, p = 0.20, as well as in the new exposure condition, r (83) = 0.01, p = 0.97.

Table 5.2 Creative performance in the divergent and convergent studies

	Pre-incubation	Post-incubation			
	Baseline scores	Repeated exposure	New exposure	Improvement of repeated exposure problems	Improvement of new exposure problems
Divergent study (Study 3)	6.55(2.09)	8.36 (2.55)	7.88(2.99)	1.81(1.64)	1.33(2.59)
Convergent study (Study 4)	1.61(1.22)	2.13 (1.56)	2.06(1.49)	0.52(0.85)	0.45(1.60)

Performances on the 0-back task

T-tests showed that there was no significant difference between the divergent and convergent studies, either on reaction time or on the accuracy rate of the 0-back task performance (see Table 5.3 for details), with the results $t (84) = 0.90$, $p = 0.37$, $d = 0.09$, and $t (84) = -1.01$, $p = 0.32$, $d = -0.13$, respectively. For the additional indicators similarly, there was no significant difference between divergent and convergent studies in terms of false alarm rate, $t (84) = 0.15$, $p = 0.88$, $d = 0.02$. However, hit rate showed significant differences between the two studies, $t (84) = -2.16$, $p = 0.03$, $d = -0.23$, with the convergent study having a higher hit rate ($M = 0.90$) than the divergent study ($M = 0.87$). It appears that participants' performance was influenced by prior tasks;

specifically, the preceding convergent task seems to be less distracting, leading to a modest increase in the 0-back task performance (e.g., hit rate). However, the lack of a significant difference in false alarm rate suggests that participants in both experimental settings have a similar tendency to respond incorrectly to non-target stimuli.

A correlation analysis was conducted to examine the relationship between the two studies on the 0-back task. The results revealed a significant positive correlation for reaction time, $r(83) = 0.60$, $p < 0.001$. This suggests that participants who have faster reaction time in divergent study also tend to have faster reaction time in convergent context, and vice versa. The analysis also showed a positive correlation for accuracy rate, $r(83) = 0.93$, $p < 0.001$. Additionally, the correlation for hit rate and false alarm rate were both statistically significant, with $r(83) = 0.68$, $p < 0.001$, and $r(83) = 0.94$, $p < 0.001$, respectively. These consistent performances on the 0-back task, along with the null relationships between convergent and divergent tasks suggest that the latter are real effects rather than the product of random variations in performance.

Table 5.3 Performance on the 0-back task in the divergent and convergent studies

	Reaction time	Accuracy rate	Hit rate	False alarm rate
Divergent study (Study 3)	615.43(198.01)	0.96 (0.08)	0.87(0.14)	0.03(0.09)
Convergent study (Study 4)	599.72(141.26)	0.97(0.08)	0.90(0.12)	0.03(0.09)

Performances on mind wandering

A t-test was used to test whether the different types of creative thinking—divergent and convergent—affected the frequency of mind wandering and its subtypes, i.e., mind wandering with and without awareness. The difference between the two studies in the frequency of overall mind wandering was not significant, t (84) = -1.41, p=0.16, d = -0.15 (see Tables 5.4 for details). Similarly, the difference in the frequency of mind wandering with awareness was not significant, with t (84) = -1.17, p = 0.25, d = -0.13, and not significant in mind wandering without awareness, t (84) = -0.99, p = 0.32, d = -0.11. A correlation analysis was conducted to examine the relationship on mind wandering between two studies. It revealed a positive correlation, r (83) = 0.47, p < 0.001, suggesting that participants' tendency to mind wandering was stable across studies. Similarly for its subtypes, there was a positive association on mind wandering with awareness (r (83) = 0.39, p < 0.001), as well as mind wandering without awareness (r (83) = 0.51, p < 0.001).

Table 5.4 Frequency of mind wandering in the divergent and convergent studies

	Mind wandering	Mind wandering with awareness	Mind wandering without awareness
Divergent study (Study 3)	0.13(0.19)	0.09(0.14)	0.04(0.09)
Convergent study (Study 4)	0.16(0.23)	0.11(0.17)	0.05(0.11)

5.3.4 Correlations between rate of mind wandering and improvement on the CRA task post-incubation

Repeated exposure condition

There were no statistically significant associations between mind wandering and overall improvement scores on repeated exposure items ($r = 0.13$, $p = 0.24$), regardless of whether it was with awareness ($r = 0.16$, $p = 0.15$), or without awareness ($r = 0.02$, $p = 0.83$). For low difficulty problems, though, there was a significant correlation between mind wandering and improvement scores ($r = 0.28$, $p = 0.008$), and with mind wandering with awareness ($r = 0.39$, $p < 0.001$). However, there was no significant correlation with mind wandering without awareness ($r = -0.14$, $p = 0.91$). For moderate difficulty problems, there were no statistically significant associations found between mind wandering and improvement scores on repeated exposure items (r = -0.004, p =

0.97), regardless of whether it was with awareness (r = 0.05, p = 0.63), or without awareness (r = -0.08, p = 0.44). Similarly, for high difficulty problems, there were no significant correlations between mind wandering and improvement scores, regardless of type of mind wandering: overall mind wandering (r = 0.09, p = 0.43); with awareness (r = -0.001, p = 0.99); or without awareness (r = 0.18, p = 0.11).

New exposure condition

There were no significant correlations between mind wandering and improvement scores for new exposure items, regardless of type of mind wandering: overall mind wandering (r = -0.12, p = 0.34); with awareness (r = 0.02, p = 0.88); or without awareness (r = -0.19, p = 0.09). For low difficulty problems, there were no significant associations between mind wandering and improvement score, regardless of type of mind wandering: overall mind wandering (r = -0.07, p = 0.56); with awareness (r = -0.04, p = 0.67); or without awareness (r = -0.06, p = 0.60). For moderate difficulty problems, where there was greatest evidence of practice effects, there was no association between mind wandering and improvement scores, (r = -0.20, p = 0.07) or with mind wandering with awareness (r = -0.08, p = 0.45), but a significant moderate negative association with mind wandering without awareness (r = -0.28, p = 0.01), indicating that less mind wandering without awareness enhanced the practice effect. For high difficulty problems, there were no significant correlations between mind wandering and improvement scores for new exposure items, regardless of type of mind wandering: overall mind wandering ($r = 0.08$, $p = 0.45$); with awareness ($r = 0.12$, $p = 0.28$); or without awareness ($r = -0.01$, $p = 0.95$).

To summarise, under repeated exposure conditions, mind wandering, particularly with awareness, was positively associated with improvement in CRA scores for low difficulty problems. However, for both moderate and high difficulty problems, mind wandering did not enhance improvement, possibly indicating that with an increment in difficulty, the need for more focused attention increased. Under new exposure conditions, mind wandering did not correlate with improvement for low and high difficulty problems, but mind wandering without awareness was negatively associated with improvement in moderate difficulty levels. This suggests that mind wandering has a differential impact on task performance based on task difficulty and type of exposure.

