Understanding the varieties of self-generated thought

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Abstract

Although self-generated thought (SGT i.e. cognition unrelated to the here and now) has traditionally been considered as a homogeneous phenomenon, recent findings challenge this assumption by showing that SGT can have both costs and benefits, and that SGT can be linked to both executive control and executive failure. To gain insight into these discrepancies, this PhD tested the hypothesis that SGT is a heterogeneous phenomenon and examined whether the content of the thoughts is one factor underlying the heterogeneities observed. By taking into account the temporal, social and emotional dimensions of SGT content, we were able to systematically identify distinct types of thoughts. In addition, we observed that these different SGT types can have heterogeneous functional outcomes (for example, in terms of their relation to task performance or to measures of self-concept). We also found that these SGT types can have different phenomenological properties, suggesting that heterogeneous cognitive correlates are recruited during the generation of distinct types of thoughts. Finally, we demonstrated that the neural substrates of SGT (as assessed using resting state fMRI) varied according to individual differences in thought content. Altogether, the empirical findings described in the current thesis strongly support the hypothesis that SGT is a heterogeneous phenomenon and highlight that taking into account SGT content allows a better understanding of the neurocognitive underpinnings supporting this subjective experience.

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Author's Declaration

I hereby declare that I am the sole author of the doctoral thesis entitled "Understanding the varieties of self-generated thought" and that the thesis has not previously been submitted for another degree at this or any other university. The work was completed under the supervision of Dr. Jonathan Smallwood. Part of the work was conducted in collaboration with others and has been previously published or presented at conferences.

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Chapter 1.
General Introduction

1.1 Self-generated thought as a heterogeneous phenomenon

Individuals can generate mental experiences based on previously acquired knowledge rather than current environmental input. These self-generated thoughts (SGT, often described as mind-wandering or day-dreaming) allow individuals to escape the here and now, by simulating future events, remembering the past or imagining someone else's thoughts (Smallwood, 2013; Andrews-Hanna et al., 2010). The current thesis aims to gain a better understanding of the neurocognitive processes supporting SGT.

1.1.1 SGT as a homogeneous experience

Because SGT allows individuals to process information that is independent from the immediate environment, research on SGT has usually emphasised a dichotomy between SGT and perceptually-guided thoughts (PGT). This dichotomy is apparent in the terms that have been used to label the two types of cognitions e.g. task-unrelated vs. task-related thought (Barron, Riby, Greer, & Smallwood, 2011; Smallwood, Obonsawin, & Heim, 2003), stimulus-independent vs. stimulus-dependent thought (Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011; Teasdale et al., 1995), or internally vs. externally-guided cognition (Smallwood et al., 2012). This dichotomy is also reflected by the methodological approaches employed to measure SGT. For example, probing methods used to assess SGT and PGT usually consist of questions such as "are you thoughts focused on the task, or on something else?" (Smallwood, Ruby, & Singer, 2013). In addition, SGT is commonly measured while participants perform complex tasks during which SGT occurrence leads to deleterious effects on their performance (Kane et al., 2007; McVay & Kane, 2012; Smallwood, Riby, Heim, & Davies, 2006; Smallwood, 2011; Stawarczyk, Majerus, Maj, et al., 2011). Taken together, both the labels and the methods employed focus on SGT as a mental experience unrelated to the here and now. As a consequence, these approaches have led to a simplified characterisation of SGT and to the assumption that SGT is a homogeneous phenomenon. Yet, evidence in the literature challenges this supposition.

1.1.2 Inconsistencies in the literature

1.1.2.1 Costs and benefits of SGT

Recent reviews illustrate the substantial body of evidence showing that SGT is associated with both negative and positive functional outcomes (Mooneyham & Schooler, 2013; Ottaviani & Couyoumdjian, 2013; Smallwood & Andrews-Hanna, 2013). Negative consequences are commonly observed when SGT occurs during complex tasks. Under laboratory conditions, SGT has been associated with reduced comprehension and increased reading durations during reading tasks (Smallwood, 2011). In tasks requiring sustained attention, SGT has been linked to absent-minded errors, cognitive failure and reduced attentional processing of external stimuli (e.g. Kane & McVay, 2012; McVay, Kane, & Kwapil, 2009). Evidence also suggests that it is associated with poor measures of fluid intelligence and reduced working memory capacity (WMC, Mrazek et al., 2012). In daily life, SGT has been involved in automobile accidents (He, Becic, Lee, & McCarley, 2011; Yanko & Spalek, 2013) and reduced learning outcomes (Lindquist & McLean, 2011; Szpunar, Khan, & Schacter, 2013). Finally, SGT has also been linked to negative mood, with some studies finding a causal negative effect of SGT (Killingsworth & Gilbert, 2010) and others reporting increases in SGT during dysphoria (Smallwood, O'Connor, Sudbery, & Obonsawin, 2007) or following negative mood inductions (Smallwood, Fitzgerald, Miles, & Phillips, 2009; Smallwood & O'Connor, 2011).

Despite the large body of evidence supporting the view that SGT is linked to negative functional outcomes, other studies also report an increasing number of benefits. SGT has been linked to more patient choices during inter-temporal discounting tasks (Smallwood, Ruby, et al., 2013), increased performance in tasks requiring creative problem solving (Baird et al., 2012) as well as mnemonic advantages and increased likelihood of enacting goals (Mason & Reinholtz, 2015). SGT also supports emotion regulation (Poerio, Totterdell, Emerson, & Miles, 2015) and pain regulation (Kucyi, Salomons, & Davis, 2013). Taken together, these studies suggest that tendencies to generate SGT may also be beneficial. The observation that SGT can be both advantageous and deleterious is therefore inconsistent with the assumption that SGT is a homogeneous phenomenon.

1.1.2.2 Role of executive functions in SGT

In addition to findings highlighting the positive and negative outcomes of SGT, another discrepancy in the literature relates to the role of executive functions in SGT. Studies investigating SGT under constraining conditions (e.g. during a complex task) have shown that its occurrence is associated with poor executive processes, for example reduced

WMC (Kane et al., 2007; McVay et al., 2009; McVay & Kane, 2009, 2012). Based on these findings, the *executive failure model* proposed by Kane & McVay (2012) affirms that SGT occurs due to a failure of the executive system in either maintaining the pursuit of an ongoing goal (such as correctly performing the task at hand), or effectively inhibiting the generation of a mind-wandering episode. However, other studies have reported data contradicting the executive failure model. Levinson and colleagues found that participants with higher WMC experienced SGT more frequently when performing non-demanding tasks (Levinson, Smallwood, & Davidson, 2012). Similarly, Rummel & Boywitt (2014) reported that individuals with larger WMC were better able to regulate the occurrence of SGT according to the demands of the external environment i.e. SGT was reduced when performing a demanding task but increased during non-demanding situations. Using functional magnetic resonance imaging (fMRI), Christoff and colleagues also showed that regions supporting executive processes were activated during mind-wandering (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009). Altogether, these data illustrate the *executive control hypothesis* which states that executive functions actively support SGT (Barron et al., 2011; Smallwood & Schooler, 2006; Smallwood, 2013a).

In summary, data in favour of both the executive failure and the executive control hypothesis suggest that SGT can be associated with better and worse executive processes. These findings as well as the observation that SGT can have both costs and benefits are therefore inconsistent with the assumption that SGT is homogeneous and highlight the need for developing an alternative model that is able to explain these conflicting results. In the current thesis, we propose to take into account SGT characteristics (e.g. the content of the thoughts and the context in which they are generated) to gain a better understanding of the contrasting findings described in the literature.

1.1.3 SGT as a heterogeneous phenomenon

The current PhD aims to resolve the inconsistencies reported in the literature by considering SGT as a heterogeneous experience. We will test the hypothesis that SGT consists of different types of thoughts, and that each type can possess a specific set of functional outcomes. For example, one type of SGT may be associated with poor executive functions whereas another may be linked to improved abilities. Considering the existence of separate types of SGT therefore provides a potential explanation for the inconsistent findings reported in the literature. In addition to describing how the complex properties of SGT may emerge, the PhD also attempts to show that a better characterisation of the cognitive and neural processes supporting SGT can be obtained by taking into account its heterogeneity.

1.2 Theoretical framework

Considering SGT as a heterogeneous phenomenon requires an explanation for i) the potential factors involved in SGT heterogeneities and ii) an outline of the mechanism underlying SGT heterogeneities. First, we propose that both the content of the thoughts and the context in which they occur may lead to SGT heterogeneities (Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015). Second, we propose to use the *component process hypothesis* as a theoretical framework to clarify how SGT heterogeneities may emerge. The component process hypothesis states that specific cognitive and neural components are selected according to the specific requirement of the SGT experienced, therefore allowing SGT to possess heterogeneous properties (Andrews-Hanna, Smallwood, & Spreng, 2014; Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015; Smallwood, 2013a).

1.2.1 Factors involved in SGT heterogeneity

1.2.1.1 <u>Content of SGT</u>

Several independent research groups have demonstrated that individuals tend to generate thoughts that are directed towards the future rather than the past (Baird, Smallwood, & Schooler, 2011; Iijima & Tanno, 2012; Smallwood, Nind, & O'Connor, 2009; Smallwood, Schooler, et al., 2011; Song & Wang, 2012; Stawarczyk, Majerus, Maj, et al., 2011). In addition to occurring more frequently, future thinking also involves goal-directed cognition (Baird et al., 2011; Cole & Berntsen, 2015; Stawarczyk, Majerus, Maj, et al., 2011) and is linked with self-referential processes (Smallwood, Schooler, et al., 2011). Altogether, this suggests that future-focused SGT, but not past-focused SGT, is related to autobiographical planning. Studies also highlight that the relation between SGT and well-being depends on SGT content. For example, past but not future SGT is linked to depressive symptoms (Ruby, Smallwood, Engen, & Singer, 2013; Smallwood & O'Connor, 2011). In addition, increases in mood levels are observed following the generation of thoughts focused on the future (Ruby, Smallwood, Engen, et al., 2013), on interesting matters (Franklin et al., 2013) and on significant others (Poerio et al., 2015). Following a stress induction, future thinking is linked to reduced physiological stress markers (Engert, Smallwood, & Singer, 2014). Finally, life satisfaction is positively related to SGT taking into account close others and negatively linked to SGT involving non-significant acquaintances (Mar, Mason, & Litvack, 2012).

Altogether, these results are summarized by the *content regulation hypothesis* (Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015) which states that different types of SGT have heterogeneous functional outcomes. Based on these findings, we propose that the content of the thoughts is an important factor underlying SGT heterogeneity. However, although the literature highlights that the content of SGT is related to its functional outcomes, studies have failed to provide a clear description of distinct types of SGT. The first aim of the PhD will therefore be to identify potential types based on the content of the thoughts.

1.2.1.2 Context of SGT

The context in which these different types of thoughts occur also plays a role in SGT heterogeneities. For example, SGT is reduced when participants perform a demanding task but is increased under less demanding conditions (Smallwood et al., 2013; Smallwood, 2013b; Smallwood, Brown, et al., 2011). In addition, SGT is linked to poor task performance when it occurs during complex tasks, but does not have a significant impact on the performance of tasks requiring less resources (Kane & McVay, 2012; Smallwood, 2013a). Moreover, the *context regulation hypothesis* proposed by Smallwood and colleagues suggests that individuals are able to efficiently regulate the generation of SGT to non-demanding conditions in order to limit their potential negative outcomes on the task at hand (Levinson et al., 2012; Rummel & Boywitt, 2014; Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015). Taken together, these findings show that the functional outcomes of SGT may vary according to the context in which the thoughts occur and highlight that the context may be an additional factor involved in SGT heterogeneities.

1.2.2 Component process hypothesis

The following section will outline the potential mechanism allowing SGT heterogeneities to arise based on the thoughts' content and context. We propose to use the *component process hypothesis* as a theoretical framework to gain a better understanding of SGT (Andrews-Hanna et al., 2014; Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015; Smallwood, 2013a). The component process hypothesis states that different sub-processes may be flexibly recruited according to the necessities of different types of SGT and that this flexible selection allows SGT heterogeneities to emerge. The potential processes involved will be discussed hereafter.

1.2.2.1 Examples of cognitive processes recruited during SGT

Smallwood (2013) proposes a model in which episodic memory, working memory and emotional processing interact in order to generate SGT. Although all these three components are involved in SGT, evidence suggests that different types of thought may rely on these processes to a different extent.

Episodic memory. As mentioned above, SGT commonly involves the simulation of future events or the retrieval of past events (Baird et al., 2011; Iijima & Tanno, 2012; Smallwood, Nind, et al., 2009; Song & Wang, 2012; Stawarczyk, Majerus, Maj, et al., 2011). Although both types of SGT rely on episodic processes, they differ with regard to the manipulation of previously-stored information. Past-related thoughts are constructed based on mental episodes that were generated during the occurrence of the corresponding event. On the contrary, future-related thoughts emerge from the generation of hypothetical episodes and therefore require the flexible reorganization of information and additional simulation processes compared to past-related SGT (Addis & Schacter, 2011). Neuroimaging studies provide evidence that both types of SGT rely on episodic memory, but that Future SGT may require additional episodic processes. For example, several regions that are part of the Default Mode Network (DMN), such as the posterior cingulate cortex (PCC) and the medial prefrontal cortex (mPFC), are activated during SGT (Andrews-Hanna et al., 2014; Christoff et al., 2009; Mason, Norton, et al., 2007; Smallwood, Tipper, et al., 2013). However, studies have found that regions such as the hippocampus are more active during the generation of future vs. past autobiographical memories (Addis, Cheng, Roberts, & Schacter, 2011; Mason, Bar, & Macrae, 2007; van Mulukom, Schacter, Corballis, & Addis, 2013). Overall this suggests that episodic memory may be involved differently in distinct types of SGT.

Working memory. Working memory is traditionally described as a mechanism that allows the manipulation of information in a goal-related fashion (Baddeley, 1992). Evidence from cognitive psychology shows that future-related SGT is frequently goal-directed and that individual differences in future-related SGT, but not past-related SGT, predicts WMC (Baird et al., 2011). Neuroimaging studies also support the assumption that working memory may be differently involved in different types of thoughts. For example, Spreng, Stevens, Chamberlain, Gilmore, & Schacter (2010) observed that during an autobiographical planning task (which required participants to generate detailed plans in order to reach specific goals), the DMN was coupled to the Frontoparietal Network (FPN), which supports working-memory and control processes. On the contrary, studies investigating the neural correlates of retrospective memory do not usually report the involvement of this network (Tulving, 2002). Overall these findings suggest that working memory may be more involved during the generation of future-related SGT compared to past-related SGT, and therefore supports the component process hypothesis.

Emotional processing. As mentioned above, several studies highlight a negative link between SGT and mood (Killingsworth & Gilbert, 2010; Smallwood, Fitzgerald, et al., 2009; Smallwood, O'Connor, et al., 2007; Smallwood & O'Connor, 2011). In addition, studies investigating the content of SGT also show that individuals often describe their thoughts as involving emotional information (e.g. Andrews-Hanna et al., 2013; Engert et al., 2014; Killingsworth & Gilbert, 2010; Ruby et al., 2013). Moreover, Tusche, Smallwood, Bernhardt, & Singer (2014) report that emotional SGT rely on similar brain structures as task-driven emotion processing. Overall these studies demonstrate that emotional processing and SGT are closely related. Nevertheless, differences may exist for different types of SGT. For example, Andrews-Hanna et al. (2013) found that SGT with different temporal aspects have on average a different valence i.e. past-SGT are more likely to be negative whereas future-SGT are more likely to be positive, in line with D'Argembeau & Van der Linden (2006). Similarly, Ruby et al. (2013) showed that Past SGT predicts subsequent decreases in mood, whereas Future SGT is associated with subsequent improvements in mood. In addition, levels of Past SGT, but not Future SGT, are increased during depression and dysphoria and patients with suicidal attempts lack future-related SGT (O'Connor & Noyce, 2008; Smallwood & O'Connor, 2011). Altogether, although SGT is linked to emotional processing, this relationship may vary according to the content of SGT.

1.2.2.2 Component process model

The evidence presented above suggests that several sub-processes (e.g. episodic memory, working memory, emotional processing) are involved in SGT but may be differentially recruited under certain circumstances. These findings illustrate the component-process hypothesis, which proposes that the brain is able to flexibly select and coordinate sub-processes according to the type of SGT being generated, therefore accounting for the heterogeneity of SGT in terms of neurocognitive processes and functional outcomes.

Flexible selection of sub-processes. From a general cognitive and neural architecture, specific component processes can be selected and others can be simultaneously neglected according to the type of SGT being processed. This leads to a functional reorganization of both the cognitive and neural architectures that is specific to the SGT experienced, similarly to the reorganization that occurs during the processing of specific PGT e.g. processing of visual stimuli reply on occipital areas (e.g. Grill-Spector & Malach, 2004) whereas processing of auditory simuli recruit the auditory cortex (e.g. Zatorre, Belin, & Penhune, 2002).

Competition for accessing the sub-processes. Because the brain can only process a limited amount of information at any current time, SGT will compete with other sources of information (e.g. other internally or externally-generated information) to access the required sub-processes. When SGT is favoured over PGT, the processing of SGT will cause a reduction in the resources directed towards PGT, therefore impairing the processing of externally-generated information. This *perceptual decoupling* is supported by electroencephalography (EEG) and pupillometry findings showing that responses to external stimuli are reduced during mind-wandering episodes (Kam et al., 2011; Smallwood, Brown, et al., 2011). Thus, the component-process hypothesis provides an explanation for SGT's negative consequences reported in the literature.

Heterogeneity in SGT consequences. Because different types of SGT recruit different cognitive and neural processes, the consequences of SGT when they occur during a task will vary. If SGT and a task rely on the same cognitive or neural processes to be performed properly, there will be a competition between internal and external inputs, and the processing of SGT will lead to worse task performance. For example, when SGT occurs during a reading task, working memory and mental simulation processes are recruited by SGT, leading to decreases in reading comprehension (Smallwood, 2011). On the other hand, if SGT and the task at hand do not rely on the same processes, the consequences of SGT on task performance may be limited. For example, in an easy task that does not heavily rely on working memory, the recruitment of WMC for the processing of SGT is not associated with reduced task performance (Levinson et al., 2012). The component process hypothesis therefore provides a potential explanation for the heterogeneous consequences of SGT observed under different contexts.

1.2.2.3 Conclusions

To summarize, findings highlight that the content and context of SGT are two features that can influence its functional outcomes. Different types of SGT occurring in different conditions can lead to a wide range of consequences on the task at hand. The component process hypothesis proposes that SGT heterogeneities are made possible through the specific recruitment of cognitive and neural sub-processes for distinct types of thoughts. In the current PhD, we will first aim to identify different types of SGT based on their content. Next, we will test whether these different SGT exhibit distinct functional outcomes and finally, whether they rely on heterogeneous cognitive and neural processes.

1.3 Current thesis

The aim of the PhD is to provide evidence for our hypothesis that SGT is a heterogeneous phenomenon. To this end, we conducted four experiments in order to test the following three predictions:

i. Different types of SGT can be characterised based on the content of the thoughts.
ii. Different types of SGT have heterogeneous functional outcomes.
iii. Different types of SGT rely on distinct cognitive and neural correlates.