5.4 Discussion

The study provides insights into the effects of incubation on convergent problems, especially regarding the role of mind wandering and task difficulty. There was a clear benefit of a break for repeated exposure CRA items, where significant improvement in scores was observed regardless of difficulty level, indicating the existence of an incubation effect. This suggests that participants' minds continued to process problems during the incubation period. More specifically, improvements were seen with repeated problems of low difficulty, that were associated with mind wandering, especially mind wandering with awareness, indicating this contributed to this particular improvement. Moderate and high difficulty problems also benefited from post-incubation repeated exposure, but mind wandering did not contribute to the improvement. The reason for these improvements is less clear, and raises questions about what other cognitive processes were occurring during the incubation period.

Improved performance on new items also suggests that participants' overall problem-solving abilities were enhanced by practice, and the opportunity to reflect on problem structure. The practice effect, while present, was relatively weak, however, and primarily benefited those who had lower performance at baseline. Significant improvement was observed only in moderate difficulty problems, which was also the only level at which the effects of practice were greater than those of incubation.

Moreover, mind wandering without awareness negatively impacted performance at this level, indicating that this kind of thinking can be detrimental when subsequently encountering new and more challenging problems. This may be because it distracts attention from more deliberate consideration of the problem structure, and solution strategies. These results suggest that mind-wandering favours creative performance only at certain difficulty levels and where there is prior exposure. A moderate amount of mind wandering, especially with awareness, appears to be beneficial when solving problems that are well within an individual's capacity. In contrast, for solving more challenging problems, focused attention on the strategy for doing so seems to have a higher advantage than mind wandering for both repeated and novel problems. It would appear that at the highest level of difficulty, both focus and prior exposure are necessary to facilitate progress.

Crucially, the comparison between the divergent and convergent studies also made it possible to establish that these effects of incubation and mind wandering only held for convergent problem solving – or at least in terms of the tasks employed in this research – contrary to the argument that such effects are more likely with divergent tasks. This was despite striking similarities in performance on the 0-back task and in mind wandering frequencies, rendering the reality of differences in the impact of incubation and mind wandering more plausible. These points are all considered in greater detail below.

5.4.1 Incubation effects and task difficulty

Incubation effects at low difficulty levels

At the low level of difficulty, the incubation effect was significant, and improvement was associated with mind wandering with awareness. There was no practice effect, though this might be in part due to the items used: since there were only two of these, problem content may have had more impact on performance. The positive results suggest that deliberate relaxation of focus facilitated responses to previously seen problems that were relatively easy. This implies a beneficial role for mind wandering experiences that are within conscious control.

Recent studies also suggest that among the different types of mind wandering, only this specific type has a positive effect on creativity: for instance Zedelius and Schooler (2016) found that only deliberate mind wandering exhibited a positive correlation with creative performance, while spontaneous mind wandering demonstrated an opposing effect, though it should be noted that this was using a divergent thinking task. Xie et al. (2023) produced similar findings, reinforcing the notion that deliberate mind wandering plays a crucial role in influencing creative outcomes. In this study, participants also engaged in a divergent thinking task, specifically the alternative uses task (AUT), in the initial phase. Subsequently, they undertook a sustained attention to response task, accompanied by thought probes aimed at measuring their thoughts during the task. Following this attentional task, participants returned to the initial divergent thinking task to generate additional uses for the same item. The results of the study revealed a significant predictive relationship between deliberate mind wandering and participants' performance in the post-incubation creative task. The findings corroborate the research conducted by Agnoli et al. (2018), collectively suggesting a relationship between this specific form of mind wandering and creative performance.

Incubation effects at moderate difficulty levels

In contrast to the low difficulty condition, at the moderate level of difficulty, the practice effect played a much larger role, with mind wandering without awareness having a negative influence. The incubation effect was significant, but not associated with mind wandering and substantially smaller than the practice effect. Since these effects were necessarily concurrent with those impacting low difficulty items, this indicates that maintaining a constraint on the relaxation of focus helped participants see the structure of the problems better and generate insights into strategies for solving them. This led to better performance on novel items that were not too difficult, especially for those who performed worse to begin with, and provided some fresh insight into such problems where they had seen these before, but diffuse reflection on the content of these either did not occur or was not productive.

Although background, controlled mind wandering helped participants see answers to low difficulty problems they had seen before, therefore, it seems constrain spontaneous mind wandering made it possible to reflect on problem structure and strategy, and they were then able to apply insights from this to subsequent problems, both repeated and novel. This benefitted the novel more, perhaps because it was easier to apply that reflection to items they had not seen before. Where items were repeated, thinking was interfered with by what they had been thinking on the previous exposure. This made it harder for participants to reflect in a productive way because they were stuck in the approach they used during earlier exposure. To improve performance on repeated problems, participants need to reflect on the specific content of what they previously thought. This type of reflection requires more mental effort compared to reflecting on general strategies or problem's structures. It implies that the key factor in how participants solved the problems was not the difficulty or cognitive demand of the task itself. Instead, what really mattered was the kind of reflection they engaged in—whether they were thinking about specific strategies, like thinking about problem structure, or revisiting prior thoughts. It is the balance between diffuse reflection on content and controlled reflection on strategy that influences the success of solving problems.

The negative effect of mind wandering without awareness in creativity is consistent with results of previous research (Agnoli et al., 2018; Hao et al., 2015), excepting one study that found mind wandering without awareness was just above the significance threshold in predicting creativity. Orwig et al. (2023), focusing on the trait of mind wandering tendencies in divergent thinking, employed the deliberate and spontaneous mind wandering questionnaire created by Carriere et al. (2013) to measure mind wandering. It was found that deliberate mind wandering had borderline significant relationship with creativity, as indicated by linear regression analysis (t =

2.00, $p = 0.0503$). Nevertheless, while there was a trend indicating that mind wandering without awareness may be related to creativity, it was not strongly statistically significant in Orwig et al.'s study, and might have been a spurious effect.

Past research is also consistent with the detrimental role of mind wandering without awareness in creativity being the result of attentional distraction. Carriere, Seli, and Smilek (2013) explored the relationships between different types of mind wandering: deliberate and spontaneous, which was measured by deliberate and spontaneous mind wandering questionnaires and cognitive traits. It was found that spontaneous mind wandering was associated with higher reported attentional distraction, which was measured by attentional control scale developed by Derryberry and Reed (2002). In line with these findings, mind wandering without awareness activates the default network, particularly the medial prefrontal cortex, which enhances free-associative thinking but divert cognitive resources away from evaluation (Christoff et al., 2009; Ellamil et al., 2012). That is, brain regions required to monitor and evaluate creative processing are occupied, resulting in imbalanced creative processing, with an overemphasis on generative function, neglecting the evaluative phase, thus leading to poor evaluation of creative ideas and outcomes. These negative associations confirm that mind wandering without awareness might reflect a cognitive control issue that leads to less productive creative outcome.