Findings in favour of these three predictions would demonstrate that the content of SGT is an important factor influencing SGT properties and that the component process hypothesis is one mechanism underlying SGT heterogeneities. Taken together, this would provide support for the general hypothesis that SGT is a heterogeneous phenomenon.

1.3.1 Identification of SGT types

Although the literature has highlighted that the content of SGT is related to its functional outcomes, studies have failed to provide a clear description of distinct types of SGT. The first aim of the PhD will therefore be to provide evidence in favour of the hypothesis that different types of SGT can be identified based on the content of the thoughts.

1.3.1.1 <u>Dimensions of SGT content</u>

Smallwood et al. (2009) found that as much as 60% of off-task thoughts are directed either towards the future or towards the past (later replicated by Baird et al., 2011; Iijima & Tanno, 2012; Song & Wang, 2012; Stawarczyk et al., 2011), therefore showing that a temporal dimension is a common component of SGT. Studies have also found that individuals generate thoughts involving oneself (Baird et al., 2011; Smallwood, Schooler, et al., 2011; Tusche et al., 2014) and others (Andrews-Hanna et al., 2013; Mar et al., 2012; Poerio et al., 2015; Song & Wang, 2012), suggesting that a social dimension is also significant. Finally, individuals frequently report thoughts with a negative or positive valence, demonstrating that SGT possesses an emotional dimension (Andrews-Hanna et al., 2013; Engert et al., 2014; Killingsworth & Gilbert, 2010; Ruby, Smallwood, Engen, et al., 2013; Tusche et al., 2014). Based on these findings, we propose that the temporal, social and emotional dimensions are significant constituents of SGT content.

Although these studies provide insight into the relevant features of SGT, each aspect has traditionally been considered independently from the others and the characterisation of clear types of thoughts has been overlooked. Here we adopt a more holistic approach and propose to described SGT content as a combination of these three dimensions. We hypothesise that the interaction between the temporal, social and emotional dimensions of SGT constitutes the basis for different types of SGT and provides individuals the freedom to engage in a wide range of subjective experiences (e.g. rumination, worry, reminiscence, prospection and so on). The first aim of the PhD will be to statistically identify how the three dimensions interact in order to define distinct types of SGT.

1.3.1.2 Overview of the methodological approach

To measure SGT content, we will use an experience sampling approach applied to laboratory conditions. SGT will be probed while participants perform a cognitive task. The task, extensively used in the SGT literature, consists of two conditions: a non-demanding Choice Reaction Time task (CRT) and a more demanding Working Memory task (WM, Smallwood, Nind, et al., 2009; Smallwood, Ruby, et al., 2013; Smallwood, Brown, et al., 2011; Smallwood, Tipper, et al., 2013). Employing two distinct conditions allows us to manipulate the context in which SGT occurs and to apply boundary conditions to SGT, therefore providing us the chance to investigate how the properties of distinct types of SGT vary according to external demands.

Participants will be probed about their SGT while performing the cognitive task. Each probe will assess the temporal, social and emotional dimensions of SGT as well as whether the thoughts were task-related or task-unrelated. We will examine how the three dimensions interact using Principal Component Analysis (PCA). PCA is commonly used to reduce a large number of variables into a smaller number of components based on the covariance among the initial variables (Jolliffe, 2002). We will take advantage of this property in order to statistically determine how the three dimensions interact and form distinct types of SGT, as represented by the components obtained via PCA. Previous studies have shown that three main types of SGT can be identified using this approach. These consist of: i) future-focused SGT (with a social element), ii) past-focused SGT (with a social element), and iii) emotional SGT (independent from the temporal and social dimensions, see Engert et al., 2014; Ruby et al., 2013).

The studies conducted in the PhD will aim to provide evidence for the claim that SGT types can be identified based on the content of the thoughts. Chapter 2 describes in detail the methods employed to measure and characterise SGT types. Subsequent chapters will demonstrate that the structure of SGT is replicable, can be validated by independent measures and can be manipulated, altogether demonstrating that the types of SGT are meaningful.

1.3.2 Investigating the functional outcomes of different types of SGT

Following the identification of distinct thought types, we will investigate whether these different types have heterogeneous functional outcomes. To this end, our analyses aim to highlight the potential similarities and differences between types of SGT. For example, Ruby et al. (2013) observed three types of SGT using PCA, namely future-related, past-related and emotional SGT. They found that both negative SGT and past-related SGT were linked to subsequent decreases in mood levels. On the contrary, future-related SGT was linked to subsequent increases. These data suggest that the relation between SGT and mood levels is heterogeneous and is related to the thought content. More generally, this study supports our claim that distinct types of SGT can be identified based on the content, and that these distinct types may have heterogeneous functional outcomes.

The studies conducted throughout the PhD rely on an individual differences approach and explore whether individual differences in SGT content can predict individual differences in other measures (e.g. questionnaire scores, task performance, and so on). First, Chapter 3 investigates the link between SGT and social problem solving. Findings show that SGT is often related to individuals' current concerns and unresolved goals (Baird et al., 2011; Cole & Berntsen, 2015; Klinger, 1978, 1999; Mason & Reinholtz, 2015). In addition, SGT commonly involves other individuals and is linked to creative problem solving (Andrews-Hanna et al., 2013; Baird et al., 2012; Mar et al., 2012; Poerio et al., 2015; Song & Wang, 2012). Taken together, this suggests that individuals who spontaneously engage in SGT may possess good social problem solving skills. Chapter 3 investigates whether SGT is related to social problem solving and whether this relation varies for different types of SGT.

Chapter 4 examines the role of SGT in shaping one's sense of self, or self-concept. Previous studies have shown that SGT is often self-related (Baird et al., 2011; Smallwood, Schooler, et al., 2011; Tusche et al., 2014) and that future-directed SGT (but not past-directed SGT) relies on self-referential processes (Smallwood, Schooler, et al., 2011). The experiment described in Chapter 4 draws on these findings and tests the hypothesis that the thoughts spontaneously generated by individuals, especially those directed towards the future, may influence their sense of self.

Taken together, both Chapter 3 and Chapter 4 aim to provide evidence in favour of our second hypothesis (i.e. that different types of SGT have heterogeneous functional outcomes) and for the general claim that SGT content plays a role in SGT heterogeneity.

1.3.3 Investigating the cognitive and neural correlates of different types of SGT

Following the identification of distinct types of SGT and having provided evidence that they possess heterogeneous properties, Chapter 5 and Chapter 6 test the prediction that the neurocognitive substrates of SGT vary for different types of thoughts. Chapter 5 focuses on the phenomenology of different types of SGT (i.e. the subjective properties that individuals associate with the SGT generated) and we propose that these properties may shed light on the cognitive processes involved in SGT generation. For example, thoughts can be represented using inner speech or visual mental imagery (Singer & Antrobus, 1972; Singer, 1966; Smallwood et al., 2003; Song & Wang, 2012; Stawarczyk, Cassol, & D'Argembeau, 2013). The first type of representation is based on semantic processes whereas the second type relies on visual simulation processes. As a consequence, types of SGT that are represented using inner speech and visual mental imagery will require distinct cognitive processes. Overall, finding differences in phenomenological properties will provide evidence for the hypothesis that SGT can have heterogeneous cognitive correlates.

Finally, Chapter 6 focuses on the neural correlates associated with different SGT types. A large body of evidence highlights the role of the DMN in SGT (Allen et al., 2013; Andrews-Hanna, Reidler, Huang, & Buckner, 2010; Andrews-Hanna et al., 2014; Christoff et al., 2009; Mason, Norton, et al., 2007; Smallwood & Schooler, 2015; Smallwood, Tipper, et al., 2013; Stawarczyk & D'Argembeau, 2015; Stawarczyk, Majerus, Maquet, & D'Argembeau, 2011). Using resting-state fMRI, we will investigate whether the main hubs of the DMN (i.e. PCC and mPFC) express different connectivity patterns depending on individual differences in SGT content. Chapter 6 therefore explores the neural correlates of SGT and provides further evidence in favour of the component process hypothesis.

1.3.4 Summary

In summary, a review of the literature highlights that considering SGT as a homogeneous phenomenon is inconsistent with recent empirical findings. Studies show that SGT can be associated with both costs and benefits, and that the relation between SGT and executive functions is mixed. To gain insight into these discrepancies, the current PhD proposes that SGT is a heterogeneous phenomenon. We aim to find evidence that the content of the thoughts is an important factor underlying the heterogeneous properties of SGT and that this is made possible by the flexible recruitment of distinct cognitive and neural processes. Using this component process view of SGT, our objective is to show that taking into account the heterogeneity of SGT allows a better characterisation of the neurocognitive correlates of SGT and therefore a better understanding of this subjective experience.

Chapter 2.
Methodology

2.1 Introduction

Although self-generated thought (SGT) has traditionally been considered as a homogeneous phenomenon, recent studies challenge this assumption and highlight discrepancies regarding SGT's functional outcomes and cognitive substrates (see Chapter 1 for a review). In order to provide an explanation for the conflicting findings present in the literature, the current PhD hypothesises that SGT is a heterogeneous phenomenon. Furthermore, we propose that the content of the thoughts plays a role in SGT heterogeneities, following the *content regulation hypothesis* (Andrews-Hanna et al., 2014; Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015).

Previous studies provide preliminary evidence in favour of this hypothesis. Regarding the temporal dimension of SGT, thoughts that are focused on the future tend to involve autobiographical planning (Baird et al., 2011) and are linked to self-referential processes (Smallwood, Schooler, et al., 2011) whereas thoughts focused on the past do not exhibit these qualities. However, past-focused thoughts are linked to negative outcomes such as low mood levels and depressive symptoms (Poerio, Totterdell, & Miles, 2013; Ruby, Smallwood, Engen, et al., 2013; Smallwood & O'Connor, 2011). In addition to the temporal dimension, the social content of thoughts also explains variance in SGT heterogeneities. For example, thinking about significant others is related to increased well-being and life satisfaction, whereas thinking about acquaintances is negatively linked to these constructs (Mar et al., 2012; Poerio et al., 2015). Altogether, these studies indicate that the functional outcomes of SGT may vary according to the content of the thoughts.

A large body of studies also highlights that the temporal, social and emotional dimensions of SGT are important constituents of thought content. For example, thoughts are frequently directed towards the future or the past (Baird et al., 2011; Engert et al., 2014; Iijima & Tanno, 2012; Ruby, Smallwood, Engen, et al., 2013; Smallwood, Nind, et al., 2009; Song & Wang, 2012; Stawarczyk, Cassol, et al., 2013; Stawarczyk, Majerus, Maj, et al., 2011; Tusche et al., 2014). They also involve oneself and other individuals (Baird et al., 2011; Smallwood, Schooler, et al., 2011; Tusche et al., 2014) and they vary in valence

(Andrews-Hanna et al., 2013; Killingsworth & Gilbert, 2010; Smallwood & Andrews-Hanna, 2013; Tusche et al., 2014). Based on these findings, we propose that the temporal, social and emotional dimensions are important aspects of SGT content that should be considered when aiming at understanding the role the content plays in SGT heterogeneities.

Although these studies provide valuable insight into the relevant dimensions of SGT, the different aspects have usually been investigated separately. However, recent evidence highlights potential interactions across dimensions. For example, Smallwood and colleagues found that priming individuals' to reflect on themselves led to significant increases in future thinking, but not past thinking (Smallwood, Schooler, et al., 2011). On the contrary, inducing a negative mood in individuals was related to increases in past thinking, but not future thinking (Smallwood & O'Connor, 2011). Both examples illustrate that different aspects of SGT content may share common variance. Following these findings, we adopt a more integrated approach by simultaneously taking into account the temporal, social and emotional dimensions. In particular, we propose that distinct types of SGT exist, with each type being characterised by a specific set of interactions between the three dimensions. The first aim of the PhD will be to statistically define these types of thoughts.

To this end, we measured individuals' SGT content using multidimensional experience sampling. While performing a short cognitive task, participants were interrupted several times and probed about the temporal, social and emotional dimensions of their thoughts. We propose to use Principal Component Analysis (PCA) to define distinct types of SGT based on the interaction between the three dimensions. This statistical technique is commonly used to reduce a large number of variables into a smaller number of principal components (PC) based on the covariance among the initial measures. We apply PCA at the probe level (i.e. one data point representing one thought report) in order to exploit the covariance over time, taking into account both the within and between-participant variance present in the data. This allows us to maximize our capacity to identify mental states that are present across our population sample.

The aim of the current chapter is to provide evidence for the first prediction the PhD set out to explore i.e. different types of SGT can be identified based on the content of the thoughts. In particular, we present the analysis pipeline that we employed throughout the thesis to characterise distinct SGT types. In addition, we provide preliminary evidence to validate the PCA approach.

2.2 Analysis pipeline

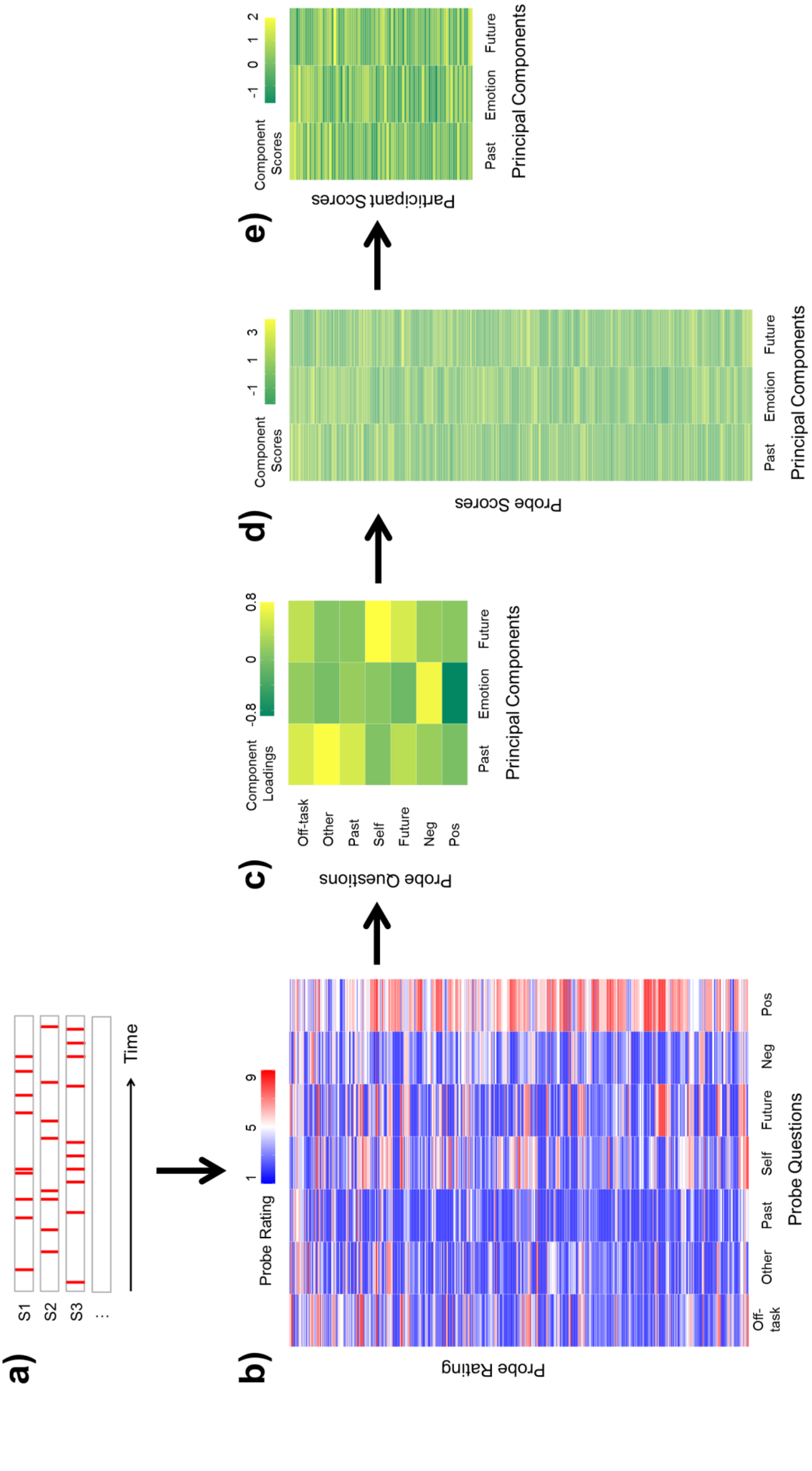
The current section presents the analysis pipeline employed to statistically identify SGT types. Data published by Ruby et al. (2013) will be used to illustrate our PCA approach. In this study, seven aspects of SGT content were probed while participants performed the Choice Reaction Time (CRT) task (Table 2-1). In addition, mood levels were also measured in order to investigate the relation between the different types of SGT and mood. In total, 83 participants were recruited and 590 probes were recorded (Figure 2-1b). More details on the methods are described in Ruby et al. (2013).

All statistical analyses reported in the thesis were computed using R (R Core Team, 2012) and SPSS (Statistics, 2011). Results were plotted using the ggplot2 package (Wickham, 2009). We first provide an overview of the analysis pipeline. More details about each step will be described in subsequent sections.

2.2.1 Overview

The analysis pipeline involves the following steps:

i. SGT content is probed several times at random intervals while participants perform a short cognitive task (Figure 2-1a and Figure 2-2).
ii. Probe data recorded across all participants are concatenated into one dataset. In our example, the data consist of a 590 x 7 matrix (Figure 2-1b).
iii. PCA with Varimax rotation is applied to the data to identify distinct SGT types based on the interaction between the temporal, social and emotional dimensions. In our example, three PC are identified and can be described as Past SGT, Emotion SGT and Future SGT (Figure 2-1c).
iv. Using the structure identified by PCA, the original data are then converted into SGT scores (Figure 2-1d).
v. Finally, SGT scores are averaged for each participant in order to represent individual differences in SGT content (Figure 2-1e).


a)
S1
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d)
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Emotion
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Principal Components
e)
Participant Scores
Component Scores
-1
0
1
2
Past
Emotion
Future
Principal Components

Figure 2-1. Analysis Pipeline (previous page)
a) Each subject (e.g. S1) is probed a number of times randomly throughout the cognitive task. Each probe is indicated by a red bar on the figure and consists of a set of questions assessing SGT content. b) The probe data collected across all participants are then concatenated into one dataset. In our example, the dataset consists of a 590 x 7 matrix. c) Principal Component Analysis (PCA) is then computed on the dataset in order to extract principal components (PC) based on the covariance between the probe questions. The heat map represents the loadings of each probe question on each PC. d) SGT scores are then generated at the probe level using the PC identified by PCA. e) Finally, the SGT scores are averaged for each participant. These scores reflect individual differences in SGT content.

2.2.2 Measuring SGT

2.2.2.1 Cognitive task

We record SGT while participants perform a short cognitive task involving two conditions: a non-demanding Choice Reaction Time (CRT) task or a more demanding Working Memory (WM) task (Figure 2-1a; Figure 2-2; Engert et al., 2014; Ruby et al., 2013; Smallwood, Nind, et al., 2009; Smallwood, Ruby, & Singer, 2013; Smallwood, Brown, et al., 2011; Smallwood, Tipper, et al., 2013).

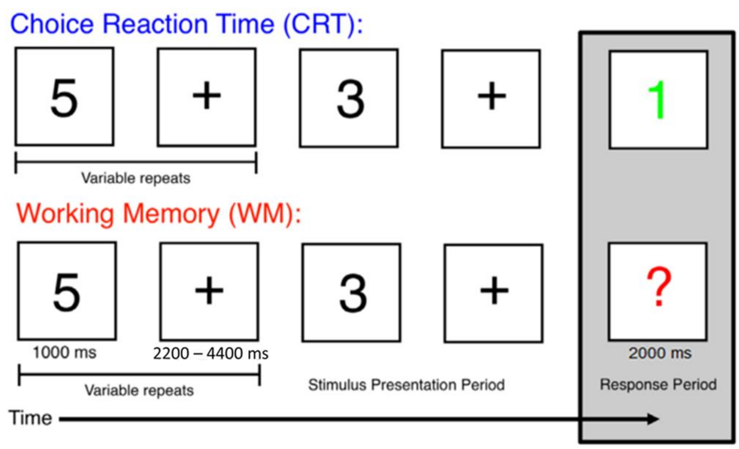

Figure 2-2. Choice Reaction Time task and Working Memory task
In both conditions, black digits are presented for 1000 ms and coloured digits are presented for 2000 ms. Events are separated by a fixation cross of random duration (2200, 2800, 3200 or 4400 ms). Targets (or question marks) and non-targets are presented with a ratio of 1/6. The average number of targets depends on the duration of the cognitive task but does not differ between Choice Reaction Time (CRT) and Working Memory (WM) tasks. The illustration was adapted from (Smallwood, Brown, et al., 2011).

During the CRT task, participants observe a sequence of black digits on a computer screen while waiting for a target (a coloured digit) to appear, at which point they have to indicate the parity of this target (odd or even) with a button push. In the WM task, participants are exposed to the same sequence of black digits, and are intermittently probed with a coloured question mark (‘?’). When the question mark is presented, participants have to make a button push to indicate the parity of the previous digit. Because the occurrence of the coloured question mark is randomly determined, the WM task requires participants to encode and retain in memory the parity of each non-coloured number and to make a response only when probed by the question mark.

The cognitive task was employed in all empirical studies reported in the thesis. In Chapter 3 and Chapter 6, participants performed both the CRT and WM tasks. In the current chapter and Chapter 5, participants only performed the CRT task. Finally, in Chapter 4 participants performed either the CRT or the WM task depending on their group. The duration of each task also varied for each study and will be described accordingly in each chapter.

2.2.2.2 Experience sampling

While performing the cognitive task, participants are intermittently interrupted and asked to answer a set of questions which assess the temporal, social and emotional dimensions of their thoughts, as well as whether they are focusing on the task (on-task) or on something else (off-task; Figure 2-1a; see Table 2-1 for a list of questions). Participants answer using a 9-point Likert scale (Chapters 2, 3) or a slider ranging from "Not at all" to "Completely" (Chapters 4 – 6). Intervals between probes are randomly determined and vary between 0.5 – 5 min. The number of probes presented depends on the duration of the cognitive task.

Note that prior to assessing SGT, probes presented in Chapter 2, 4 and 6 also measured participants' mood levels. Mood levels were recorded as a large body of literature highlights a link between SGT and well-being (Killingsworth & Gilbert, 2010; Poerio et al., 2013; Smallwood, Fitzgerald, et al., 2009; Smallwood, O'Connor, et al., 2007; Smallwood & O'Connor, 2011). The question "Please describe your current mood:" was presented twice to participants, who answered once using a slider ranging from "Not at all" to "Extremely positive" and once using a slider ranging from "Not at all" to "Extremely negative".

Table 2-1. List of probe questions assessing SGT

Dimension	Questions
Off-task	Were you thinking about the task, or about something else?
Temporal	Were you thinking about an event that could happen in the future?
	Were you thinking about an event that happened in the past?
Social	Were you thinking about yourself?
	Were you thinking about other people?
Emotional	How negative were your thoughts?
	How positive were your thoughts?

2.2.3 Principal Component Analysis

Following the recording of SGT content, the probe data collected from several participants are concatenated into one dataset (Figure 2-1b). PCA is then applied to the data to determine how the three SGT dimensions interact. In our example, the data are organized in a 590 x 7 matrix with the seven columns containing the ratings obtained from the seven probe questions, and therefore consist of a 7-dimensional space (Figure 2-1b)[1]. PCA allows reducing the number of initial dimensions i.e. seven variables, into a smaller set of dimensions i.e. PC (Jolliffe, 2002). Based on a correlation matrix (i.e. correlations between all seven variables), PCA estimates the shared variance between the seven variables and computes PC. These PC represent the interaction between the temporal, social and emotional aspects of SGT. We propose to use the PC as proxies for thought types. Following the computation of the PCA, we also apply Varimax rotation to the PC generated (Jolliffe, 2002). This allows maximizing the orthogonality between PC i.e. forcing the new dimensions to be as independent as possible (i.e. non-correlated). Varimax rotation therefore ensures that the PC represent types of SGT that are as distinct as possible from each other.

PC are characterised by a set of loadings and an Eigen value. Each loading represents the correlation between a PC and a given variable and therefore indicates how each aspect of SGT content relates to each SGT type; the Eigen value describes the amount of variance explained by the PC (see Table 2-2 for an example). The output of PCA is then represented using a heat map, where variables loading positively on a PC are represented in yellow, and variables loading negatively are represented in dark green (Figure 2-1; Figure 2-3).

2.2.4 Example of Principal Component Analysis

An example of PCA is provided using probe data published by Ruby et al. (2013). As can be seen in Figure 2-3 and Table 2-2, the first PC loads positively on off-task, past, and other ratings and was named *Past SGT*. The second PC loads positively on negative ratings and negatively on positive ratings and was named *Emotion SGT*. Finally, the last

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[1] Please note that the term “dimension” represents different concepts when referring to the data’s dimensional space and when describing the dimensions of SGT. In the former case, the term dimension is a statistical construct. Each variable in our dataset represents one dimension; our dataset therefore consists of a 7-dimensional space. In the latter case, the term dimension is a theoretical construct. For example, we suspect that negative and positive aspects of SGT are anti-correlated constructs i.e. they represent two extremes of the emotional dimension.

PC loads positively on off-task, future and self ratings i.e. *Future SGT*. Altogether, these three PC explain 69% of the variance in the probe data.

Important observations can be made based on the PCA results. First, Emotion SGT mainly loaded on negative and positive ratings, suggesting that the emotional dimension is fairly independent from the temporal and social dimensions of SGT. In addition, this PC did not load positively or negatively on off-task ratings, suggesting that it may represent thought valence in general, whether on-task or off-task. Regarding Past SGT, the positive loadings on past and other ratings suggest a strong interaction between the temporal and social dimensions of SGT. Similarly for Future SGT, the positive loadings on future and self ratings also suggest that the temporal and social dimensions interact in order to support this type of thought. Taken together, these findings illustrate that distinct types of thoughts can be identified based on the shared variance across the temporal, social and emotional dimensions. The PCA results therefore provide empirical support for our holistic approach to SGT content.

Note that the names attributed to the types of thoughts i.e. Future and Past SGT, focus on the temporal dimension of SGT. This choice takes into account all the results presented in the current thesis and in particular, the fact that PCA commonly generates two PC that differ in terms of their temporal focus (i.e. one involving past thinking, the other one involving future thinking) but not necessarily in terms of their social aspect (e.g. both Future and Past SGT load on other ratings in data presented in Chapters 3 – 6). This suggests that differences between types of SGT are highlighted by their temporal focus rather than by their social aspect, and SGT names take this observation into account.

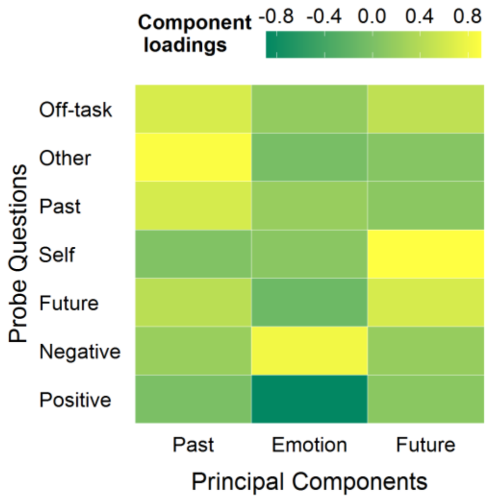

Figure 2-3. Principal Component Analysis for the probe data published by Ruby et al. (2013).
The loadings represented on the heat map are also provided in Table 2-2.

Table 2-2. Results of the Principal Component Analysis for the probe data published by Ruby et al. (2013).

	Principal Components		
	Past	Emotion	Future
Off-task	0.64	0.16	0.47
Other	0.88	-0.03	0.07
Past	0.62	0.20	0.11
Self	0.04	0.10	0.91
Future	0.43	-0.11	0.63
Negative	0.20	0.82	0.18
Positive	-0.01	-0.89	0.10
Eigen values	2.55	1.42	.85

2.2.5 Transformation of probe ratings into SGT scores

Based on the covariance patterns identified by PCA, the original probe data are then converted into SGT scores (Figure 2-1d). Each thought probe can now be described using the three scores rather than ratings from the seven initial variables. Note that in certain datasets (Chapters 2, 4, 6). Emotion SGT is represented by a PC which loads positively on negative ratings. Under those circumstances, we reverse the Emotion SGT scores so that a higher average reflects more positive SGT.

Finally, the data measured at the probe level are averaged for each participant (Figure 2-1e). These mean SGT scores estimate individuals' tendencies to generate Future and Past SGT as well as their general SGT valence.

2.2.6 Relation between SGT and independent measures

Once SGT scores are computed, subsequent analyses can be performed to explore the relation between SGT types and other independent variables such as task performance (e.g. Chapter 3) or phenomenological properties (Chapter 5). These analyses can be done either at the probe level or at the participant level depending on the independent variable examined.

Probe level. Analyses computed at the probe level require independent measures to be simultaneously recorded with SGT content. These analyses are computed on probe data (Figure 2-1d) and require the use of linear mixed models (LMMs, see Chapter 5). For example, Ruby and colleagues investigated the effect of different SGT types on transient mood levels. They found that the occurrence of Future SGT predicted subsequent increases in mood levels, whereas the occurrence of Past SGT predicted subsequent decreases in mood levels (Ruby, Smallwood, Engen, et al., 2013). These data illustrate that the thought content plays a role in the relation between mood and SGT, and that the SGT types generated using PCA capture meaningful covariance.

Participant level. Analyses computed at the participant level involve independent variables which are trait measures (e.g. task performance or questionnaire score). These analyses can be used to investigate the cognitive correlates and functional outcomes of SGT. These analyses require averaged SGT scores (Figure 2-1e) and are usually computed using ANOVAs or linear regressions. For example, Ruby et al. tested whether individual differences in SGT were linked to individual differences in depressive symptoms, as assessed using the Beck Depression Inventory (BDI; Beck, Steer, & Brown, 1993). They found that participants who on average experienced more frequently Past SGT also had higher BDI scores, suggesting that past thinkers tend to experience depressive tendencies and replicating previous findings (Smallwood & O'Connor, 2011). These results provide additional support that PCA is capturing meaningful covariance present in the probe data.

2.3 Discussion

In summary, the data presented in the current chapter illustrate that distinct types of SGT can be statistically identified. Using PCA, we were able to characterise three PC and we suggest that they represent three types of SGT: Emotion, Future and Past SGT. Whereas Emotion SGT mainly relied on the emotional dimension of thought content, Future and Past SGT were both characterised by a specific interaction between the temporal and social dimensions of thought. Taken together, these results support our prediction that distinct types of thought can be characterised based on the interaction between the three dimensions.

Subsequent chapters will explore the functional outcomes and neurocognitive substrates of the different types of SGT. The findings described above can guide these studies. In particular, the PCA data highlight that Future and Past SGT share similar properties. For example, both types of SGT are off-task thoughts and involve an interaction between the temporal and social dimensions. Moreover, future and past thinking are commonly referred to as mental time travel (MTT, e.g. Suddendorf & Corballis, 2007) and studies investigating task-driven MTT provide evidence that both prospection and memory rely on a set of shared and distinct neurocognitive substrates (Addis & Schacter, 2011; Addis, Wong, & Schacter, 2007; Schacter, Addis, & Buckner, 2007). Based on these findings, we suggest that the similarities and differences between Past and Future SGT will be particularly important to explore and the analyses conducted throughout the PhD will take this observation into account.

In the following chapters, the PCA pipeline will be systematically applied in order to statistically identify distinct types of thoughts. Each empirical chapter will aim to provide support for the hypothesis that SGT is a heterogeneous phenomenon. To this end, we will explore whether the different SGT types possess heterogeneous functional outcomes (Chapter 3; Chapter 4) and whether they rely on similar or distinct cognitive (Chapter 5) and neural processes (Chapter 6).

Chapter 3.
Relation between
Social Problem Solving and SGT

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3.1 Introduction

The social world poses many of the most complex problems that we as a species have to solve. Our interactions with other people directly impact upon success in inter-personal relationships and influence many aspects of our lives such as our happiness, our health, and our success in our job and as a family member. The capacity to define and implement the correct strategy in a given social setting is therefore a skill that determines the degree of fit between individuals and their social environment.

Recent work in psychology and cognitive neuroscience has highlighted that in daily life cognition is not always generated from perceptual information. Instead states such as mind-wandering or daydreaming illustrate that humans have the capacity to self-generate thoughts based on previously-stored information rather than events in the perceptual environment (Smallwood, 2013a). Experience sampling studies suggest that such self-generated thoughts (SGT) account for fifty percent of waking thought and content analysis suggests that across cultures these experiences are mainly focused on the self in the future (e.g. Smallwood et al., 2009; Andrews-Hanna et al., 2010; Baird et al., 2011; Iijima and Tanno, 2012; Song and Wang, 2012), implying that these episodes may reflect a form of autobiographical planning (Baird et al., 2011). Despite the high frequency of SGT in daily life, there is no clear consensus on the purpose that these experiences may serve. The current experiment examines whether these states may be related to social problem solving processes.

Successful problem solving depends on two related processes (D'Zurilla & Goldfried, 1971). The first is a capacity to imagine conditions that would allow the agent to move forward on the problem, and the second is a capacity to selectively implement the most effective strategy, a process we will refer to as controlled processing. Although the capacity for controlled processing can arguably be common to both self-generated and perceptually guided thought (Smallwood, 2013a) it is possible that the role of imagination necessary for social problem solving could be specifically related to SGT. For example, the ability to imagine the series of steps that allow a social problem to be solved and the ability to self-generate thought both depend on the capacity to imagine events that are unrelated to the present moment (Frith & Frith, 2006; Smallwood, Tipper, et al., 2013). The main goal of the current study was to assess whether individual differences in SGT are related to processes of social problem solving, and if so, whether specific forms of mental content mediate this relation.

In a large cohort of participants social problem solving was assessed using the Means-End Problem Solving (MEPS) task, a validated measure of individuals' abilities to solve common everyday social problems (Lyubomirsky & Nolenhoeksema, 1995; Marx, Williams, & Claridge, 1992; Platt & Spivack, 1975). The task of the participants is to create a story that would allow her/him to resolve a given problem (e.g. an argument with one's partner, making friends in a new neighbourhood). The MEPS is used to assess two distinct aspects of social problem solving: i) the ability to generate relevant means (RM) i.e. the number of specific steps that the participant provides to solve a given problem; ii) the overall efficiency of the story, a metric for individuals' capacity to implement an appropriate and efficient strategy (Marx et al., 1992).

As the SGT experience varies depending on the context in which it occurs (for a review, see Smallwood and Andrews-Hanna, 2013), we measured SGT during two cognitive tasks: a) a moderately-demanding Working Memory (WM) task and b) a non-demanding Choice Reaction Time task (CRT; for previous use of these tasks see (Smallwood, Ruby, et al., 2013; Smallwood, Brown, et al., 2011; Smallwood, Schooler, et al., 2011). The use of two tasks with variable difficulty allows us to manipulate SGT occurrence and to introduce within-subject variance, as SGT is routinely reduced in the WM task relative to the CRT task. Thought-sampling was used to measure participants' SGT while they performed these tasks. Participants reported the content of their thoughts on a number of dimensions: i) their relevance to the task being performed, ii) their temporal focus (future or past), iii) their social focus (self- or other-related) and iv) the relative level of detail. Finally, task performance was also measured (response time (RT) and accuracy) and provided a measure of individuals' effectiveness at implementing cognition related to perceptual information.

In this study we were motivated to understand whether patterns of variance in the content of SGT, as well as the conditions under which they arise provide informative information on the psychological nature of different types of thought (Smallwood & Andrews-Hanna, 2013; Smallwood, 2013a). The methodological approach used in the current study to describe SGT content is based on our prior published work (Ruby, Smallwood, Engen, et al., 2013). Using similar probe questions, we applied Principle Component Analysis (PCA) to decompose the probe ratings based on the pattern of covariance between the reports. This allowed us to define different categories of thoughts based on trial-by-trial changes in co-variance. Because we apply unconstrained PCA to decompose our data, this step captures both within-subject and between-subject sources of variance. Using these PCA components as dependent variables in subsequent analyses, we next quantify whether SGT are related to independent variables (such as the task context in which the measure was taken, or features of the individual who made the report). As this technique is relatively novel, we will compare the results obtained using the PCA components with results where rating averages were used in a more standard way. In the discussion we consider in detail the rationale for employing this approach.

The main goal of the current experiment was to assess how social problem solving skills are related to individual differences in SGT. To assess this question we adopted an individual difference analysis and examined the co-variance between different elements of MEPS performance and different types of SGT. One possibility is that SGT, regardless of its content, may be related to performance on the MEPS. This would be the case if all types of SGT predicted MEPS performance in a similar way and would be reflected by a main effect of MEPS. A second possibility is that only SGT with specific content are related to social problem solving. This would be the case if our analysis revealed that only certain types of SGT significantly predict MEPS performance and would be reflected by an interaction between the specific form of SGT and performance on the MEPS. For example, as social problem solving is important for anticipating how others may react in the future it is possible that SGT directed towards the future or other people may be stronger predictors of MEPS performance compared to SGT directed towards the self or the past. Finally, our experimental design also allowed us to assess two subsidiary questions: i) the relation between MEPS and cognitive tasks performance and ii) the link between SGT and performance on the two cognitive tasks.

3.2 Methods

3.2.1 Participants

The study was part of a broader research project which was approved by the Ethics Commission of the Medical Faculty of the University of Leipzig under the code 360-10-13122010. 94 right-handed individuals were recruited from the database of the Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany (Mean age = 29 years, Age range 19–38 years, 49 females). All of them were native German speakers, had normal or corrected-to-normal vision, no history of psychiatric or neurological conditions and no history of substance abuse. Ten participants were subsequently excluded from the analysis due to extreme scores on the CRT, the WM or the MEPS (scores were considered as extreme when higher than (Q3 + 1.5 x IQR) or lower than (Q1 – 1.5 x IQR), with Q1 and Q3 the first and third quartiles, and IQR being the Interquartile Range).