Incubation effects at high difficulty levels

At the high level of difficulty, the incubation effect was significant, but even less so than for the moderate problems, and again not associated with mind wandering. There was no practice effect, possibly because these problems are too challenging for insights into problems structure and solution strategies on their own to be productive. Instead, as with the moderate difficulty problems, the combination of problem insight and previous time spent thinking about specific problems is helpful, but to a lesser than there because of the difficulty of the problems. This suggests that the constraint on the relaxation of focus and improved strategy insight facilitates some improved insights into difficult problems where they have been seen before, but this does not extend to novel problems, where the combination of difficulty and lack of familiarity prevent any progress. The incubation effect is still present in this situation, but its impact is smaller due to the task's demands.

Overall pattern of effects

These results suggest that the incubation effect is not universal, and task difficulty plays a vital role in determining the nature and impact of incubation effects on convergent thinking processes. Participants may not have enough cognitive resources to allocate to creative processing of high difficulty problems, but when the task difficulty is too low, participants may not be sufficiently challenged to engage in creative thinking except where problems have been seen before and interim insights have been generated. The aligns with the account of individuals' regions of proximal learning (RPL) mentioned in Study 2, according to which there exists an optimal environment for learning where the information just beyond learners' mastery (Xu & Metcalfe, 2016). As a result, the impact of incubation effects might be influenced by various factors, including task difficulty.

In summary, the incubation effect plays a role in creative solving of convergent problems of varying difficulty, with mind wandering with awareness contributing to the solution of easy problems, while controlled concentration is more effective for the completion of moderately difficult items, and for high difficulty items that have been thought about before. These findings emphasise the importance of considering task difficulty in investigating the effectiveness of incubation in creative problem solving.

5.4.2 Factors contributing to the differences in divergent and convergent investigations

In this research, the incubation effect was observed more prominently in convergent problem solving than in divergent, possibly due to the basic nature of the creative tasks employed. Since the experimental structure, sample, performance on the 0-back task, and extent of mind wandering were comparable across both studies, these factors can be ruled out as contributing to the differences observed. This points to the nature of divergent and convergent thinking itself as the likely explanation.

The generation of a new idea or concept in the creative thinking process often involves reconstruction based on existing relevant knowledge extracted from long term memory, accompanied by sustained attention and cognitive control, all of which are inseparable from the involvement of working memory (De Dreu et al., 2012). It is worth considering the link between working memory and creativity to explain the variation of incubation effects in the present findings. Ash and Wiley (2006) demonstrated that working memory capacity (WMC) positively correlated with convergent performance. Participants were asked to complete six problems, for instance, the coins problem and a matchstick operator problem, with two versions:

one has a smaller problem space with fewer movement possibilities, and the other has a larger problem space with more movement possibilities. Both versions of the task had the same answer. The results indicated that high WMC participants performed better than low when completing problems with a larger problem space and movement possibilities. De Dreu et al. (2012) further found that the link between WMC and convergent thinking was positive. They had participants complete a convergent task, the remote associates test to identify the association among the given words, and a delayed serial recognition task assessing WMC by presenting participants with eight images or words sequentially, requiring them to maintain them during a brief delay before indicating if a subsequent item was part of the presented items or not. It was found that WMC was positively correlated with convergent performance, with participants who had high WMC scores performing better on the convergent task.

Further research by Lin and Lien (2013), which employed both divergent and convergent tasks to investigate the relationship between WMC and creative performance, supports these findings. The results showed that participants' WMC correlated with convergent task performance as predicted but not with divergent task performance, suggesting that divergent and convergent thinking involve different cognitive resources. Working memory, as a construct related to focused attention, with differential effects on divergent and convergent thinking, suggests that convergent thinking heavily reliance on working memory resources, while divergent thinking performance is less affected by these limitations. In line with this, a meta-analysis study found that there was a positive relationship between working memory and convergent thinking but no specific relationship with divergent thinking (Gerver et al., 2023).

Thus, it is possible that the differences between the two studies stems from convergent thinking needing more working memory resources than divergent thinking. In convergent tasks, options are usually reduced to a single right answer, necessitating the maintenance and manipulation of information in working memory while following predetermined guidelines or limitations. In order to ensure that the right answer is found, this approach primarily necessitates concentrated attention and focus, as appeared to be the case to achieve impact on subsequent moderate and high difficulty problems. Divergent activities, on the other hand, require production with a variety of connections or solutions, sometimes without predetermined guidelines or limitations.

Because divergent activities prioritise creativity, exploration, and the development of a wide variety of options above the selection of a single correct solution, they may not demand the same amount of concentrated attention or cognitive resources as convergent tasks. Although it is not possible to verify this, one potential reason for the difference between the impact of incubation on the two tasks is that this sample had a relatively high working memory capacity, thus performing better in convergent tasks compared to divergent tasks, because of being better able to devote attention to problem structure and solution strategy while allowing low level deliberate mind wandering to generate answers to previously seen simple problems. None of this would have helped on the divergent task, especially if – as appears to be the case – it was associated with a tendency to constrain diffusion of focus.

As part of this, the increasing difficulty of the convergent problems compared to the divergent task might have induced higher levels of motivation or interest in the former. Motivation has an important role in the occurrence of mind wandering. That is, participants with higher motivation are less likely to report mind wandering experiences (Unsworth & McMillan, 2013). At the same time, people with higher motivation might be able to regulate and allocate their attention (He et al., 2023). The significant improvement observed in convergent task may be due to the goal-directed nature of mind wandering which is facilitated by higher motivation. Hasenkamp et al. (2012) used functional magnetic resonance imaging (fMRI) to reveal the brain regions of the cognitive circle, from the state of mind wandering to the state that focuses on the ongoing task. The circle was further divided into four intervals: mind wandering, awareness of mind wandering (i.e., identifying the condition of mind wandering), shifting of attention (i.e., moving focus from mind wandering to the current task), and sustained attention. It was found that the dorsal and ventral prefrontal cortex, lateral inferior partial cortex, and right hemisphere regions were activated during the shifting of attention phase, which are included in the executive network. It is, thus, possible to say that motivation influences the state of redirecting attention from mind wandering to the ongoing task and management of the frequency of mind wandering under the control of the executive network.

While the results indicate that mind wandering during the incubation periods did not contribute to the enhancement of divergent thinking performance, this does not rule out the potential benefits of mind wandering for incubation effects on divergent thinking in other contexts. Orwig et al. (2022) used the trait level of self-report measures to assess the propensity to mind wandering in daily life and observed a positive association between mind wandering and divergent thinking. Similarly, Baird et al. (2012) found mind wandering at trait level was connected to divergent thinking. This raises the question of why it is more common to observe failed incubation effects in laboratory settings, where participants respond to thought probes based on their in-the-moment experiences, as opposed to in the daily life setting. Insights from Kane et al.'s study (2017) on the variability of mind wandering across daily life and laboratory settings could offer some answers. Their study found, for example, that working memory capacity and attention ability predicted the frequency of mind wandering in a laboratory setting, while in a daily-life setting they were predictive only during periods of focused effort. That is, the ability to sustain attention and inhibit irrelevant thoughts is valid when participants consciously make an effort to focus their attention on a task. The findings for personality traits also revealed differences in two settings: openness was associated with the frequency of mind wandering in a daily-life setting, while neuroticism was associated with the rate of mind wandering in a laboratory setting.

The experimental environment itself may not be an ideal condition for fostering natural mind wandering. In the present study, participants were likely focused on maintaining full engagement with the ongoing task, aiming to avoid errors that could harm their performance. This contrasts with real life settings, where mind wandering can occur more freely and naturally. The heightened attention required in a controlled lab setting may suppress the occurrence of mind wandering that has been linked with creativity. In addition to this, the tasks used in experiments could be one possible explanation for the discrepancy between laboratory and real-life findings. These tasks often isolate single aspects of creativity, such as focusing solely on either divergent or convergent thinking, while real-life creative problems are rarely narrowly defined. In daily-life situations, problems usually require the dynamic interplay of both divergent and convergent thinking, as well as other cognitive processes. This might limit the applicability of experimental results to real-life creativity.

The absence of incubation effects in the divergent study compared to past research may also be due to a methodological difference. This study used in-the-moment thought probes to measure mind wandering, which avoids memory bias, but revealed null relationship between mind wandering and divergent task performance. In contrast, Baird et al. (2012) used a retrospective questionnaire (i.e., the daydreaming frequency subscale of the Imaginal Process Inventory) to observe the incubation effect. Steindorf et al. (2021) manipulated four incubation conditions to investigate the role of probes in the relationship between mind wandering and divergent thinking. The results showed that the frequency of mind wandering measured during the incubation period was not influenced by thought probes. However, it is worth noting that probes interrupted thinking during the incubation period and may have influenced the contents of mind wandering, with particular effects on divergent thinking, where greater diffusion of focus may be more important. Based on participants' retrospective mind wandering assessments, they reported higher levels of thoughts about the divergent task before the incubation period in the no-probe incubation condition compared to the thought-probe incubation condition. The conjecture is that probes do not influence the frequency of mind wandering but influence the content of mind wandering and hinder creative processing. Moreover, participants' awareness of their mental state prompted by probes might, in return, remind them to focus on the current task—the incubation task—rather than the previous divergent tasks.

5.4.3 Conclusion

The present study explored the incubation effect, task difficulty, and the relationship between mind wandering and creative problem solving. The study supports the existence of the incubation effect in the context of facing difficulties during problem-solving. Such an effect tends to be more evident in low and intermediate difficulty problems, indicating the need to match the degree of difficulty with an individual's expertise for incubation to be effective, rather than straying too far from it. The influence of task difficulty on creative problem solving suggests that different cognitive pathways may be activated depending on the complexity of the tasks. Tasks with low difficulty may benefit from a diffuse attentional state, while tasks with high difficulty may benefit from a focused attentional state. This is consistent with earlier studies demonstrating that participating in low-demanding tasks during an incubation period might increase the incubation effect. Furthermore, the study investigated the connection between various forms of mind wandering in the context of creativity. It suggests that there might be a connection between mind wandering with awareness and increased creative capacity, indicating a need for further study in this field.

The difference in performance within the same sample across divergent and convergent tasks implies a complex set of factors shaping creative problem solving. Despite the comparable mind wandering frequencies, divergent and convergent tasks seem to have elicited different cognitive engagement levels. These differences may stem from individual preferences for divergent or convergent thinking, which are influenced by working memory capacity. Convergent thinking relies heavily on working memory resources, but the impact of working memory on divergent thinking remains inconclusive with some studies report null effects. The incubation effect observed in the convergent study is influenced by the difficulty level of the tasks. Optimal task difficulty level fosters effective engagement in convergent thinking processing. However, the incubation effect is not universal, as excessively high difficulty level may hinder creative engagement.

6. Chapter six: General discussion

The chapter summarises the findings of the research, which were to explore the understanding of mind wandering in relation to cognitive processes like working memory and creativity, discusses the implication of these, and then addresses limitations and further research directions.

6.1 Summary of findings

6.1.1 Study 1

Study 1 focused on the content and causes of mind wandering experiences. It showed that mind wandering tends to involve thoughts about future issues or personal concerns and is influenced by both internal states and the nature of the ongoing activity. The results showed that participants were aware of their mental state and sometimes chose to let it continue, challenging the view of mind wandering as purely unintentional. Importantly, the findings on mind wandering experiences and the mixed terminology in existing literature suggest the need for an updated definition of mind wandering that is characterised by self-generated thoughts arising from intrinsic changes. Despite differing definition, there is a consensus that mind wandering involves a shift from ongoings tasks or events to self-generate thoughts or feelings. The study also conducted cultural analysis between British and Chinese samples and found similar frequencies of mind wandering but slight differences in the perception of mind wandering. British participants believed that mind wandering had both positive and negative effects, while Chinese participants focused more on negative impacts. This variation might link to cultural values, such as individualism versus collectivism.

6.1.2 Study 2

Study 2 focused on working memory capacity (WMC) and task demand in mind wandering. It was predicted that there was an interaction effect between WMC and task demand. Specifically, participants with high WMC were predicted to be more prone to mind wandering than those with low WMC under low demand settings, whereas those with high WMC were expected to be less inclined to mind wandering under high demand conditions. It was found out that, though the setting of task demand was effective, supported by a significant difference in task performance, the predicted interaction between WMC and task demand did not appear. There was no significant difference in mind wandering between different task demand conditions, and frequency was in general low. Participants with high WMC did not report more mind wandering experiences in the 0-back task or less in the 2-back task compared to those with low WMC. The clear evidence that the objective of varying task demand had been achieved and consistence differences in WMC suggests that the lack of effects does not seem to be attributable to poor operationalisation of the key study variables. Based on the U-shaped relationship between task demand and mind wandering (Randall et al., 2019), it is reasonable that both the 0-back and 2-back tasks in this study were within the optimal level of difficulty so led to lower and equal amount of mind wandering. That is, these employed tasks or that task demand may not be sufficient to produce significant differences in the rate of mind wandering. The changes in mind wandering frequencies were also influenced by another factor – motivation, as higher motivation inhibits the occurrence of mind wandering (Miller et al., 2009). The results may also reflect the influence of collectivist values with emphasis on fulfilling social roles and expectations of groups, as well as the Confucian principles of diligence and effort in achieving success, which may lead to greater focus on tasks and avoid distractions.