3.2.2 Experimental session

The experimental session lasted 2 hours and was divided into three blocks (block order counterbalanced across subjects). Participants were allowed to take short breaks between the blocks if desired. One block consisted of performing the cognitive tasks; another block consisted of performing the MEPS. A number of other tasks were measured during the third block and results have been previously published (Smallwood, Ruby, et al., 2013). All participants gave written consent before the beginning of the experiment and were remunerated at least 16 € for their participation (8 € per hour of participation plus an additional reward according to their performance during a temporal discounting task). E-prime 2 was used for stimulus presentation (Schneider, Eschman, & Zuccolotto, 2002). All statistical analyses were performed using R and results were plotted using the ggplot2 package (R Core Team, 2012; Wickham, 2009).

3.2.3 Cognitive tasks

Participants performed two sessions of two cognitive tasks: a Choice Reaction Time Task (CRT) and a Working Memory Task (WM; Smallwood, Nind, et al., 2009; Smallwood, Ruby, et al., 2013; Smallwood, Brown, et al., 2011). Each session lasted 400 s and participants could take a short break between sessions if desired. During the CRT task, participants observed a sequence of black digits on a computer screen while waiting for a target (a coloured digit) to appear, at which point they had to indicate the parity of this target (odd or even) with a button push. In the WM task, participants were exposed to the same sequence of black digits, and were intermittently probed with a coloured question mark (‘?’). When the question mark was presented, participants had to make a button push to indicate the parity of the previous digit. Because the occurrence of the coloured question mark is randomly determined, this task requires participants to encode and retain in memory the parity of each non-coloured number and make a response only when probed by the question mark. In both tasks, black digits were presented for 1000 ms and coloured stimuli were presented for 2000 ms. Events were separated by a fixation cross of random duration (2200, 2800, 3200 or 4400 ms). Targets (or question marks) and non-targets were presented with a ratio of approximately 1/6. The average number of targets did not differ between CRT and WM tasks (mean target number, CRT task: $M = 22.5$, $SE = .4$; WM task: $M = 22.8$, $SE = .5$).

During both the CRT and WM tasks, SGT was recorded using thought-sampling (average number of probes: CRT task, $M = 7.10$, $SE = .2$; WM task, $M = 7.07$, $SE = .2$). Intermittently throughout the tasks, participants were interrupted and asked to rate how much their thoughts were i) unrelated to the current task (i.e. “off-task”); ii) detailed; iii) future-focused; iv) past-focused; v) self-focused and vi) other-focused. Participants used Likert scales to answer the probes (1 to 9, a greater score indicating higher relevance. See (Christoff et al., 2009; Mrazek, Smallwood, Franklin, et al., 2012) for previous uses of this method).

3.2.4 Means End Problem Solving Task

Social problem solving ability was assessed using a modified version of the Means-End Problem Solving task (MEPS; Platt and Spivack, 1975; Marx et al., 1992). The German version of the task was obtained from Svaldi et al. (2011). Participants read short scenarios presenting a problem (e.g. “you just moved into a new neighbourhood and you do not know anybody”) and a solution (e.g. “the story ends when you have several good friends and you feel at home in the new neighbourhood”). The task consists of creating a story that would allow the participant to reach the stated solution and therefore solve the problem. Participants are instructed to be as specific as possible, so that other people reading their story would easily understand how the solution was achieved. Following Lyubomirsky and Nolenhoeksema (1995), problems were written using second person pronouns and participants were asked to provide a story based on what they would actually do if they were indeed confronted with such problems. Four different scenarios were used. Each scenario was presented on a computer screen and participants had 4 minutes to type in a story that would link the stated problem to the solution.

Two independent raters coded each story according to two measures: i) number of relevant means (RM), representing the number of discrete steps that would allow the participant to get closer to the goal; ii) Efficiency, representing the global efficiency of the story proposed (how efficient the strategy would actually be at solving the problem) and rated using a 0 to 7 Likert scale. For each participant, a mean Efficiency score and a mean RM score was obtained by averaging the ratings across stories and across raters (Inter-rater reliability Cronbach's α, Efficiency: $\alpha = .79$; for RM: $\alpha = .79$).

3.3 Results

3.3.1 Descriptive analyses

3.3.1.1 MEPS performance

Measures obtained during the MEPS were similar to previously-reported findings (e.g. Watkins and Baracaia, 2002). Mean efficiency was 3.39 (SE = .14) and mean RM was 2.68 (SE = .11). Both measures were highly correlated (Pearson's correlation coefficient $r = 0.72$, $p < .001$). Measures of MEPS Efficiency and RM were z-scored prior to performing subsequent analyses.

3.3.1.2 Task performance

The average Error rate for the CRT task was .053 (SE = .006) and for WM task .033 (SE = .005). The average RT was 799 ms (SE = 13 ms) for the CRT task and 759 ms (SE = 22 ms) for the WM task. Consistent with previous studies (e.g. Baird et al., 2012), both error rate and RT for correct responses were lower during the WM compared to the CRT task (paired sample t-test, Error rate: $t = 2.62$, $p = .01$, RT: $t = 2.25$, $p < .03$). This confirms that during the WM task, participants were more focused on the task than during the CRT.

3.3.1.3 Task modulation of SGT

Off-task ratings were higher in the CRT than the WM task (paired sample t-test, $t = 4.84$, $p < .001$). Regarding temporal questions, a repeated-measures 2 x 2 ANOVA with task (CRT, WM) and probe question (future, past) revealed two main effects and a significant interaction (task: $F = 5.13$, $p = <.03$; probe question: $F = 76.54$, $p < .001$; interaction: $F = 5.02$, $p < .03$). As can be seen in Figure 3-1, future ratings were higher than past ratings and ratings were higher in the CRT compared to the WM task. The difference in ratings across tasks was especially pronounced for the future probes. These results replicate previous findings of a future bias of SGT that has now been observed in several different cultures (Baird et al., 2011; Iijima & Tanno, 2012; Smallwood, Nind, et al., 2009; Smallwood, Brown, et al., 2011; Song & Wang, 2012). A similar ANOVA was performed with social questions (Probe Question: self, other). We observed a significant main effect of task ($F = 11.38$, $p = .001$) and a trend for an effect of probe question ($F = 3.01$, $p < .09$). No significant interaction was obtained ($F = 1.88$, $p = .17$). This suggests that social-related ratings are higher during the CRT compared to the WM task (Figure 3-1). Finally, we found no evidence for a difference of detail ratings across tasks (paired sample t-test, $t = -0.89$, $p > .35$). Overall, these results suggest that there is significant within-subject variance present in thought-probe ratings across cognitive tasks.

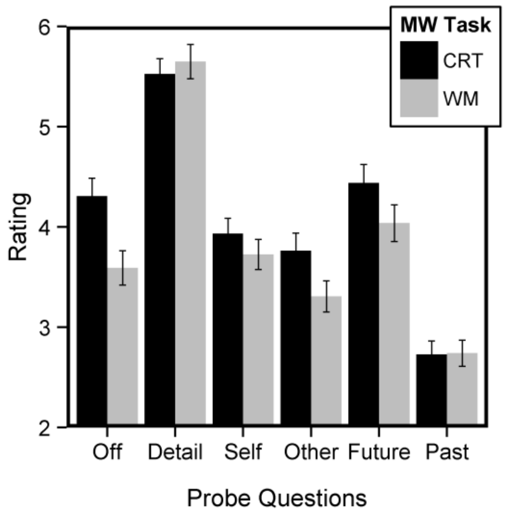

Figure 3-1. Mean SGT ratings across mind-wandering (MW) cognitive tasks
SGT in the CRT task was rated as more off-task, more self and other-related, and more future-related than SGT in the WM task. In addition, thoughts were overall more future than past-related.

3.3.2 Link between social problem solving and SGT

3.3.2.1 Decomposition of SGT content

As it can be seen in Table 3-2, ratings from different probe questions were highly correlated, suggesting that there is a significant amount of shared variance that should be accounted for. Following Ruby et al. (2013) we used Principal Component Analysis (PCA) to explore the co-variance between off-task ratings and measures of SGT content. PCA with Varimax rotation was applied on the off-task, future, past, self and other ratings of 1200 thought probes i.e. regrouping probes from both tasks and all participants. Applying PCA at the thought-probe level allows to take into account both within- and between-subject sources of variance and to compute a measure of the general patterns of SGT that are present in our data. As our variable of interest is SGT i.e. “mental content that is unrelated to the task in hand” (Smallwood, 2013a) the off-task ratings were included in the PCA to appreciate whether the factors obtained were reflecting on-task or off-task thoughts. The detail ratings were excluded from the PCA to replicate the methods published by Ruby et al. (2013). Two principal components were obtained that explained 64% of the variance in our sample (Figure 3-2; Table 3-1). Both components reflected a combination of social and temporal aspects of SGT: The first socio-temporal component loaded positively on off-task, future, self and other ratings (hereafter **ST-FSO**). The second socio-temporal component loaded positively on off-task, past and other ratings (hereafter **ST-PO**). The pattern of co-variance indicates that other-related thoughts are prevalent in both past- and future-related SGT which supports the assumption that both types of SGT may reflect attempts at social problem solving.

To take into account the possibility that the context in which SGT is measured can have implications for its psychological correlates, we computed 4 SGT scores for each subject for subsequent analyses at the group level: mean ST-FSO in the CRT, mean ST-FSO in the WM, mean ST-PO in the CRT and mean ST-PO in the WM. We performed a 2-by-2 ANOVA with task (CRT, WM) and components (ST-SFO, ST-PO) which revealed a main effect of task ($F(83) = 18.57$, $p < .001$). This suggests that the amplitude of both components was larger in the CRT than in the WM task, in a similar manner than the ratings they load on (Figure 3-3). A trend for a task x component interaction ($F(83) = 3.0$, $p = .087$) was also observed. For each component, a difference measure was computed between CRT and WM tasks and a paired t-test between these measures revealed a trend for a difference across tasks for one component more than the other ($t = 1.73$, $p = .09$). Paired t-test for each component indicated that the difference observed across tasks may be especially pronounced for ST-FSO (paired t-test for ST-FSO, $t = 4.33$, $p < .001$; for ST-PO, $t = 1.84$, $p = .07$). The results obtained here are very similar to the results obtained from raw probe data: i.e. all probe questions had significantly higher ratings in the CRT vs. the WM task, and future ratings were higher than past ratings, especially in the CRT task. Our PCA approach therefore yields results that are consistent with standard group-level averages and replicates previous findings showing that future-related thinking is higher during easy vs. hard tasks.

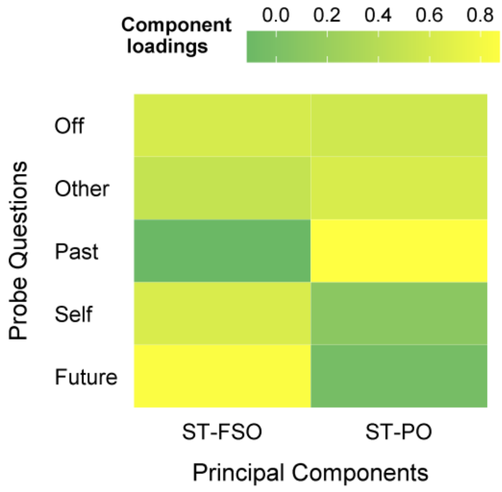

Figure 3-2. PCA on SGT ratings
PCA revealed two Principal components, one loading positively on Off-task, Future, Self and Other ratings (ST-FSO) and one loading positively on Off-task, Past and Other (ST-PO). PCA with Varimax Rotation was applied on 1200 thought probes i.e. regrouping probes from both tasks and all participants.

Table 3-1. Component loadings obtained from the PCA with Varimax rotation on the SGT measures
This information is graphically represented in Figure 3-2.

	ST-FSO	ST-PO
Off	.602	.555
Other	.485	.617
Past	-.115	.875
Self	.623	.106
Future	.852	-.041

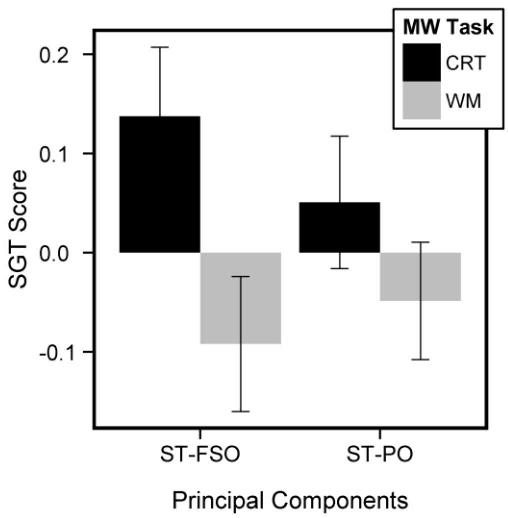

Figure 3-3. Mean SGT scores across subjects for each Principal Component and each task
SGT scores were higher in the CRT than the WM task.

Table 3-2. Correlation matrix for SGT ratings, task performance and MEPS measures
Significance levels are represented with $^{+}$ (p-value < .1), *(p-value < .05), **(p-value < .01), and ***(p-value < .001).

	Efficiency	RM	RT	Error rate	Off-task	Detail	Self	Other	Future	Past
CRT task										
RT	-.071	-.089	1.000							
Error rate	-.069	-.094	-.063	1.000						
Off-task	-.052	.109	.002	-.103	1.000					
Detail	-.144	-.261*	.138	-.076	.027	1.000				
Self	-.214*	-.166	-.019	.141	.306**	.107	1.000			
Other	-.057	.157	-.201^{+}	-.162	.694***	.073	.250*	1.000		
Future	-.097	.044	-.120	-.155	.565***	.127	.436***	.600***	1.000	
Past	-.136	.042	-.028	.123	.400***	.085	.338**	.501**	.308*	1.000
WM task										
RT	-.152	-.196^{+}	1.000							
Error rate	-.334**	-.168	.262*	1.000						
Off-task	-.173	.058	.012	.113	1.000					
Detail	-.265*	-.331**	.242*	.065	-.066	1.000				
Self	-.117	-.103	-.108	.072	.447***	-.035	1.000			
Other	-.219*	.071	-.105	.098	.702***	-.121	.266*	1.000		
Future	-.052	.057	-.107	.149	.472***	-.169	.379***	.531***	1.000	
Past	-.119	.103	-.052	-.007	.307***	-.096	.368***	.274*	.235*	1.000

3.3.2.2 Link between SGT and MEPS performance

Table 3-2 shows Pearson's correlations between probe ratings and MEPS measures. Although informative, raw correlations do not take into account the shared variance between measures (e.g. the relation between MEPS measures) or the nested structure of our data (e.g. within-subject sampling across cognitive tasks). To that end, we favoured the use of repeated measures ANOVAs that allow accounting for within- and between-subjects effects. To investigate the link between SGT and MEPS, we first performed a 2-Way repeated measure ANOVA with task as a single factor (CRT vs. WM), predicting off-task ratings from MEPS scores. We observed two main effects (Efficiency: $F = 4.60$, $p < .04$; RM: $F = 4.04$, $p < .05$) but no significant interactions. We therefore computed a mean off-task score and ran a linear regression with Efficiency and RM as covariates. We observed that an increase in off-task was negatively correlated with Efficiency ($t = -2.13$, $p < .04$) but positively correlated with RM ($t = 2.0$, $p < .05$). These results seem to contrast with the raw correlations presented in Table 3-2. However, the significant effects may emerge when applying the ANOVA because both MEPS measures are included in a single analysis and as a consequence, control for each other. Our results therefore suggest that only the individual variance of each measure (rather than their shared variance) has an opposite relationship with off-task.

To investigate whether the link between off-task and MEPS varies according to SGT content, we performed a repeated measures 2 x 2 ANOVA (task: CRT, WM; components: ST-FSO, ST-PO) predicting SGT with MEPS measures as between-participant covariates. We observed main effects for both Efficiency and RM (Efficiency: $F = 7.63$, $p = .007$, RM: $F = 5.72$, $p = .02$) but no significant interactions, suggesting that MEPS predicted SGT regardless of content. Separate ANOVAs indicated that both ST-SFO and ST-PO had similar relations to MEPS performance (ANOVA predicting mean ST-PO score from MEPS performance, Efficiency: $t = -3.19$, $p= .002$, RM: $t = 3.07$, $p = .003$; ANOVA predicting mean ST-SFO score from MEPS Performance, Efficiency: $t = -1.470$, $p= .14$, RM: $t = 1.01$, $p =.3$). To visualize the results we computed a mean SGT score (mean SGT between ST-SFO and ST-PO, across both tasks) and performed a univariate ANOVA predicting mean SGT score again with MEPS scores as covariates. Mean SGT score was negatively predicted by Efficiency ($t = -2.76$, $p = .007$) but positively predicted by RM ($t = 2.39$, $p < .02$, Figure 3-4). To confirm that these results are not an artefact of applying the analysis at the trial level, we computed 2 “pseudo-components” by averaging the ratings that characterized ST-FSO and ST-PO (i.e. averaging the probe questions that had a loading coefficient higher than .40). This resulted in two pseudo-components: i) pseudo-FSO (average of off-task, other, future and self ratings) and ii) pseudo-PO (average of off-task, other and past-ratings). Each pseudo-component was computed separately for each subject and each task, therefore only containing within-subject variance, unlike the group-level PCA components which contain within-subject and between-subject variance. When implementing the 2-by-2 ANOVA with the pseudo-components, we obtained very similar results (main effect of Efficiency, $F(83) = 7.07$, $p = .009$, main effect of RM, $F(83) = 5.32$, $p = .02$). This again confirms that our PCA approach yields results that are consistent with a standard group level average and did not lead to artificial results.

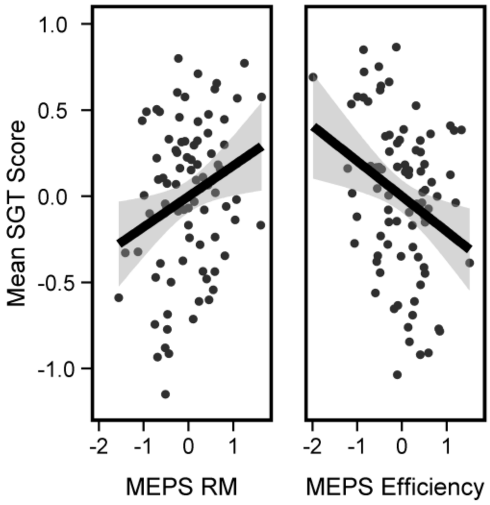

Figure 3-4. Link between SGT and MEPS performance
Mean SGT was associated with higher number of RM (left panel) but lower Efficiency (right panel). Mean SGT Score corresponds to the mean of [ST-FSO in CRT, ST-FSO in WM, ST-PO in CRT and ST-PO in WM] computed for each subject. Black lines represent best-fitted linear regressions and grey areas represent 95% confidence intervals.

3.3.3 Link between social problem solving and cognitive tasks performance

3.3.3.1 Link between MEPS and CRT / WM performance

In addition to the link between SGT and social problem solving, our data also allowed us to look at the relationship between the MEPS and cognitive task performance i.e. whether efficient problem solvers were also good at performing the CRT and WM tasks. Pearson's correlations between MEPS measures and task performance are reported in Table 3-2. We computed a measure of task performance, by averaging Error Rate and RT (previously z-scored) and reversing the score. This was calculated separately for the CRT and WM task. We computed a repeated-measures 2-way ANOVA (task: CRT, WM) predicting task performance with Efficiency and RM as covariates. This analysis revealed a trend for a triple interaction (task x Efficiency x RM, $F = 3.52$, $p = .06$) but no significant main effects (Efficiency, $F = .67$, $p > .4$; RM, $F = .84$, $p > .3$). Separate ANOVAs for each task indicated that the interaction between Efficiency and RM was almost significant in the WM task ($t = -1.9$, $p = .06$) but not in the CRT task ($t = .21$, $p > .8$). To visualize the interaction, we performed median splits on both Efficiency and RM and plotted these against WM task performance. As can be seen in Figure 3-5, WM performance was particularly poor when both Efficiency and RM were low. Although our result is only at trend level, it suggests that participants with poor performance at the WM task, but not the CRT, also performed poorly on the MEPS.

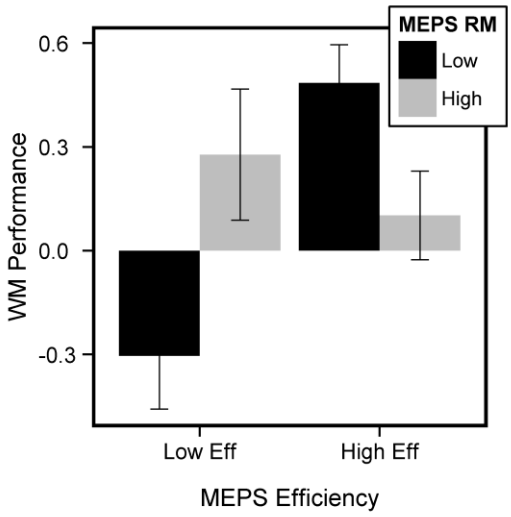

Figure 3-5. Link between MEPS and cognitive tasks performance
Participants with poor WM performance also had poor MEPS performance (low efficiency, low RM). We performed median splits on Efficiency and RM scores and computed a measure of mean WM performance for each of the 4 groups of participants (both low Efficiency and RM, both high Efficiency and RM, low Efficiency – high RM, high Efficiency – low RM). Error bars represent standard error of the mean.

3.3.3.2 Shared variance between SGT and cognitive task performance

As both WM task performance and SGT significantly predicted the MEPS, we investigated whether these two measures explained shared or separate MEPS variance. We conducted a repeated measures 2-Way ANOVA predicting MEPS Efficiency and RM, with WM task performance and mean WM SGT score as covariates. Both measures still significantly predicted MEPS performance (main effect of WM performance, $F = 7.32$, $p = .008$; WM mean SGT x MEPS interaction, $F = 11.05$, $p = .001$). Similarly to the previous analysis, WM performance was associated with poor overall MEPS (univariate ANOVA predicting mean MEPS performance, main effect of WM task performance: $t = 2.81$, $p = .006$). SGT was associated with increased RM and reduced Efficiency (univariate ANOVA for RM controlling for Efficiency, mean WM SGT: $t = 2.81$, $p = .006$; univariate ANOVA for Efficiency controlling for RM, mean WM SGT: $t = -3.34$, $p = .001$). This suggests that both WM performance and SGT explain distinct features of MEPS variance.

3.3.4 Link between SGT and cognitive tasks performance

Finally, we investigated the relation between SGT and the cognitive tasks being performed. To account for the nested structure of our data, we used a linear mixed model (Bates, Maechler, & Bolker, 2012) in order to predict performance on each task based on SGT. *p*-values were estimated using the *pvals.fnc* function provided in the languageR package (Baayen, 2008). ST-PO, ST-FSO and Task (CRT, WM) were defined as fixed effects and subject as a random effect. We observed a significant positive effect of ST-FSO on performance (t = 1.99, p < .05) whereas ST-PO had no significant effect (t = -.59, p > .5). In addition, an interaction between task and ST-FSO was also observed at trend level (t = -1.88, p = .06). ANOVAs performed separately on each task revealed a trend for an effect of ST-FSO on CRT performance (t = 1.84, p < .07) but not on WM performance (t = -.62, p > 0.5, Figure 3-6). This suggests that an increase in SGT directed towards the future, and involving oneself and others, may be associated with better task performance, especially during the CRT task. Again, we confirmed that these resulted were not artefacts caused by our PCA by performing the linear mixed model again using the pseudo-components calculated before. The results were again very similar (main effect of pseudo-FSO, t = 2.13, p = .02; main interaction between task and pseudo-FSO, t = -2.01, p = .04; effect of pseudo-PO, t = -1.72, p = .09; task x pseudo-PO x pseudo-FSO interaction, t = -1.79, p = .08).

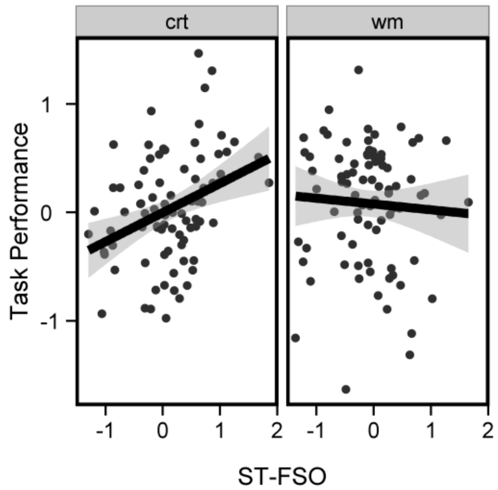

Figure 3-6. Link between SGT and cognitive task performance
Task performance was plotted against the ST-FSO Score for each subject, separately for each cognitive task. Increase in ST-FSO was associated with increased performance during the CRT task (left panel, p < .07) but had no significant effect in the WM task (right panel). Black lines represent best-fitted linear regressions and gray areas represent 95% confidence intervals.

3.4 Discussion

This study sets out to explore the relationship between social problem solving and SGT. We were interested in examining whether general SGT levels or specific types of SGT are linked to problem solving abilities. To define types of SGT, we decomposed our thought-sampling data using PCA at the trial level, which revealed two components that were differentiated by temporal focus (past vs. future) and both loaded strongly on other-related thoughts. This pattern of co-variance suggests that regardless of temporal focus, SGT often involves thoughts about other people and so is consistent with the general premise that many of these experiences may reflect attempts at solving social problems. When investigating the link between SGT and MEPS, we observed that increases in SGT levels, regardless of the content, were linked to reduced efficiency but increases in RM. Our findings therefore do not support the hypothesis that different types of SGT may have different links to social problem solving. It is possible that the absence of differentiation between types of SGT reflects idiosyncratic features of our sample, or a failure to operationalize the content of SGT in an appropriate manner. However, as we replicated the finding that future-related thinking was higher in the non-demanding CRT vs. WM task, our German sample is broadly similar to groups studied in a number of different countries (Smallwood et al., 2009; Andrews-Hanna et al., 2010; Baird et al., 2011; Iijima and Tanno, 2012; Song and Wang, 2012). Moreover, our finding that ST-FSO (but not ST-PO) varied with task demands and was associated with better performance on the CRT task demonstrates that our different measures of content are operationalized sufficiently well as to be able to differentiate between experimental manipulations and objective-dependent measures. It seems reasonable to assume that our failure to find evidence of a clear differentiation between specific content of SGT and social problem solving cannot therefore be explained by unique features of our population or from a failure to operationalize the content of SGT. Importantly, we obtained very similar findings when using pseudo-components computed at the group level, therefore demonstrating that our results did not arise because of a possible artefact arising from our PCA approach (see the Limitations section for a complete discussion of this issue).

Although it remains a possibility that the association between SGT and social problem solving may depend on the content of thought if we had operationalized our questions differently, it is also possible that our results illustrate a general relationship between SGT and social problem solving. Plausibly SGT and social problem solving share a common dependence on the capacity to generate mental content that is based on memory rather than a direct representation of reality as it is now. This is consistent with accounts of SGT that emphasize that the unique features of such experiences is the motivated generation of mental content that are distinct from perception (Smallwood, 2013a) and with formulations of problem solving which emphasize the importance of generative thinking in the production of novel solution steps. It is also consistent with prior work showing that individuals who engage in daydreaming (as assessed via a retrospective measure) generate more solutions to creative problems (Baird et al., 2012). More generally, the positive association between SGT and RM is consistent with the *Current Concerns Hypothesis* proposed by Eric Klinger (Klinger, 1978, 1999). According to this hypothesis, cognition is often devoted to events that are salient to individuals, and when the external environment lacks sufficiently compelling input, individuals engage in SGT to provide a source of stimulation. As the *Current Concerns Hypothesis* assumes that the motivating feature for SGT is an attempt to resolve personal concerns, it elegantly captures our finding that individuals who habitually engage in SGT generate more RM in order to solve the MEPS problems.

Not only was SGT associated with more RM, it was also associated with a reduction in the effectiveness of the solutions, as judged by our independent raters. One interpretation of this result is that the relation between SGT and social problem solving may take the form of Yerkes-Dodson relationship, with optimal problem solving being achieved by individuals who display a suitable balance between SGT and cognition derived from perceptual input. Plausibly, there may be three different populations of problem-solvers: one who generates low levels of SGT and produces short but efficient solutions to problems, a second who produces large numbers of solutions with reasonable levels of efficiency and a third who generates the most steps but whose solutions are ineffective. Although speculative, this interpretation of our data is consistent with evidence that SGT can have both costs and benefits to task performance (for a review, see Smallwood, 2013). Moreover, it suggests a reason why interventions that cultivate mindfulness and which reduce the tendency for mind-wandering (Mrazek, Franklin, Phillips, Baird, & Schooler, 2013; Mrazek, Smallwood, & Schooler, 2012) may be beneficial in daily life. By restraining the mind’s habitual tendency to wander, interventions that emphasize being in the moment may help individuals gain a degree of control over SGT which may in turn allow them to employ this basic capacity for conscious thought to generate problem solutions in a more efficient manner.

We also found that participants with poor problem solving abilities (characterized by both low RM and Efficiency) performed poorly on a moderately demanding WM task when controlling for SGT. As the WM task relies on greater controlled processing than does the CRT, this suggests that the capacity to deploy controlled processing to an external task and to social problem solving relies on similar cognitive processes (such as working memory or attentional resources). This is consistent with prior studies that have demonstrated that individuals high on measures of controlled processing are also good problem solvers, as well as fMRI investigations which link domain general processes of control to the solution of both spatial and autobiographical problems (Spreng et al., 2010).

Finally, a positive link between SGT and task performance was in particular observed during the non-demanding CRT task and may reflect the finding that future-related thought in the CRT is linked to higher working memory (Baird et al., 2011). Our result of better performance associated with ST-FSO is in contrast to other studies that find that in general, experience unrelated to a task elicits a negative influence on task performance (for a review see Smallwood, 2011). This result suggests that future studies understanding the negative influence of SGT on task performance should take in account both task context as well as the content of thoughts (Smallwood & Andrews-Hanna, 2013).

3.5 Limitations

The overarching framework guiding the current study is the hypothesis that meaningful psychological information is contained in the variation in SGT content across situations and individuals (Smallwood & Andrews-Hanna, 2013). As a consequence, we sought to define categories of SGT that have the potential to simultaneously vary within and between participants. We applied unconstrained PCA at the trial level and examined how the resultant components varied in a quantitative fashion across individuals and situations. This novel approach allowed us to investigate three types of psychological relationships to SGT: (i) possible within-subjects effects on the SGT content (e.g. "Does SGT vary depending on the task?"), (ii) between-subject effects (e.g. "Does SGT content vary according to MEPS performance?") and (iii) their interaction (e.g. "Do certain individuals exhibit different patterns of thoughts in different contexts?"). Given the novelty of our data analysis strategy, it is worth explicitly considering its strengths and weaknesses.

One practical question is whether our approach yields results that are either unreliable or inconsistent with what is known about SGT: this would provide straightforward evidence that this approach lacks utility. In terms of replicability, the PCA components we obtained in the current study have a striking resemblance to previously published SGT components obtained from an independent dataset (Ruby, Smallwood, Engen, et al., 2013). This consistency across datasets suggests that the components obtained from an unconstrained trial-level PCA are reasonably reliable. Our work using the trial-by-trial PCA also found results consistent with previous findings in the SGT literature. In terms of within-participant variance, ST-FSO was higher in a non-demanding task: this is consistent with a prospective bias to SGT found by several different laboratories (Andrews-Hanna et al., 2010; Baird et al., 2011; Iijima & Tanno, 2012; Smallwood, Nind, et al., 2009; Song & Wang, 2012). Our PCA approach also yielded group-level effects that have been demonstrated by prior studies. Ruby and colleagues reported that ST-PO is linked to higher BDI scores (Ruby, Smallwood, Engen, et al., 2013), an observation that is consistent with the elevated retrospective focus found in dysphoria and unhappiness (Poerio et al., 2013; Smallwood & O'Connor, 2011; Stawarczyk, Majerus, & D'Argembeau, 2013). The application of PCA at the trial level therefore captures both within and between-participant variation consistent with other methods of analysis. Altogether this suggests that trial level PCA can yield reliable results that are both replicable and are consistent with prior work.

There are also theoretical questions regarding how to best decompose SGT in order to characterize the psychological correlates of the within and between-participant variance in thought content (for a review see Smallwood, 2013; Smallwood and Andrews-Hanna, 2013). Dimension reduction techniques can be employed that control for both within and between-subject variance during data decomposition e.g. multi-level exploratory factor analysis (Reise, Ventura, Nuechterlein, & Kim, 2005). These provide a more generalizable description of the thoughts of the population because they seek covariance that is common across the sample (or to a particular context). These techniques make categorizing variation *across* individuals, or contexts, more difficult, because by optimizing the decomposition process to seek commonality, differences across people or context are a feature of the unexplained variance. As we are interested in describing the psychological significance of the co-variance between and within participants, we did not want to constrain the decomposition process using this information. Instead, we tested the psychological features of within and between-participant variance derived from our unconstrained PCA by including the individual and context as factors in the subsequent analysis. Our demonstration that ST-FSO was higher in the CRT task (i.e. within-participant variance) for individuals who performed the task especially well (i.e. between-participant variance, see Figure 3-6) indicates that we were successful in this regard. Although the specific features of SGT that we find using trial-by-trial PCA may not generalize to other samples, this result demonstrates that co-variance across both tasks and participants provide meaningful psychological information regarding the content of thought (Smallwood & Andrews-Hanna, 2013; Smallwood, 2013a). A second alternative would be to employ PCA *separately* to each task at the group level; this would allow an investigation of qualitative differences in PCA structure in different contexts; however it would make it impossible to quantify how specific patterns of thought change across situations because the PCA components calculated in this fashion would not be directly comparable. While the possibility remains that the application of PCA at the trial level could lead to unrepresentative results, the available data suggests that the technique yields results that are (i) reliable across independent data sets, (ii) provides valid accounts of existing phenomena, (iii) captures psychological differences that are contained in the patterns of covariance in multiple reports of SGT and (iv) allows the quantitative capture of both within and between-subject co-variation in different aspects of SGT. We suggest that future research should continue to use this technique in an exploratory fashion because of its potential value in mapping the heterogeneity of SGT that arises through the combination of the constraints placed by different environmental situations and the range of individual differences that contribute to the content of thought.

There are a number of further limitations that should be borne in mind when considering our data. Concerning our methodological approach, we only administered a measure of *social* problem solving and it remains to be seen whether the link between problem solving and control processes or SGT is specific to the social domain or may generalize to other forms of problem resolution. In addition, although problems were chosen to mimic daily-life concerns, they remain hypothetical. Anderson and colleagues (Anderson, Goddard, & Powell, 2009) compared measures of problem solving abilities obtained from the MEPS and from a "Real-Life problem solving diary task", in which participants' reported a problem when it occurs and describe afterwards the strategy they used to solve it. Although they found that the performance at both tasks could predict future depressive symptoms, they also observed that both measures explained different portions of variance and did not correlate. This suggests that, although the MEPS remains an important tool as it measures the ability to generate responses to problems under laboratory conditions, Anderson notes that "it is the successful implementation of such strategies that ultimately impacts upon the situation's outcome" (p. 54 Anderson et al., 2009). Although our data suggests that individuals reporting more SGT may also have improved problem solving skills, it does not allow us to draw conclusions regarding their actual success in daily life. Our data is also correlational and though our results confirm links between social problem solving and SGT, we cannot identify whether fluency at social problem causes SGT or vice versa, nor can we specify the mechanism that links these two phenomena without further study. Based on studies showing a positive relation between MEPS performance and autobiographical memory retrieval (e.g. Evans et al., 1992; Goddard et al., 1997, 1996) and the link between SGT and autobiographical memory (Baird et al., 2011; Smallwood, 2013a), the association between SGT and social problem solving may emerge through their mutual requirement of autobiographical memory. One important future direction would therefore be to assess memory capacities or to use neuroimaging methods to determine the specific cognitive processes that mediate the link between social problem solving skills and SGT (e.g. Spreng et al., 2010). Given that social problem solving is important to the success of every member of society, understanding the mechanism that links this experience to states of perceptually-guided thought and particularly SGT are recommended.

Chapter 4.
Relation between Self-Concept and SGT

4.1 Introduction

The evidence presented in Chapter 3 provides initial support for the predictions that distinct types of SGT can be statistically identified based on the content of the thoughts, and that these different SGT types may possess heterogeneous functional outcomes. The current chapter aims to gather further evidence in favour of these predictions by investigating the relation between SGT and the sense of self (or self-concept).

A large body of research highlights that individuals' SGT strongly relates to individuals' sense of who they are and how they see themselves i.e. their self-concept (Markus, 1987). As reviewed by Gruberger, Ben-Simon, Levkovitz, Zangen, & Hendler (2011), SGT can be considered as a "continuous self-referential processing" which supports the ongoing creation and maintenance of a sense of self. Empirical evidence for this claim can be found in recently published studies. For example, D'Argembeau, Lardi, & Van der Linden (2012) found that projecting oneself into the past or the future has self-defining properties i.e. both types of simulations provide individuals self-relevant information that can be used to create and shape one's sense of self. In addition, SGT often involves projecting oneself into the past or the future (Baird et al., 2011; Engert et al., 2014; Iijima & Tanno, 2012; Ruby, Smallwood, Engen, et al., 2013; Smallwood, Nind, et al., 2009; Song & Wang, 2012; Stawarczyk, Cassol, et al., 2013; Stawarczyk, Majerus, Maj, et al., 2011; Tusche et al., 2014) and focuses on current concerns i.e. self-relevant, unresolved issues and ongoing goals (Baird et al., 2011; Cole & Berntsen, 2015; Klinger, 1978, 1999; Mason & Reinholtz, 2015). These self-projections create a sense of continuity between one's past, present and future self, therefore maintaining one's self-concept (Gruberger et al., 2011). Taken together, these studies illustrate that SGT is strongly related to one's sense of self.

Nevertheless, evidence also suggests that the relation between SGT and self-concept may vary according to the content of the thoughts generated. Baird et al. (2011) and Cole & Berntsen (2015) found that especially future-directed, rather than past-directed thoughts, were goal-related and self-relevant. Using experience sampling and Principal

Component Analysis (PCA), Ruby et al. (2013) identified distinct types of SGT based on the shared variance between the temporal, social and emotional dimensions of thoughts. Future SGT consisted in self-related future thoughts, whereas Past SGT was characterised by other-related past thinking. These results suggest that future thoughts may involve self-related information more frequently than past thoughts. Altogether, both lines of evidence suggest that self-referential processes may be preferentially recruited during the simulation of future events rather than the reminiscence of past events.