6.1.3 Study 3

Study 3 investigated the impact of mind wandering during an incubation on divergent thinking. Contrary to the initial expectation that mind wandering in general would facilitate divergent thinking, the findings failed to find evidence to support this, as there was no correlation between mind wandering (which was no more frequent than in Study 2) and the post-incubation scores of creative performances, whether in terms of originality or fluency. This held for the contribution of mind wandering with awareness, as well as mind wandering without awareness. As there was no difference between the repeated and new exposure conditions, the data imply that incubation effects – even if not based on mind wandering – may not play a beneficial role in this particular experimental context. Studies that found the lack of effects, such as Steindorf et al. (2021) with an accuracy rate of 0.93 and Murray et al. (2021) with 0.91, reported similar high accuracy rates to the present study's 0.96. This suggests that participants were highly engaged in the incubation task (i.e., the 0-back task), which may have limited the cognitive resources available for creative thinking. There possibly exists a competition between mind wandering related to creativity and the cognitive resources needed for the incubation task. The present study used the 0-back task involving verbal processing, where participants responded to letter stimuli rather than spatial locations, aligning the employed divergent thinking task in terms of processing resources. The similarity in processing resources may hinder concurrent operation, potentially limiting the generation of creative solutions.

6.1.4 Study 4

Study 4 examined the influence of mind wandering during incubation on convergent thinking and found that incubation positively contributed to the solution of convergent problems, with significant improvement in repeated exposure conditions, regardless of difficulty level. For repeated problems, mind wandering with awareness was beneficial on low-difficulty problems. For novel problems, practice appeared to enhance performance on moderate difficulty problems, where mind wandering without awareness negatively affected it. The data suggest that the space for more focused reflection on problem structure and solution strategy became more important with the increase in difficulty level, where a certain level of unfocused mind wandering was helpful for insights into the answers to low difficulty problems that had been seen before. Despite similarities in performance on the 0-back task and mind wandering frequencies, the comparison between the convergent and divergent thinking established that incubation effects appeared to exist only in convergent studies, at least in the present research – and that divergent and convergent performance was unrelated in terms of both process and outcome, something that the past tendency for research to focus solely on one or the other has failed to uncover.

6.2 Further discussion of key findings

6.2.1Cultural differences in mind wandering

The findings from Study 1, which explored cultural differences in mind wandering between British and Chinese participants, provide insights into the universality of mind wandering as a cognitive phenomenon, while also highlighting how cultural values and beliefs shape its perception and evaluation. The results suggest that the basic process of mind wandering is indeed universal, as both British and Chinese participants reported similar frequencies and content of mind wandering episodes. However, the way in which these experiences are perceived and evaluated appears to be influenced by cultural factors.

Chinese participants were more likely to view mind wandering as having negative effects on task performance. In contrast, British participants expressed a more balanced view, with some acknowledging positive or neutral effects of mind wandering. This divergence in perception can be attributed to cultural values and beliefs, particularly the influence of Confucian values and collectivist orientations in Chinese culture. The Chinese participants' emphasis on the negative effects of mind wandering can be understood through the Confucian values, which prioritize effort, discipline, and focus. In Confucian tradition, learning and task performance are closely tied to hard work and self-discipline, and lapses in attention, such as those caused by mind wandering, are often seen as failures to meet these cultural expectations (Tweed & Lehman, 2002). This cultural emphasis on effort and focus may lead Chinese individuals to perceive mind wandering more negatively, as it conflicts with their cultural values and the importance placed on maintaining attention and fulfilling social obligations.

Additionally, the collectivist nature of Chinese culture, which emphasizes group harmony and social responsibility, may further contribute to the negative evaluation of mind wandering. In collectivist cultures, individuals are often motivated by a desire to meet societal and familial expectations, and lapses in attention may be perceived not only as personal failures but also as failures to meet the expectations of the group or family. This cultural context may lead Chinese participants to view mind wandering as a threat to their ability to perform well and meet social obligations, resulting in a more negative evaluation of its effects. The results of Study 2, which examined the relationship between mind wandering and WMC in a Chinese sample, further reflect the influence of collectivist values and Confucian principles. The study found that Chinese participants exhibited a strong focus on task performance, even during mind wandering episodes, with many reporting task-related thoughts.

6.2.2 The sensitive balance between task difficulty and mind wandering

Studies 2 and 4 provide an understanding of how task difficulty influences the occurrence and utility of mind wandering. In Study 2, the relationship between WMC and mind wandering was explored under varying task demands. The findings revealed that low-demand tasks (the 0-back task) and high-demand tasks (the 2-back task) showed comparable mind wandering frequencies. The findings suggest that both 0-back and 2-back tasks fell within participants' optimal difficulty range, which led to greater attention to their immediate requirements, explaining the low rates of mind wandering. This aligns with the region of proximal learning (RPL) model, which proposes that tasks within individuals' proficiency level lead to reduced mind wandering; only tasks far beyond their abilities or relatively easy result in frequent mind wandering experiences. The increase in task difficulty does not necessarily suppress or enhance mind wandering. Task difficulty needs to reach a certain threshold before it has a significant impact on mind wandering frequency. This further suggests that mind wandering does not occur in a uniform, predictable manner simply based on task demand. Mind wandering with awareness was frequent in both tasks compared to mind wandering without awareness, and this is primarily associated with anterior prefrontal cortex in the executive network. The activated region supports self-awareness, and increases resources for external monitoring, which may result in reduced occurrence of overall mind wandering. The default network is also thought to underlie the occurrence of mind wandering in both 0-back and 2-back tasks. The results of Study 2 may represent the dynamic interaction between default network and executive network. These tasks are not demanding enough to fully engage the executive network or easy enough to disengage it completely. It is possible that participants feel that when the task is simple, they can afford to engage mind wandering without impairing performance.

Similarly, Study 4 investigated the role of mind wandering in convergent thinking, using tasks of varying difficulty levels (low, moderate, and high). The results showed that mind wandering had differential effects depending on task difficulty. Mind wandering with awareness was beneficial for low-difficulty tasks, while mind wandering without awareness was detrimental to performance on moderate-difficulty tasks. The findings suggest that when difficulty was low, there was spare cognitive resources that allow mind wandering to be productive. When difficulty was higher, cognitive load limited the ability to engage in constructive mind wandering, and unregulated mind wandering disrupted performance. Even though moderate difficulty problems may engage participants' cognitive processes without overwhelming them, it creates a conducive environment for creative processing that is more readily upset. High level difficulty may impose a cognitive strain that simply shuts out other influences. While this pattern hints (as in Study 2) at a potential U-shaped relationship—where moderate difficulty tasks are most sensitive to mind wandering—the study did not explicitly frame its findings in this way. Instead, the results may be taken to confirm the more general point that the occurrence and effect of mind wandering are highly sensitive to task difficulty, as is the type of mind wandering (with or without awareness) that occurs.