Smallwood and colleagues tested this hypothesis in two independent studies (Smallwood, Schooler, et al., 2011). In the first study, they found that priming participants to reflect on themselves led to subsequent increases in future thinking, but not past thinking. In the second study, they found that participants who generated more future-directed thoughts were better able to remember previously-presented self-related vs. other-related words (i.e. they had a stronger self-reference effect). Altogether, these results support the idea that self-referential processes may be preferentially involved in future rather than past-focused SGT.

Based on these findings, we propose that the link between SGT and self-concept may vary according to the content of the thoughts. For example, imagine Robert got recently fired from his job. Ruminating negatively about his lost job may lead Robert to carry a sense of failure and may therefore negatively affect his self-concept. On the contrary, planning his future actions with the goal of finding a job that fits better with his competences may lead Robert to reflect on his valuable skills and may therefore positively influence his self-concept. This example illustrates our hypothesis that SGT may have heterogeneous consequences on one’s sense of self depending on the content of the thoughts spontaneously generated. In addition to improving the understanding of the link between SGT and self-concept, findings in favour of this hypothesis will illustrate our prediction that different types of SGT can have heterogeneous functional outcomes, and therefore that SGT can be considered as a heterogeneous phenomenon.

As well as providing evidence for SGT heterogeneities, the current study also aims to shed light on the mechanism underlying the link between SGT and self-concept. We propose that the mechanism supporting the relation between SGT and self-concept relies on the capacity of SGT to manipulate and consolidate information from a self-relevant event and to transfer this information into one’s sense of self (see also Gruberger et al., 2011). For example, imagine Charlie got recently married. Remembering events such as the moment he and his partner said “yes”, or imagining moving in a new house with his partner may allow Charlie to start considering himself as a married man. We suggest that these SGT may help him assimilate the wedding as part of his personal history, integrate it into his definition of who he is and who he will be in the future, which as a consequence will shape his self-concept.

Current experiment

The current study aims to shed light on i) the role of SGT content in the relation between SGT and self-concept, and ii) the mechanism underlying this relation. To this end, our experiment consisted in priming a particular mind-set in participants, followed by measuring SGT while they performed a short cognitive task. Subsequently, their self-concept was assessed using the Twenty Statements Test (TST, Gardner, Gabriel, & Lee, 1999; Kuhn & McPartland, 1954). This experimental design allowed us to explore whether SGT support the transfer of information from an event (i.e. priming) into one's self-concept, and whether this depends on the content of the SGT generated.

In order to induce a particular mind-set, we used the pronoun circling task (Gardner et al., 1999; Kühnen & Haberstroh, 2004) which is traditionally used in social psychology to prime either independent or interdependent views of the self (defining oneself using personal characteristics and traits e.g. "I am a cheerful person", or defining oneself by including relationships and other individuals e.g. "I am the mother of two children"). We hypothesised that priming would influence the social dimension of SGT (e.g. thinking about oneself, about others) as well as the temporal dimension of SGT, similarly to findings published by Smallwood, Schooler, et al. (2011). We also manipulated the content and occurrence of SGT by changing the demands of the cognitive task. Participants performed either an easy non-demanding Choice Reaction Time (CRT) task or a harder Working Memory (WM) task that requires more cognitive resources to be performed appropriately. These two tasks have been used extensively in the mind-wandering research to manipulate SGT occurrence (Ruby, Smallwood, Sackur, & Singer, 2013; Smallwood, Nind, et al., 2009; Smallwood, Ruby, et al., 2013; Smallwood, Brown, et al., 2011). In particular, SGT levels are lower during the WM vs. CRT task as less cognitive resources can be devoted towards internal mentation. Furthermore, the content of the thoughts is also altered by the task manipulation, with participants reporting SGT that are less future-, self- and other-related (Chapter 3 and Iijima & Tanno, 2012; Smallwood et al., 2009). Taken together, we propose that the effects of priming and task difficulty on SGT will depend on the interaction between the two manipulations. For example, whereas SGT occurrence may be reduced during the WM task, priming may overcome this effect and increase self or other-related SGT. Both manipulations therefore provide boundary conditions under which to investigate the potential links between SGT and self-concept.

Overall, our experiment had a 3 x 2 between-subject design, with participants first undergoing *one* of 3 priming conditions (independent, interdependent or no priming at all) and then performing *one* of the cognitive tasks (either CRT or WM task). The social (self, other), temporal (future, past) and emotional (negative, positive) content of SGT was measured using experience sampling and PCA was employed to characterise distinct types of thoughts (see Chapter 2 for more details). Mood levels were also recorded during the cognitive task as several lines of evidence have found a robust relation between SGT and mood (Killingsworth & Gilbert, 2010; Ruby, Smallwood, Engen, et al., 2013; Smallwood, Fitzgerald, et al., 2009; Smallwood & O'Connor, 2011). Following the cognitive task, participants completed the TST which consists in participants providing 20 answers to the question "Who am I?". Answers are usually rated according to whether they reflect an independent or interdependent sense of self (Gardner et al., 1999; Kühnen & Haberstroh, 2004). We extended the TST coding scheme to also include coding of temporal (future, past) and emotional (negative, positive) features of the responses, paralleling the dimensions of SGT. This allowed us to investigate in more detail how different types of SGT may mirror different aspects of self-concept.

The current study tested two hypotheses: i) the relation between SGT and self-concept varies according to thought content and ii) SGT allows the transfer of information from a self-relevant event to participants' self-concept. To this end, we first explored how priming and task manipulation influenced SGT. Next, we explored whether SGT and self-concept were related, and how the experimental manipulations affected this link. For example, Future SGT but not Past SGT may relate to individual differences in TST measures, as predicted by (Smallwood, Schooler, et al., 2011). However, the content of SGT measured during the WM task may not relate to aspects of self-concept as thoughts might be constrained by the limited cognitive resources devoted to internal mentation (e.g. Smallwood et al., 2013). Finally, our experiment also allowed us to assess how priming and task manipulation affected the link between SGT content and i) mood levels and ii) task performance.

4.2 Methods

4.2.1 Participants

The study was part of a broader research project which was approved by the Ethics Commission of the Medical Faculty of the University of Leipzig under the code 360-10-13122010. We recruited 182 individuals from the database of the Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany (mean age = 24.8 years, age range 18–35 years, 113 females). All of them were native German speakers, had normal or corrected-to-normal vision, no history of psychiatric or neurological conditions and no history of substance abuse. Ten participants were subsequently excluded from the analysis due to low accuracy on the cognitive tasks (cut-off: .70).

4.2.2 Experimental session

Participants were randomly assigned to a priming condition (independent, interdependent, or no priming) and to a cognitive task (CRT or WM). The experiment lasted approximately one hour and participants were remunerated 7 Euro. Participants undergoing priming started with the pronoun circling task, followed by the cognitive task and finishing with the TST. Participants who did not undergo priming started the experiment directly with the cognitive task. Distribution of the participants across conditions was as follow: independent priming (CRT/WM): 30, 30; interdependent priming (CRT/WM): 29, 28; no priming (CRT/WM): 29, 26. Mean age and gender distribution did not differ across conditions (univariate ANOVA testing for age differences between conditions, $F(5,163) = .66$, $p > .6$; Pearson's Chi-squared test for gender distribution across conditions, $X^2(5) = 4.36$, $p > .4$).

4.2.3 Self-construal priming

Priming was done using an adapted version of the pronoun circling task (Gardner et al., 1999; Kühnen & Haberstroh, 2004). The task consists in reading two short paragraphs and circling all 20 pronouns present in the text. In the independent condition, the pronouns represented the individual self (e.g., “I,” “me,” “mine”), while in the interdependent condition the pronouns represented the relational self (e.g., “we,” “our,” “us”). Previous studies have shown that this task is efficient at influencing individuals’ self-concept towards more independent or interdependent descriptions (Gardner et al., 1999; Kühnen & Haberstroh, 2004). In the current experiment, we hoped to prime the social dimension of SGT e.g. increase reports of self- or other-related thoughts.

4.2.4 Cognitive task

Participants performed either the CRT task ($n = 88$) or the WM task ($n = 84$) for 18 min, during which SGT was recorded using experience sampling (average number of probes: CRT, $M = 8.12$, $SE = .2$; WM, $M = 8.35$, $SE = .2$). Participants reported whether their thoughts were on or off-task, future-focused, past-focused, self-focused, other-focused, negative and positive. Before each probe, participants also rated how negative and how positive their mood was. Participants answered the questions using sliders ranging from "Not at all" to "Completely". In total, 1490 probes were recorded across 172 participants. For more details regarding the cognitive task and experience sampling, the reader is referred to Chapter 2.

4.2.5 Twenty Statements Test

During the TST, participants were asked to provide 20 answers to the question "Who am I?" (Gardner et al., 1999; Kuhn & McPartland, 1954). Three independent raters blind to the conditions coded all answers on the following dimensions: other-related (if the description involved other individuals e.g. "I am the mother of two children"), future-related, past-related, negative and positive. For each dimension, we then averaged the ratings across the three raters (Inter-rater reliability Cronbach's α, Other: α = .75; Past: α = .78, Future: α = .81, Negative: α = .93, Positive: α = .88). We then computed three variables for each participant: i) *Social score* (averaged proportion of other-related statements), ii) *Temporal score* (averaged proportion of future-related minus proportion of past-related statements) and iii) *Emotional score* (averaged proportion of positive minus proportion of negative statements).

4.3 Results

4.3.1 Definition of SGT types

4.3.1.1 Thought probe descriptives

We first investigated how priming and task manipulation influenced participants' SGT (Figure 4-1). We conducted a univariate ANOVA to determine whether off-task reports varied depending on priming (independent, interdependent, none) and/or Cognitive task (CRT, WM). We observed a trend for a main effect of cognitive task ($F(1,166) = 3.63$, $p = .06$). A post-hoc t-test revealed that off-task reports were higher during CRT vs. WM task at trend level ($t(169) = 1.91$, $p = .06$), replicating previous findings (e.g. Smallwood et al., 2013).

Next, we tested whether the social content of SGT (i.e. self, other ratings) changed depending on the manipulations (Figure 4-1). We computed a repeated measures ANOVA with probe ratings predicted by probe type (self, other), cognitive task (CRT, WM) and priming (independent, interdependent, none). We observed a main effect of probe type ($F(1, 166) = 18.24$, $p < .001$), a main effect of cognitive task ($F(1, 166) = 4.25$, $p = .04$) and a trend for a main effect of priming ($F(2,166) = 2.30$, $p = .1$). Post-hoc t-tests were computed. SGT content was significantly more self- than other-related ($t(342) = 3.19$, p

= .002). Social ratings were overall higher in CRT vs. WM task (t(165) = 1.97, p = .05), replicating previous findings (Chapter 3 and Ruby, Smallwood, Engen, et al., 2013). Finally, social ratings were overall higher after independent vs. interdependent priming (t(114) = 2.07, p = .04). However, ratings after priming were not significantly different compared to no priming (independent vs. none, t(113) = 1.11, p > .2; interdependent vs. none, t(110) = 97, p > .3).

We also investigated whether the temporal content of SGT changed according to priming and/or cognitive task (Figure 4-1). A repeated measures ANOVA predicting probe ratings from probe type (future, past), cognitive task (CRT, WM) and priming (independent, interdependent, none) revealed a main effect of probe type (F(1, 166) = 137.25, p < .001) and a trend for an interaction between probe type and cognitive task (F(1, 166) = 3.28, p = .07). Post-hoc t-tests showed that SGT content was more future- than past-related (t(326) = 9.53, p < .001). In addition, there was a trend for SGT being more future-related during CRT vs. WM task (t(170) = 1.78, p = .08). Both results are consistent with previous findings (Chapter 3 and Ruby, Smallwood, Sackur, et al., 2013; Smallwood, Nind, et al., 2009; Smallwood, Schooler, et al., 2011).

Finally, we investigated the emotional content of SGT (Figure 4-1). A repeated measures ANOVA predicting probe ratings from probe type (negative, positive), cognitive task (CRT, WM) and priming (independent, interdependent, none) revealed a main effect of probe type (F(1, 166) = 131.18, p < .001) and a significant interaction between probe type and cognitive task (F(1, 166) = 6.92, p = .009). Thoughts were overall more positive than negative (t(342) = 14.83, p < .001), and more positive in the CRT vs. WM task (t(168) = 3.24, p = .001).

Altogether, these results highlight that the characteristics of the SGT data are similar to previously published datasets (Baird et al., 2011; Iijima & Tanno, 2012; Ruby, Smallwood, Engen, et al., 2013; Smallwood, Nind, et al., 2009; Smallwood, Schooler, et al., 2011). In particular, participants reported SGT that were more future- than past related as well as more self- than other-related. However, the findings show that priming did not significantly increase social ratings contrary to our expectations.

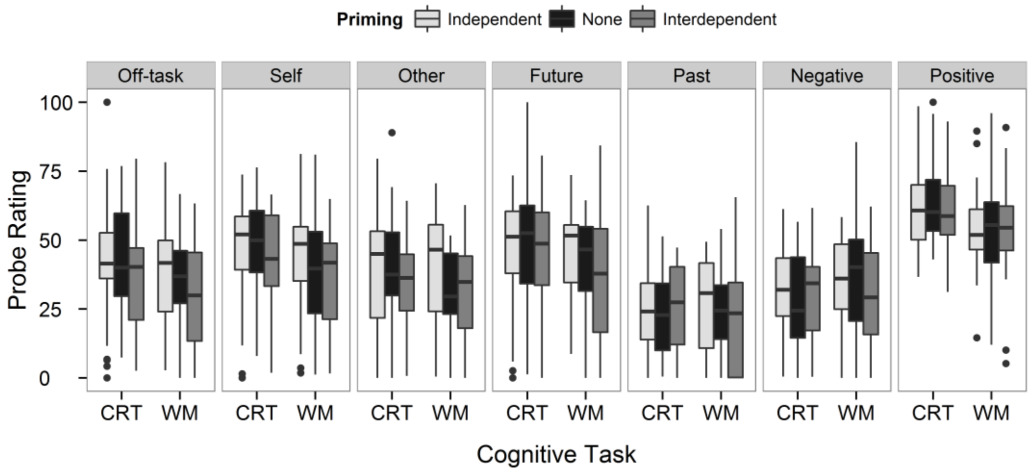

Figure 4-1. Variations in thought content depending on priming and task manipulation
The boxplots illustrate that off-task thinking was higher during the CRT task vs. WM task. SGT was significantly more future- than past-related, more self than other-related and more positive than negative. SGT was also more positive in the CRT vs. WM task. Finally, SGT was more self- and other-related following an independent vs. interdependent priming. Abbreviations: CRT: choice reaction time, SGT: self-generated thought, WM: working memory.

4.3.1.2 Principal Component Analysis

In order to statistically determine different types of thought, we computed a PCA with Varimax rotation on rating data obtained from the 1420 probes (i.e. pooling together data recorded across all participants and all conditions). We obtained 3 principal components (PC) that explained 70% of variance in our data (Figure 4-2; Table 4-1): i) *Future SGT*, loading positively on Future, Off-task, Other and Self questions; ii) *Emotion SGT*, loading positively on Negative and negatively on Positive questions; and iii) *Past SGT*, loading positively on Past, Other and Off-task questions. Our results were similar to findings obtained in Chapter 3 and to previously published data (Engert et al., 2014; Ruby, Smallwood, Engen, et al., 2013). Overall, the PC represent three unique types of thoughts: prospective, retrospective and emotional processes.

Using the PC loadings, we computed averaged SGT scores (see Chapter 2 for more details). We also reversed the average scores for Emotion PC, so that a higher average would reflect more positive SGT. These averages describe how much a participant's SGT loads on the three types of thoughts identified by the PCA, and these scores will be used as regressors in subsequent analyses.

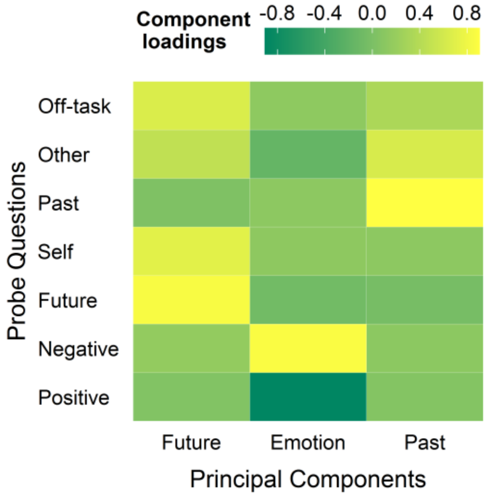

Figure 4-2. Principal Component Analysis of probe data
The principal component analysis of the thought sampling data (n = 172 participants, 1420 probes) revealed three PC that explained 70% of the variance present in our data. The three PC can be described as: i) Future SGT, loading positively on off-task, future, self and other ratings; ii) Emotion SGT, loading positively on the negative ratings and negatively on the positive ratings, and iii) Past SGT, loading positively on off-task, past and other ratings. Abbreviations: PC: principal component, SGT: self-generated thought.

Table 4-1. Results of the Principal Component Analysis
The table presents the loadings of each probe question on the three principal components (PC) generated using principal component analysis. 70% of variance in the probe data was explained by the three PC. See Figure 4-2 for a graphical representation of the loadings.

	Principal Components		
	Future	Emotion	Past
Off-task	0.65	0.13	0.33
Other	0.47	-0.16	0.63
Past	0.03	0.12	0.90
Self	0.70	0.13	0.12
Future	0.86	-0.07	-0.04
Negative	0.16	0.87	0.12
Positive	0.04	-0.90	0.06
Eigen values	2.35	1.60	0.96

4.3.2 Effects of priming and task manipulation

The following sections will explore the effect of task manipulation and priming on SGT. Based on previous findings, we hypothesised that SGT scores will be lower in the WM vs. CRT task, especially for Future SGT (Chapter 3 and Iijima & Tanno, 2012; Smallwood, Nind, et al., 2009). In addition, we also hypothesised that priming may influence Future and Past SGT, similarly to findings provided by Smallwood, Schooler, et al. (2011). We also explored the relation between SGT and mood levels, as well as the relation between SGT and task performance, with the aim to highlight potential effects of priming and task manipulation.

4.3.2.1 SGT occurrence

First, we investigated whether SGT scores varied according to priming and/or cognitive task (Figure 4-3). A Multivariate ANOVA predicting SGT scores (Future, Emotion, Past) from priming (independent, interdependent, none) and cognitive task (CRT, WM) revealed a main effect of cognitive task ($F(1,166) = 5.12$, $p = .002$). Post-hoc t-tests showed that SGT was more future-related and more positive during the CRT vs. WM task (Future SGT, $t(170) = 2.54$, $p = .01$; Emotion SGT, $t(168) = 2.71$, $p = .007$), replicating Chapter 3 results. Past SGT did not vary between tasks ($t(169) = .23$, $p > .8$). Altogether, this shows that our task manipulation (but not priming) had a significant effect on participants' SGT.