It is worth noting that the difficulty level of the task is individually variable. For instance, the 2-back task seems to be more difficult for some people, but the difficulty level is still within the present sample's mastery level. This suggests that the difficulty of the task was not sufficient to induce the higher levels of mind-wandering experiences needed to observe the changes in distinct contexts. When exploring the relationship between mind wandering and difficulty, it is important to consider the factor—individuals' perception of difficulty—as it might influence how they allocate attention.

Barrington and Miller (2023) employed a modified Sustained Attention to Response Task (SART) where the target stimuli changed across blocks rather than remaining constant throughout the whole task, as in the standard SART. Participants perceived the modified SART to be more difficult than the standard SART, but the objective difficulty indicators were the same, and there were no significantly different hit rate and false alarm rate between the two versions. With the increase in perceived difficulty, however, intentional mind wandering experiences (as measured by inserted thought probes) decreased, while unintentional mind wandering remained unchanged. It appears that the perception of difficulty (i.e., the need to sustain attention to changing stimuli) reduces the occurrence of intentional mind wandering, importantly, although this was independent of the actual task demand. The potential role of perception of difficulty in the relationship between attention allocation and mind wandering has been underestimated and needs further investigation.

6.2.3 The complex relationship between mind wandering and creativity

Although the findings of Study 3 and Study 4 did not fully support the expectation that mind wandering universally facilitates creativity, this cannot not rule out the beneficial role of mind wandering. Mind wandering is a dynamic and fleeting cognitive process that interacts with multiple brain networks (e.g., the default and executive networks), making it challenging to study consistently. Its multifaceted nature has led to the growth of diverse definitions and models in the field. Researchers sometimes draw parallels between mind wandering during incubation tasks and spaced learning, as both involve temporal breaks in cognitive processing and can influence memory and learning. However, it can be argued that they involve fundamentally different processes.

In mind wandering paradigms, employing creativity tasks followed by incubation periods, participants are not instructed as to whether or not to think about the task during the incubation period, but simply engage in low-demand tasks during this period in order to encourage mind wandering – or potentially, other forms of reflection. Creativity is measured after the incubation period to assess the impact of this unstructured engagement. Spaced leaning studies, in contrast, typically employ memory or learning tasks with structured intervals between study sessions. Participants are explicitly instructed to engage with the material during each session, and with the intervals planned to optimise memory retention, during which they actively engaged in other activity designed to distract attention away from any consideration of the learning material. The focus is on how spacing out learning sessions without intervening thought improves long-term memory and learning efficiency.

While mind wandering during incubation and spaced learning have overlapping characteristics therefore, they engage different cognitive functions. Mind wandering is an unintentional process that may support creativity, while spaced learning is a structured, intentional strategy for enhancing memory. Mind wandering primarily involves the default and executive networks, associated with self-reflective thinking, not necessarily memory consolidation, which may lead to creative insights, but not improvement in memory. Spaced learning relies on memory reactivation and consolidation after breaks, which directly improves memory retention and recall. Thus, while mind wandering and spaced learning share similarities in their use of temporal intervals, they are distinct in their mechanisms and outcomes.

The results of the present study raise questions about the role of mind wandering in creative problem-solving. Since the overall frequency of mind wandering was not significantly different between divergent and convergent creative tasks, it appears that the quantity of mind-wandering experiences alone may not be a crucial element in boosting creative thinking. While more mind wandering episodes may imply better cognitive flexibility and a greater willingness to try out novel answers, this oversimplifies the relationship between mind wandering and creativity. The number of ideas created through creative problem-solving is important, but so is the applicability of those ideas.

Hao et al. (2015) investigated the effects of mind wandering in the course of creative idea generation. In this study, participants were asked to complete the Alternative Use Task (AUT) within 20 minutes, and mind wandering frequency during the AUT task was measured by probes. Then they were categorised into high and low mind wandering groups based on the median of the mind wandering distribution. The study compared the performance and mind wandering frequencies of the two groups, and the results showed that the high mind wandering group's mind wandering frequency throughout the idea generation process increased with time, but originality on the AUT declined with time. The low group's mind wandering frequency remained constant, and the originality increased with time. This strongly indicates that a higher quantity of mind wandering does not necessarily equate to better creative problem-solving abilities.

Given this, which aspect of mind wandering is actually playing a role in creativity? It appears that diffuse attention throughout the incubation phase can contribute to an incubation effect. A study that tested the cognitive process and problem-solving ability of creative thinking and analytic thinking provides a possible answer to this question (Ansburg & Hill, 2003). This study first presented a memory task with two forms of words: one list of words to memorise (i.e., focal cues) and an alternative list of words played repeatedly in the background to ignore (i.e., peripheral cues). Then participants completed an anagram task in which solutions were related to the memory list and background words. After this, they were asked to recall both words from the memorised list and the background words. Finally, they were asked to solve a Remote Associates Test (RAT) task and deductive reasoning problems. The results showed that RAT scores significantly predicted performance on peripheral and focal anagrams. In contrast, scores on deductive reasoning problems (analytic thinking) did not significantly predict performance on peripheral anagrams, only on focal anagrams. The findings suggest that there are differences between creative thinking and analytic thinking in their relationship to cognitive processes, and creative thinking is more likely to allocate their attention to a broad, focused one. Creative people seem to be more involve a broad or diffused focus, in contrast to analytic thinking, which is more structured and concentrated. Study 4 supports this, but also indicates that the impact of a diffused focus is limited, and more analytic reflection can be productive as well. Notably, Study 3 showed no evidence of either process.

The present research on divergent and convergent thinking implies a duality of mind wandering in creativity. As the controversial findings of mind wandering in neuroscience show, mind wandering is not only associated with default networks but also executive systems that mainly involve the dorsal anterior cingulate cortex and dorsolateral prefrontal cortex regions (Christoff et al., 2009), which indeed implies the dual perspective of mind wandering that it could be goal-directed or spontaneous. This duality suggests mind wandering can have both negative and positive effects on creative problem solving, as found in Study 4.

One way mind wandering might hinder creative thought is by disturbing the creative process. The executive functions of the brain may briefly become weak as a result of this disturbance, making it more difficult to stay focused and make meaningful judgements. The disruption then eventually hampers the controllability of the creative process, which prevents the creative thinking process from proceeding in a coherent manner. Consequently, it may become more difficult to direct and purposefully use creative thoughts, which decreases the effectiveness and quality of creative problem-solving. On the other hand, mind wandering may enhance creativity by encouraging more diffuse creative processes. By allowing thoughts to wander freely, individuals can engage in associative thinking, which in turn helps to spontaneously make connections between seemingly disparate ideas, fostering the exploration of novel solutions. While this dual impact of mind wandering was expected, its effects may depend on the type of creative tasks being performed, with certain tasks benefiting more than others, as seen with convergent thinking in Study 4.

Though it was not apparent in the present research, mind wandering without awareness may facilitate tasks that explore various avenues and consider numerous perspectives, especially divergent tasks that aim to produce a wide range of ideas, some of which may be unconventional. Mind wandering with awareness emphasises purposeful association and intentional exploration of mental landscapes; it is, thus, more helpful for tasks involving systematically evaluating and comparing the potential solution, eliminating less viable options, which aligns with the goal of convergent tasks. Specifically, during tasks based on divergent thinking, creative performance may be favoured when there is a higher percentage of mind wandering without awareness. In contrast, tasks involving convergent thinking may benefit more from a higher percentage of mind wandering with awareness. The paradoxical effects of mind wandering on creativity are driven by the tendency to both impede controlled, conscious thought while stimulating spontaneous, unconscious thought. The dynamic change of cognitive states determines how mind wandering affects creativity. It is, thus, necessary to consider mind wandering as two distinct varieties rather than viewing it as a homogeneous phenomenon – in line with the results of Study 1.

The results of Study 4 support the assumption about the opposing roles of the two types of mind wandering. Mind wandering with awareness was positively correlated with convergent thinking. In contrast, mind wandering without awareness was negatively correlated with convergent thinking – though at a different difficulty level. Convergent thinking relies heavily on working memory as it requires focused attention, and the ability to integrate information to arrive at a single correct solution (De Dreu et al., 2012). As discussed in Study 2, mind wandering with awareness is primarily associated with anterior prefrontal cortex, which is linked to executive network. It is logical that this type of mind wandering facilitates convergent thinking. Mind wandering without awareness is primarily associated with the medial prefrontal cortes, a core region of the default network. Since it disrupts working memory processes, it leads to a loss of task-relevant information and increased unregulated distraction. This distinction may explain why previous research has reported conflicting findings on the effects of mind wandering. Some studies have shown that mind wandering enhances creativity, while others have found that it impairs performance. Failing to distinguish between mind wandering with and without awareness may be a key reason for these inconsistencies. Studies that capture mind wandering with awareness are more likely to report positive effects – in the context of convergent thinking, at least – while those measuring mind wandering without awareness often highlight its disruptive nature. Further research should continue to explore how awareness shapes mind wandering, ensuring that this complex cognitive process is better understood.

6.3 Implications regarding mind wandering in education

The implication of the present research for education would appear to be that it is necessary to suppress its negative effects, as in previous work, and more controversially, to encourage its positive aspects. Incorporating quizzes during lecture can reduce mind wandering and improve retention (Szpunar et al., 2013). Active learning interventions can help re-set students' concentration levels. Burke and Ray (2008) explored the effectiveness of active learning interventions in the concentration levels of undergraduate students during college lectures. In this study, students were exposed to each of four interventions: truth statement (i.e., students wrote down a statement they believed to be true about upcoming topic, shared it with the class, and discussed its validity), student-generated questions (i.e., student wrote down a question, exchanged it with a peer, and they attempted to answer each other's questions), guided reciprocal peer questioning (i.e., students created specific questions based on generic prompts provided by the instructors, then asked and answered these questions with a peer), and think-pair-share (i.e., students individually reflected on a question, paired up to discuss their thoughts, and then shared their ideas with the class). They rated their concentration level on a scale at five intervals: 7 minutes after the start of class, immediately before the intervention, at the end of the intervention, 7 minutes post-intervention, and 15 minutes post-intervention. The results showed that the highest concentration ratings occurred at the end of the interventions, indicating that active learning strategies can help refocus. However, the effect was relatively small, possibly because the baseline concentration levels were already high. The guided reciprocal peer questioning and student-generated questions had maximal impact on concentration levels, suggesting that the two interventions encouraged deeper engagement with the material. It is worth noting that all students experienced the interventions in the same order, so it is possible that the observed effects were influenced other factors rather than the interventions themselves. For example, the practice effects could inflate the effectiveness of later interventions. The experience of the first intervention might have influenced how students responded to subsequent interventions. The last two interventions were the most effective interventions, which might be due to their position in the sequence rather than their inherent effectiveness. Conversely, the first two interventions may have appeared less effective because they were positioned earlier in the study, where students were less familiar with the process. The lack of counterbalancing means that the results should be interpreted with caution, but these findings are still valuable as an exploratory study.

The RPL model offers additional insights for educational practice by emphasizing the importance of task difficulty in optimizing cognitive engagement and minimizing mind wandering. According to the RPL model, tasks that are too easy or too difficult are more likely to lead to mind wandering, while tasks within the learner's RPL that are moderately challenging maximise engagement and learning outcomes (Xu & Metcalfe, 2016). Educators can apply this framework by designing tasks and modules that are tailored to students' current skill levels, ensuring that tasks are challenging enough to promote growth but not so difficult that they cause frustration or disengagement. For example, differentiated instructions or strategies can help students work within their RPL, reducing mind wandering and enhancing learning efficiency. Additionally, incorporating formative assessments to monitor students' progress and adjust task difficulty accordingly can help maintain optimal challenge levels and minimise mind wandering.

As suggested by Study 3 and Study 4, the benefits of mind wandering for learning may be limited and context-dependent. Rather than attempting to suppress mind wandering entirely, though, a more effective approach may involve breaks where it can occur naturally and encouraging it in a productive way. Apart from active learning strategies, mindfulness training is a promising approach to channelling mind wandering. Rather than eliminating mental activities, guiding them purposefully can foster creativity and deeper cognitive processing. Bennike et al., (2017) tested the effect of mindfulness training on mind wandering, using the Headspace app that emphasises focusing attention on the present experience and learning to focus attention. This app provided guided audio meditation led by an instructor, including breath awareness (i.e., focusing on the rhythm of the breath), body scan (i.e., bringing attention to body parts to cultivate awareness of physical sensations), mindful observation (i.e., noticing thoughts and emotions), and returning to present (i.e., redirecting attention back to the present moment when the mind wanders). Participants initially completed the SART with inserted thought probes measuring mind wandering, which served as the baseline performance. Then they divided into two groups, one taking the mindfulness training, the other as the control group engaging in non-specific effects online training. After the 4-week intervention, participants repeated the SART to assess changes in mind wandering and behavioural indicators. The results showed that mindfulness group had significant improvement in the SART performance and reductions in mind wandering, while the control group did not. However, rather than suppressing mind wandering, mindfulness training enhances metacognitive awareness, helping students recognise when their attention has drifted and redirect it back to the task. The idea is further supported by the study by Teng and Lien (2022), which suggests that mindfulness helps direct mind wandering in a productive and creative way. Participants in the group with mindfulness training outperformed those in low-demanding condition (i.e., the 0-back task) in divergent thinking performances, with fewer but more diverse mind wandering experiences, such as intentional, unintentional, aware and unaware mind wandering. The suggests that mindfulness does not suppress mind wandering entirely but instead guiding these experiences toward productive avenues. By fostering a state of awareness, mindfulness enables individuals to channel their mind wandering toward creative problem-solving. Given its accessibility and potential to enhance both attention and creative thinking, mindfulness training is a promising intervention for education settings.