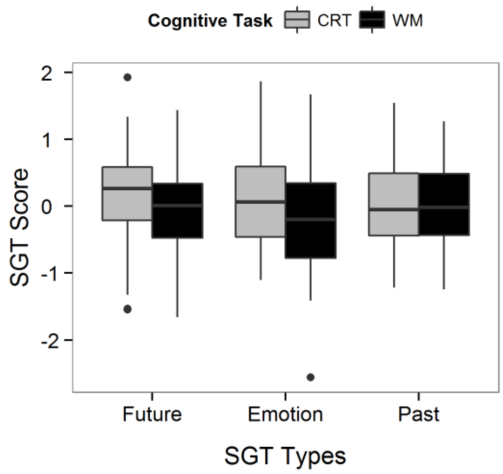

Figure 4-3. Influence of task manipulation on SGT scores
Individuals reported thoughts that were significantly more future-related and more positive during the CRT vs. the WM task. Abbreviations: CRT: choice reaction time, SGT: self-generated thought, WM: working memory.

4.3.2.2 Mood levels

Previous studies have shown that mood levels and SGT are linked, and that this relation varies according to the content of the thoughts (e.g. Poerio et al., 2013; Ruby, Smallwood, Engen, et al., 2013; Smallwood & O'Connor, 2011). In the current study, we were able to investigate whether this relation was influenced by priming and task manipulation. Beforehand, we explored whether mood levels varied across groups. A univariate ANOVA predicting mood from cognitive task (CRT, WM) and priming (independent, interdependent, non) revealed a significant effect of cognitive task ($F(1, 166) = 9.6$, $p = .002$). Subsequent t-test revealed that participants' mood levels were higher during the CRT vs. WM task ($t(170) = 3.06$, $p = .003$).

4.3.2.3 Relation between mood levels and SGT

Next, we explored the link between SGT content and mood levels, as well as the effect of task manipulation and priming. We ran a repeated measures ANOVA with SGT scores as dependent variables and mood, SGT type (Future, Emotion, Past), priming (independent, interdependent, none) and cognitive task (CRT, WM) as independent variables. We observed a significant interaction between SGT type and cognitive task ($F(2,320) = 5.40$, $p = .005$). We also observed a significant interaction between SGT type and mood ($F(2,320) = 111.79$, $p < .001$), and a triple interaction between SGT type, priming and mood ($F(4,320) = 2.66$, $p = .03$). Post-hoc univariate ANOVAs were carried out, predicting each SGT type from priming and mood.

The univariate ANOVA predicting Emotion SGT revealed a significant effect of mood ($F(1,166) = 588.75$, $p < .001$) and an interaction between priming and mood ($F(2,166) = 2.63$, $p = .08$). However, correlations separate for each priming condition showed that Emotion SGT and mood levels were strongly correlated across all situations (all $r > .85$ and $p < .001$).

The univariate ANOVA predicting Past SGT revealed a significant interaction between mood and priming ($F(2, 166) = 3.54$, $p = .03$). Separate correlations for each priming condition revealed that Past SGT was negatively correlated with mood only after interdependent priming, but not after independent or no priming (Figure 4-4a; Independent, $r = .12$, $p > .3$; interdependent, $r = -.30$, $p = .02$; none, $r = .14$, $p > .3$). No significant effect was observed when computing the univariate ANOVA for Future SGT.

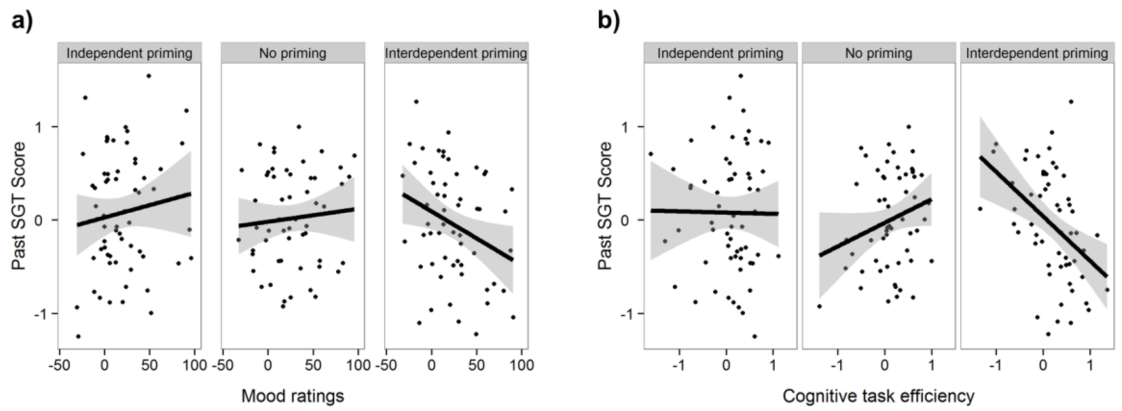

Figure 4-4. Link between Past SGT, mood levels and cognitive task performance
Following interdependent priming, Past SGT significantly predicted low mood levels (a, right panel) and was associated with reduced cognitive task efficiency (b, right panel). These negative effects were not observed following independent priming or without priming. Abbreviation: SGT: self-generated thought.

4.3.2.4 Relation between cognitive task performance and SGT

Prior studies also provide evidence that the relation between SGT and task performance varies according to thought content (Chapter 3 and Baird et al., 2011). We therefore investigated whether a relationship existed in our data between SGT content and cognitive task performance, and whether this was influenced by priming and/or cognitive task.

First, we computed a measure of task efficiency by z-scoring the error rate and RT, computing an average of the two measures and reversing this score. We then performed a repeated measures ANOVA predicting SGT scores from task efficiency, SGT type (Future, Emotion, Past), priming (independent, interdependent, none) and cognitive task (CRT, WM). We observed a triple interaction (SGT type x task efficiency x priming, $F(4,320) = 3.59$, $p = .007$) as well as a quadruple interaction (SGT type x task efficiency x priming x cognitive task, $F(4,320) = 3.91$, $p = .004$). Post-hoc univariate ANOVAs were carried out for each SGT type separately.

For Future SGT, we observed a significant interaction between task efficacy, priming and cognitive task (Figure 4-5, $F(2,160) = 4.80$, $p = .009$). To follow-up this interaction, we ran additional univariate ANOVAs separately for each cognitive task. In the CRT condition, we observed a significant interaction (task efficiency x priming, $F(2,82) = 3.53$, $p = .03$), caused by task efficiency and Future SGT being negatively correlated after independent priming (although at a non-significant level, $r = -.29$, $p = .12$), but positively correlated without priming ($r = .40$, $p = .03$). No correlation was observed between the two variables after interdependent priming ($r = .05$, $p > .7$). In the WM condition, the task efficiency x priming interaction was also significant ($F(2,78) = 7.80$, $p < .001$). Task efficiency and Future SGT were positively correlated after independent priming or without priming (independent, $r = .35$, $p = .06$; none, $r = .39$, $p = .05$), but negatively correlated after interdependent priming ($r = -.48$, $p = .01$). In summary, these results show that Future SGT predicted better task performance without priming, replicating previous findings (Chapter 3). In addition, interdependent priming changed this relationship, causing Future SGT and WM task performance to become negatively correlated.

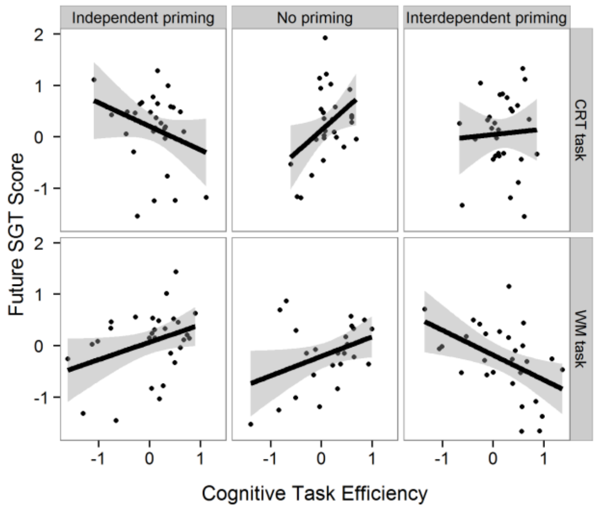

Figure 4-5. Link between Future SGT and cognitive task performance
Without priming, Future SGT predicted significant increases in CRT and WM task efficiency (middle panels). Following interdependent priming, Future SGT predicted significant decreases in WM task efficiency (bottom right panel). On the contrary, independent priming led to a positive correlation between Future SGT and WM task efficiency (left bottom panel). Abbreviations: CRT: choice reaction time, SGT: self-generated thought, WM: working memory.

Next, the univariate ANOVA predicting Past SGT from task efficiency, priming (independent, interdependent, none) and cognitive task (CRT, WM) revealed a significant interaction between priming and task efficiency ($F(2,160) = 4.40$, $p = .01$). Past SGT and task efficiency were positively correlated at trend level without priming ($r = .23$, $p = .09$) but negatively correlated after interdependent priming (Figure 4-4b; $r = -.43$, $p < .001$). The variables were not significantly correlated after independent priming ($r = -.01$, $p > .9$).

Finally, the univariate ANOVA predicting Emotion SGT from task efficiency, priming (independent, interdependent, none) and cognitive task (CRT, WM) revealed a significant interaction between cognitive task, priming and task efficiency ($F(2,160) = 4.10$, $p = .02$). Univariate ANOVAs separate for each cognitive task revealed a significant interaction between priming and task efficiency only in the CRT condition (CRT: $F(2,82) = 3.43$, $p = .04$; WM: $F(2,78) = 1.38$, $p > .2$). There was a trend for positive SGT being associated with poor CRT task efficiency, only without priming (independent: $r = .15$, $p > .4$; interdependent: $r = .25$, $p = .19$, none: $r = -.36$, $p = .06$).

Overall, our data suggest that both Future and Past SGT are linked to better task performance under "normal" conditions. On the contrary, interdependent priming causes both types of SGT to be associated with poor task efficiency. This suggests that interdependent priming may lead to more cognitive resources being devoted towards internal vs. external mentation, leading to decreases in task performance.

4.3.2.5 Link between Past SGT, mood and cognitive task performance

The results described above suggest that Past SGT is associated with both low mood and poor task efficiency after interdependent priming (Figure 4-4). To test whether these two effects are independent from each other, we conducted a regression analysis on data obtained from the interdependent priming condition (n = 57 participants), predicting Past SGT from mood and task efficiency. Both covariates significantly predicted Past SGT, but no significant interaction was observed (Model: $F(3,53) = 5.82$, $R^2 = .25$, $p = .001$; Mood: $t = -2.08$, $p = .04$; task efficiency: $t = -2.92$, $p = .005$; Mood x Cognitive task efficiency: $t = .65$, $p > .5$). This result suggests that the negative relation between Past SGT and poor task performance is not mediated by low mood levels.

4.3.3 Relation between SGT types and self-concept

In the last set of analyses, we explored whether SGT allowed the transfer of information from the prime to self-concept. To this end, we explored whether TST measures varied due to priming and/or task manipulation, and whether individual differences in SGT content predicted individual differences in TST measures.

4.3.3.1 TST descriptives

Altogether, 22.8% of the answers provided by participants were classified as interdependent / other-related. In addition, answers were positively biased ($t(171) = 8.85$, $p < .001$. Average Emotional TST: .14, range: [-.58; .80]), consistent with the theory that individuals have a natural tendency to maintain positive views of themselves (Sedikides & Gregg, 2008). Reports were also directed towards the future rather than the past (Temporal TST: $t(171) = 7.02$, $p < .001$. Average proportion: .03, range: [-.10;.18]). TST measures were z-scored prior to performing subsequent analyses.

4.3.3.2 Effect of priming and task manipulation on TST

Next, we examined whether priming or cognitive task manipulation had significant effects on TST. We conducted a repeated measures ANOVA predicting TST scores from priming (independent, interdependent, none), cognitive task (CRT, WM) and TST type (Temporal, Social, Emotional). We found a between-subject effect of priming ($F(2,166) = 3.46$, $p = .03$). Post-hoc t-test between priming conditions showed that TST scores were overall higher without priming (Figure 4-6; independent vs. none, $t(106) = -2.55$, $p = .01$; none vs. interdependent, $t(109) = 2.08$, $p = .04$; independent vs. interdependent, $t(112) = -.68$, $p = .5$).

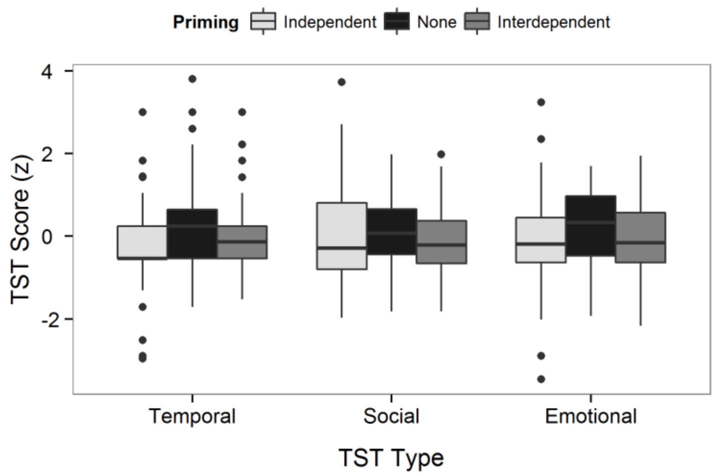

Figure 4-6. Influence of priming on self-concept reports
Our data show that Temporal, Social and Emotional Twenty Statements Test (TST) scores were significantly lower following independent or interdependent priming compared to no priming.

4.3.3.3 Relation between SGT types and TST

Next, we investigated whether TST reports and SGT content were linked and whether their relation was influenced by our manipulations. We computed three separate repeated measures ANOVAs predicting TST scores from TST type (Temporal, Social, Emotional), priming (independent, interdependent, none) and cognitive task (CRT, WM). Each ANOVA also included one of the three SGT scores as covariate (note that we did not include all SGT scores in a single ANOVA as this would have led to an extensive number of interactions).

Future SGT. The ANOVA with Future SGT as covariate revealed a trend for an interaction between TST type, priming, cognitive task and Future SGT ($F(4,320) = 2.32$, $p = .06$). We computed post-hoc univariate ANOVAs separately for each TST score. These analyses revealed a significant interaction between priming, cognitive task and Future SGT only for Temporal TST (Figure 4-7; $F(2, 160) = 5.88$, $p = .003$). To follow this interaction, we ran subsequent ANOVAs separately for the CRT and WM tasks. We observed a significant interaction between priming and Future SGT only during the WM task (WM: $F(2,78) = 5.25$, $p = .007$; CRT: $F(2,82) = 1.14$, $p > .3$). In the WM task, Future SGT and Temporal TST were positively correlated after independent priming but negatively correlated without priming (independent: $r = .37$, $p = .05$; none: $r = -.42$, $p = .03$; interdependent: $r = .24$, $p = .22$). The correlation was significantly different under no priming compared to independent and interdependent priming conditions (independent vs. none, $t(52) = 3.04$, $p = .004$; none vs. interdependent, $t(50) = -2.54$, $p = .01$; independent vs.

interdependent, t(54) = .85, p = .4). In the CRT task, Future SGT predicted increased Temporal TST at trend level (F(1,82) = 2.49, p = .12). Although not significant, these data show that the negative relation between Future SGT and Temporal TST was only observed in the WM task under no priming conditions, and not following priming or when Future SGT occurred in the CRT task.

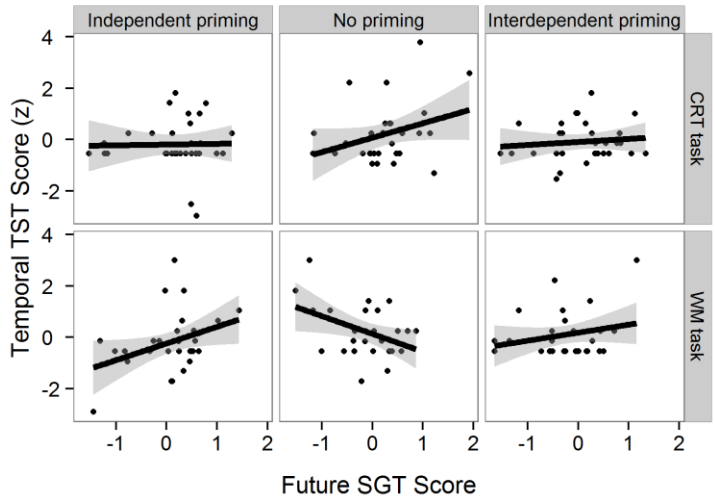

Figure 4-7. Relation between Future SGT and Temporal TST scores
The relation between Future SGT and TST was affected by both priming and task manipulations. Without priming (central panels), Future SGT experienced during the CRT task was associated with TST reports that were more directed towards the future than the past (top central panel). On the contrary, in the WM task and without priming, Future SGT predicted significantly less future-directed TST answers (bottom central panel). This suggests that out task manipulation affected the link between individuals' SGT and the temporal direction they adopted to describe themselves. However, the effect of the task manipulation was limited in primed participants: both independent (left panels) and interdependent priming (right panels) prevented the negative relation between Future WM SGT and Future TST. Abbreviations: CRT: choice reaction time, SGT: self-generated thought, TST: twenty statements test, WM: working memory.

Emotion SGT. The repeated measures ANOVA including Emotion SGT as covariate and predicting TST scores revealed a trend for an interaction between TST type and Emotion SGT (F(2,320) = 2.93, p = .06) and a significant interaction between priming, TST type and Emotion SGT (F(4,320) = 2.87, p = .02). Post-hoc univariate ANOVAs separately for each TST type revealed an interaction at trend level for Social TST (priming x Emotion SGT, F(2,166) = 2.72, p = .07). Positive SGT predicted more social TST only after independent priming (independent, r = .29, p = .03; none: r = .00, p = 1; interdependent: r = -.05, p > .7). Univariate ANOVA predicting Emotional TST from Emotion SGT and priming revealed a significant main effect of Emotion SGT (F(1,166) = 13.08, p < .001) and an interaction at trend level between Emotion SGT and priming (F(2,166) = 2.63, p = .08). Overall positive SGT predicted more positive TST (r = .26, p

< .001), especially after interdependent priming (independent: r = .18, p = .18; none: r = .11, p = .4; interdependent: r = .54, p < .001). These results are in line with previously published data (Krans, de Bree, & Moulds, 2015). Finally, the repeated measures ANOVA predicting TST scores with Past SGT as covariate did not yield any significant result.

4.3.3.4 <u>Link between Emotion SGT, Emotional TST and mood levels</u>

Finally, we explored how the relation between positive SGT and positive self-concept may be influenced by participants' mood levels (Figure 4-8). We computed a univariate ANOVA predicting Emotional TST from Emotion SGT, mood and priming (independent, interdependent, none). As before, we observed that more positive SGT was linked to more Positive TST reports (main effect of Emotion SGT: (F(1,160) = 5.5, p = .02). However, the interaction Emotion SGT x priming was not significant anymore (F(2, 160) = 1.48, p > .2). Instead, we observed a significant interaction between Emotion SGT and mood (F(2,160) = 5.92, p = .02). In order to understand the interaction, we computed a median split of mood levels. We found that, when mood levels were high, TST were overall more positive and Emotion SGT did not predict Emotional TST (t(70) = 1.00, p > .3; Figure 4-8 right panel). On the other hand, when mood levels were low, more positive thoughts were associated with more positive TST reports (t(98) = 6.93, p = .009; Figure 4-8 left panel). This suggests that individuals' SGT may alleviate the negative relation between low mood levels and negative views of oneself.