6.4 Limitations

6.4.1 Sample size

Challenges regarding the recruitment of participants, particularly the British sample in Study 1, somewhat impacted the generalisability of the findings. Although the number of British participants was slightly smaller compared to the Chinese sample, this imbalance in sample size may limit the ability to fully represent the British sample and may fail to show the uncover cultural differences. It potentially skews the overall interpretation of the data. However, the sample size is still adequate for drawing meaningful conclusions. If possible, the future study on the cultural comparison should collect more data to balance the sample sizes.

6.4.2 Insufficient task demands

In Study 2, task demands were manipulated to create two distinct cognitive conditions: the 0-back and 2-back tasks. The significant differences on reaction time and accuracy rate between the 0-back and 2-back tasks suggest that the manipulation was effective; however, mind wandering frequencies were similar between the two tasks. It implies that the task demands may be insufficient to differentiate mind-wandering frequencies. The 2-back does not appear to be challenging enough to the current sample to induce a noticeable increase in mind wandering. It is evidenced by Randall et al.'s (2013) study that participants in difficult conditions reported more mind-wandering experiences compared to those in moderate conditions. Thus, future research should consider adjusting task difficulty based on the experimental sample to capture variations in mind wandering.

6.4.3 Cognitive resources overlap in incubation periods

The task used during the incubation period possibly resulted in unrepresentative null results, that is, there was no observable beneficial role of mind wandering in the divergent study (e.g., Study 3). Incubation tasks have been shown to influence creative performances (Gilhooly, Georgiou & Devery, 2013). Specifically, when incubation tasks and creative tasks use different cognitive resources, like one involving verbal processing and the other involving spatial processing, they can be conducted together with little interference. However, if both tasks rely on the same types of cognitive resources, such as verbal processing for both in Study 3, they are more likely to interfere with each other and compete for those resources, making it harder to do both tasks effectively. Study 4 employed the same setting as Study 3 that both incubation tasks and creative tasks involve verbal processing; nevertheless, the results found the positive effect of mind wandering in convergent tasks. This inconsistency further indicates that the relationship between mind wandering and creativity is complex, with other unknown factors possibly contributing to the positive effects. It is thus important to consider the type of incubation task used when focussing on creative performances, as the overlapping of cognitive resources may impact the creative outcomes.

6.4.4 Creativity assessment

Despite the creativity study employing both divergent and convergent thinking, attempting to provide a holistic view, the use of alternative tasks and remote associate tasks seems to be limited in measuring individuals’ creativity abilities. The two assessments reflect certain parts of individuals’ creativity rather than representing all facets of their creativity levels. It is reasonable that several researchers have criticised the low correlation between laboratory test results and actual creative performance (Zeng et al., 2011). The lack of ecological validity means that the laboratory results might not effectively apply to real-life situations in terms of both creative performance and the impact of mind wandering. There is therefore a need to find an assessment that mirrors the real-life problems to yield more reliable and valid results.

6.5 Future directions

Although the research did not directly measure motivation, the findings suggest that it may play a significant role in reducing mind wandering, as observed in Study 2, where increased task demands did not lead to differences in mind wandering. It indicates that motivation might be closely linked to the ability to control attention. Highly motivated participants might be better at allocating their cognitive resources, thus minimising the occurrence of mind wandering and improving task performance. Yee and Braver (2018) argued that motivation enhanced reactive control, allowing individuals to respond well to the immediate stimuli, resulting in improved task performance. Further research has explored the neural mechanisms behind the interaction between motivation and cognitive control, in particular the role of dopamine. This helps individuals focus on the task and adjust attention in response to relevant stimuli, suggesting that it may be a key factor in regulating task performance (Yee & Braver, 2018). The research on motivation mainly uses external incentives, such as rewards or monetary incentives, but this present sample with a higher motivated state produced good performances – relatively high accuracy and fast reaction time in the 0-back task, likely due to internal motivation. It is crucial to understand how motivation, both internal and external, moderates the interaction between mind wandering and cognitive performance – and acknowledge that this may have a cultural dimension.

Study 4 used a convergent thinking test with various difficulty levels, revealing differential incubation effects for these difficulty conditions. However, the study failed to capture the dynamic changes in mind wandering and its subtypes with the increase of difficulty levels. As discussed in above, the qualities of mind wandering itself might not be a necessary condition for the success of the incubation effect. Instead, the ratio of mind wandering with awareness to mind wandering without awareness could play a key role in modifying the relationship between mind wandering and creativity in different task contexts. In order to further examine this hypothesis, it would be possible to adjust the experimental setting based on the current Study 4. For instance, each participant completes three blocks of tasks with counterbalanced difficulty levels. Each block consists of a convergent thinking task with varying difficulty (e.g., low, moderate, and hight), an incubation task with inserted thought probes to measure mind wandering, and a return to the original creative task (plus new problems with the same difficulty). The key difference in the experimental procedure between the Study 4 and the modified one is that the Study 4 procedure groups all problems into a single task with mixed difficulty levels, while the modified one separates the problems into three blocks, each with a specific difficulty level. The separation by difficulty allows for direct tracking of how mind wandering dynamically varies across low, moderate, and high difficulty tasks and possibly offers the chance to investigate the relationship between cognitive load and mind wandering.

The value and contribution this research can be summarised in three points. First, this research distinguishes mind wandering from related constructs and provides a clear definition of its characteristics. Second, this research contributes to the understanding of WMC and task demand on mind wandering, revealing that while this factor impact task performance, their relationship with mind wandering is more complex than initially expected. Third, previous research on mind wandering has been concerned with either divergent thinking or convergent thinking, and not much research has considered a holistic view of creativity, bringing together the two aspects of creative problem solving. This research acknowledges the dual nature of mind wandering and varying impacts on different types of creative tasks, contributing to the understanding of the cognitive processes underlying creativity.

7. References

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