Figure 4-8. Relation between Emotion SGT, mood levels and TST valence
TST answers were overall more positive when participants' mood levels were high (right panel). However, when mood levels were low, participants experiencing more positive SGT also provided more positive descriptions of themselves (i.e. higher Emotion SGT scores predicted higher Emotional TST scores, left panel). Abbreviations: TST: twenty statements test, SGT: self-generated thought.

4.4 Discussion

The current study was designed to shed light on two research questions. First, we explored whether the relation between SGT and individuals' sense of self varied according to the content of thoughts, in order to provide further evidence for our prediction that different types of SGT have heterogeneous functional outcomes. Second, we aimed to investigate the mechanism supporting the relation between SGT and individuals' sense of self. In particular, we hypothesised that SGT allows the transfer of information from an external event (e.g. the prime) into one's sense of self (as measured using the TST).

Using PCA, we generated three distinct types of SGT (Future, Past and Emotion SGT), thus replicating previous findings (Engert et al., 2014; Ruby, Smallwood, Engen, et al., 2013). We observed that individuals reporting more Future SGT tended to provide descriptions of themselves that were focused on the future rather than the past. This effect was blocked for participants performing a demanding task (which limited Future SGT occurrence), unless they were primed with either an independent or interdependent self-concept. These results suggest that priming influenced participants' SGT and restored the link between Future SGT and self-concept, providing support for our hypothesis that the information elicited by priming was consolidated during SGT and transferred to individuals' sense of who they are.

We also investigated how the emotional content of SGT and mood levels interacted to determine how individuals described themselves. Participants with high mood levels provided self-definitions that were more positive, independent of the emotional tone of their SGT. On the contrary, for participants with low mood levels, thinking more positive thoughts allowed them to alleviate the negative effects of a low mood and they described themselves with a more positive view. Our data therefore show that the emotional content of SGT is related to individuals' self-esteem (similar to D'Argembeau, Lardi, & Van der Linden, 2012), adding further support to our claim that SGT and self-concept are linked.

Taken together, the results described above show that different types of SGT relate to different aspects of self-concept, therefore supporting our claim that the relation between SGT and self-concept is influenced by the content of the thoughts, replicating (Smallwood, Schooler, et al., 2011). Particularly, our data suggest that Future SGT, but not Past SGT, may have provided individuals the chance to transfer self-relevant information from an external event (the prime), to consolidate it and to integrate it into their sense of self . We speculate that certain but not all types of SGT may have consolidating properties due to the different processes involved in the recollection of past experiences and the simulation of future events. Future SGT involves the manipulation of previously-acquired information in order to generate new sequences of events and to predict what might happen (Addis, Pan, Vu, Laiser, & Schacter, 2009), whereas Past SGT only requires the retrieval of information. This may explain why only the former but not the later type of SGT may be linked to consolidation and may influence individuals' self-concept.

Our data also show that priming and task manipulation interacted when influencing the relation between Future SGT and self-concept. This relation was hindered when the cognitive task required more cognitive resources (i.e. during the WM task). One reason might be that in addition to reducing the occurrence of Future SGT, the task manipulation might have interfered with other qualities of the thoughts generated. Although speculative, it is possible that the limited cognitive resources available for internal mentation while performing the WM task may have induced participants' to experience Future SGT that were over-general or not self-relevant, thus reducing the capacity of these thoughts to affect one's self-concept. However, we found that priming alleviated the negative effect of the task manipulation. One possibility is that influencing the social dimension of the SGT via priming may have restored the qualities of Future SGT necessary for the consolidation of self-relevant information. However, our results show that independent and interdependent primes had opposite effects on self- and other-related thoughts (with independent priming overall increasing both types of ratings and interdependent priming decreasing them). It therefore remains unclear why both types of priming seem to have had similar influences on Future SGT. Follow-up studies are required to clarify the mechanisms involved.

Our results also suggest that priming and task manipulation influenced Past and Future SGT differently. Unlike Future SGT, we did not find an effect of task manipulation on the occurrence of past-focused thoughts, replicating previous findings (Chapter 3 and Smallwood, Nind, et al., 2009; Smallwood et al., 2013; Smallwood, Brown, et al., 2011). However, we found that interdependent priming led to Past SGT being linked to both low mood levels and reduced task performance, and these results deserve further consideration. Regarding the link to low mood levels, our data are concordant with previous studies reporting similar effects, whether mood was considered as a transient state or as a chronic trait (Ruby, Smallwood, Engen, et al., 2013; Smallwood & O'Connor, 2011). With regard to task performance, it is to our knowledge the first reported evidence that Past SGT may be linked to poor task implementation. Nevertheless, this is consistent with studies showing that inducing dysphoric participants to ruminate (i.e. to dwell on negative past experiences) leads to poor academic performance (Lyubomirsky, Kasri, & Zehm, 2003). The mechanisms linking interdependent priming and negative consequences of Past SGT remain unclear. Because interdependent priming is commonly used to activate inter-personal views of the self, but self and other-related ratings were reduced following this type of priming, we speculate that the negative consequences of Past SGT might arise because of the type of inter-personal information retrieved rather than due to the frequency of the retrieval. For example, interdependent priming may have induced participants to remember negative rather than positive past events, therefore causing SGT to have negative effects on mood and task performance. Additional investigations are required to shed light on these different possibilities.

Despite our results showing that independent and interdependent priming influenced the functional outcomes of SGT, their effects on the social and temporal dimensions of SGT were less clear. We only observed that self- and other-related ratings were higher following an independent vs. interdependent priming, but ratings were not significantly different under priming and no priming conditions. Moreover, no significant effect on the future and past ratings were observed. As a consequence, subsequent studies aiming at manipulating the social or temporal content of SGT may consider using other forms of manipulations, for example using self-reflection (Smallwood, Schooler, et al., 2011) or prompting individuals to think about personal goals (Stawarczyk, Majerus, Maj, et al., 2011). We suspect that these manipulations may have stronger effects on individuals' SGT.

Finally, the finding that distinct types of SGT had a different relation to self-concept (e.g. Emotion SGT linked to self-esteem, Future SGT linked to the temporal focus of self-concept) adds to a growing body of evidence that SGT can have heterogeneous properties when the content of the thoughts is taken into account (Chapter 3 and Engert et al., 2014; Ruby, Smallwood, Engen, et al., 2013; Smallwood & O'Connor, 2011; Smallwood, Schooler, et al., 2011). In the current experiment, defining different types of SGT using PCA allowed us to investigate how each type of thought related to various aspects of TST and this therefore provided us the chance to observe heterogeneous relations between SGT and self-concept. These data and other findings therefore highlight the importance of considering SGT as a heterogeneous phenomenon, and support our prediction that taking into account the content of the thoughts allows a better understanding of the functional outcomes of SGT (Ruby, Smallwood, Engen, et al., 2013; Smallwood & Andrews-Hanna, 2013).

To conclude, our findings provide novel evidence that the thoughts and emotions spontaneously generated by individuals shape how they define themselves and may support a sense of continuity between their past, present and future selves. For healthy individuals, the natural tendencies of projecting oneself into the future and having positive views of oneself may be part of the "arsenal of psychological mechanisms" supporting self-enhancement and psychological well-being (D'Argembeau et al., 2012; Nes & Segerstrom, 2006; Scheier & Carver, 1992; Sedikides & Gregg, 2008). However, this relation may become deleterious under psychopathological conditions such as depression. Negative cycles between ruminative thoughts and negative views of oneself may emerge, strengthening depressive symptoms (Ciesla & Roberts, 2007). Further investigations of the neurocognitive substrates underlying SGT and self-concept are required in order to improve the understanding of self-enhancing cognitions and to allow the development of new strategies alleviating deleterious cycles present under certain pathological conditions.

Chapter 5.
Phenomenological Properties of SGT

5.1 Introduction

The empirical studies presented in previous chapters as well as published findings highlight the importance of taking the content of SGT into account when investigating its functional outcomes. In particular, we found using Principal Component Analysis (PCA) that the temporal, social and emotional dimensions of SGT interact in order to generate three distinct types of thoughts, namely Future, Past, and Emotion SGT (Chapter 3, Chapter 4 and Engert, Smallwood, & Singer, 2014; Ruby, Smallwood, Sackur, & Singer, 2013). Identifying different types of SGT allowed us to examine their properties individually. For example, we observed that Future but not Past SGT was linked to better performance at the Choice Reaction Time (CRT) task (Chapter 3; Chapter 4). In addition, Future SGT was linked to subsequent increases in mood levels, whereas Past SGT was related to subsequent decreases in mood (Ruby, Smallwood, Engen, et al., 2013). Finally, our data and others suggest that Future but not Past SGT is related to self-referential processes (Chapter 4 and Baird, Smallwood, & Schooler, 2011; Cole & Berntsen, 2015; Smallwood, Schooler, et al., 2011). Altogether, these findings support our prediction that the content of SGT can influence the functional outcomes of mind-wandering episodes, in line with the *content regulation hypothesis* (Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015).

Nevertheless, the mechanisms supporting SGT heterogeneities remain unclear. According to the *component process hypothesis* proposed by Smallwood and colleagues, the rich variety of mental experiences is made possible via the flexible combination of cognitive and neural processes (Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015; Smallwood, 2013a). Thus, different types of SGT may have heterogeneous functional outcomes because these thoughts rely on distinct neurocognitive processes. Shedding light on these neurocognitive correlates may allow us to gain insight into the mechanisms supporting SGT heterogeneities. In the current chapter, we focus on the cognitive correlates of SGT. To this end, we investigated the phenomenology of different types of thoughts, with the rationale that distinct phenomenological properties rely on specific cognitive processes.

An extended body of research highlights important phenomenological aspects of SGT, including the modality employed to represent the thoughts i.e. inner speech or visual mental imagery (Gorgolewski et al., 2014; Krans et al., 2015; Singer & Antrobus, 1972; Singer, 1966; Smallwood et al., 2003; Song & Wang, 2012; Stawarczyk, Cassol, et al., 2013), their structure and specificity (Gorgolewski et al., 2014; Stawarczyk, Cassol, et al., 2013), their purpose e.g. if they are goal-directed or involve planning (Baird et al., 2011; Cole & Berntsen, 2015; D'Argembeau, Renaud, & Van Der Linden, 2011; Stawarczyk, Cassol, et al., 2013), the control exerted over the them e.g. whether they are spontaneous, intrusive or voluntary (Brewin & Smart, 2005; Forster & Lavie, 2009) and their persistence e.g. perseverative cognitions (Ottaviani et al., 2014). We suggest that thoughts with distinct phenomenological properties rely on a specific set of cognitive processes. For example, inner speech recruits semantic processes (Shergill et al., 2001) whereas visual mental imagery relies on visual processes (Thompson & Kosslyn, 2000). Consequently, we suspect that thoughts employing inner speech and those using visual imagery will rely on distinct cognitive substrates. Similar predictions can be made for other phenomenological properties e.g. voluntary and specific thoughts may recruit executive control processes, whereas intrusive thoughts may occur due to reduced executive functions. Altogether, we suggest that assessing the phenomenology of SGT may provide insight into its cognitive correlates.

In the current chapter, we propose that different types of SGT (Future, Past, Emotion) may have heterogeneous phenomenological properties. A limited number of studies have investigated the relation between the content and phenomenology of SGT. Findings show that future-directed thoughts are more personally relevant and goal-oriented than other types of thoughts (Baird et al., 2011; Cole & Berntsen, 2015; Stawarczyk, Cassol, et al., 2013). In addition, future thoughts may rely more on inner speech compared to non-future oriented thoughts (Stawarczyk, Cassol, et al., 2013). These findings provide preliminary support for our hypothesis that different types of SGT may have different phenomenological properties. The current chapter will draw one these findings to shed light on the relationship between the content and phenomenology of SGT. Exploring the phenomenological similarities and differences across SGT types may allow us to find evidence for our prediction that distinct types of thoughts rely on specific cognitive processes (i.e. the component process hypothesis), which may in turn provide insight into the mechanisms supporting SGT heterogeneities.

Current study

Overall, the current study aims at investigating the relation between the content and phenomenology of SGT. Both aspects were measured using experience sampling while participants performed the CRT task (see Chapter 2 for more details). The number of features probed was kept to a minimum so as to facilitate introspection. One set of questions assessed the phenomenological properties of SGT and focused on the modality of the thoughts (whether they were in the form of words, in the form of images), how intrusive the thoughts were perceived and how vague / specific the thoughts were considered. The second set of questions targeted the content of participants' SGT, in particular the temporal (future, past), social (self, other) and emotional dimensions of thoughts. We performed PCAs on the thought probe data separately for each set of questions in order to: i) statistically identify the pattern of phenomenological properties, and ii) replicate the pattern of SGT content previously observed (Chapter 3; Chapter 4 and Engert et al., 2014; Ruby, Smallwood, Sackur, et al., 2013).

After defining the different types of SGT and the distinct phenomenological properties, we investigated their relationship using two sets of analyses. The first set explored the phenomenological characteristics of SGT types and was conducted at the *probe level* used linear mixed models[2] (LMMs, Bates, Maechler, & Bolker, 2012). These analyses allowed us to investigate whether different types of thoughts (namely Future, Past and Emotion SGT) had similar or distinct phenomenological properties e.g. whether Future SGT is more in the form of words (as suggested by Stawarczyk, Cassol, et al., 2013). The second set of analyses explored the relation between individual differences in SGT content and in SGT phenomenology. These analyses were computed at the *participant level*. For example, they explored whether individuals who tend to think about the future also tend to use inner speech rather than visual imagery. Finding a relation between individual differences in SGT content and in SGT phenomenology will indicate that both SGT features rely on common underlying processes.

In addition to the CRT task, participants also filled in various questionnaires and performed additional tasks. These additional measures were employed in order to provide further insight into the cognitive correlates and functional outcomes of SGT. In particular, we measured depressive tendencies using the Centre for Epidemiologic Studies Depression Scale Revised (Eaton, Smith, Ybarra, Muntaner, & Tien, 2004) as previous findings

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[2] LMMs are statistical analyses which allow the investigation of fixed effects i.e. effects that one is interested in, whilst controlling for random effects i.e. effects that arise due to multiple sampling within participants, such as when several thought probes are collected from a single participant.

suggest that the relation between depressive symptoms and SGT may depend on thought content (Ruby, Smallwood, Engen, et al., 2013; Smallwood & O'Connor, 2011). Next, SGT has also been associated with both lower and higher cognitive task performance (Chapter 3; Chapter 4; McVay & Kane, 2009; Smallwood, McSpadden, & Schooler, 2007; Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011). We explored this relation using the CRT task as well as the stop signal response task (SSRT), which assesses response inhibition (Verbruggen & Logan, 2009). Finally, we also investigated the link between SGT and self-referential processes using the self-reference task (SRT; Rogers, Kuiper, & Kirker, 1977; Smallwood, Schooler, et al., 2011). Altogether, these analyses aim at replicating previous findings, which would provide support for the replicability and reliability of the methodology employed to measure the content of SGT.

5.2 Methods

5.2.1 Participants

The study was approved by the York NeuroImaging Centre (YNiC) Research Ethics & Governance. 40 participants were recruited using the YNIC participant mailing list (mean age = 22.7 years, age range = 18–31 years, 17 females). All were native English speakers, right-handed, had normal or corrected-to-normal vision, no history of psychiatric or neurological conditions and no history of substance abuse.

5.2.2 Experimental session

The experiment was divided into three sessions, each session lasting approximately one hour. The first session consisted in the recording of structural and functional MRI data. The two remaining sessions involved the completion of various cognitive tasks and a battery of questionnaires. Sessions usually took place on three consecutive days or within a week. Participants were remunerated £20 or 4 course credits for taking part in the experiment.

5.2.3 Cognitive task

Participants performed the CRT task during 15 min during which SGT was recorded using experience sampling. Intermittently throughout the task, participants were interrupted and asked to rate how much their thoughts were unrelated to the current task (i.e. "off-task"). Five questions also assessed the *content* of SGT (future, past, self, other, emotion) and four assessed the *phenomenology* of SGT (images, words, intrusive, vague). Participants answered the questions using sliders ranging from "Not at all" to

“Completely”. In previous studies, we recorded the emotional aspect of SGT using two questions (“How negative” and “How positive are your thoughts?”). Because we repeatedly observed that the two questions shared a very high amount of variance (Chapter 3; Chapter 4 and Engert et al., 2014; Ruby, Smallwood, Engen, et al., 2013), we used a single question in the current experiment: “The content of my thoughts was:”. Participants answered using a slider ranging from “Negative” to “Positive”.

5.2.4 Additional tasks

5.2.4.1 <u>Stop signal response task</u>

We also administered the stop signal response task (SSRT) to measure response inhibition as a proxy for cognitive control (Verbruggen & Logan, 2009). The task consisted in sequentially presenting arrowheads pointing either towards the left (<) or the right (>) on a computer screen for 1000 ms, separated by a 500 ms fixation cross. Participants were instructed to indicate the direction of the arrow as fast as possible using the corresponding arrow key. In 20% of the trials, a beeping sound (the stop signal) preceded the presentation of the arrow and participants had to inhibit their response. The stop signal was initially presented 250 ms after the visual stimulus and varied according to the participants’ performance. If the participant accurately inhibited her response, the stop signal delay (SDD) was increased by 50 ms; if she responded to the arrow despite hearing the stop signal, the SDD was decreased by 50 ms. Overall, the task consisted of 150 experimental trials and lasted approximately 7 min.

5.2.4.2 <u>Self-reference task</u>

Participants also completed the SRT (Rogers et al., 1977; Smallwood, Schooler, et al., 2011). The SRT is designed to measure self-reflection tendencies and consisted in two phases. During the first phase, trait adjectives were sequentially presented on a computer screen and participants were asked to judge whether the words applied to a particular referent i.e. themselves, their best friend or to David Cameron (the UK prime minister at the time of the experiment). In total, 3 lists of 18 adjectives were presented, each list being associated to one referent. The order in which adjectives and lists were presented was randomized, and word presentation was self-paced. In addition, lists were rotated across conditions.

The second phase of the SRT consisted in a surprise memory test. 108 trait adjectives were sequentially presented and participants had to indicate using a key press whether each word was “new” or “old” (i.e. they had seen it during the first phase). Half of the adjectives were new. Words were presented in a random order and presentation was self-paced.

5.2.5 Questionnaires

A battery of questionnaires was administered at the end of the second testing session. It included the Centre for Epidemiologic Studies Depression Scale Revised (CESDR, Eaton et al., 2004), and questionnaires assessing mind-wandering tendencies: the Daydreaming Frequency Scale (DDFS, Singer & Antrobus, 1970), the Mind Wandering Spontaneous (MWS) and the Mind Wandering Deliberate Scales (MWD; Seli, Carriere, & Smilek, 2014). Participants also completed the Mindful Attention Awareness Scale (MAAS), which assessed participants' tendencies to be aware and attend to present experiences (Brown & Ryan, 2003).

5.3 Results

5.3.1 Definition of SGT types

5.3.1.1 Thought probe descriptives

We first investigated whether the current data had similar characteristics to previously published datasets. Boxplots of the averaged probe data are represented in Figure 5-1. Participants' reported off-task thoughts half of the time ($M = 49.9$, $SE = 3.13$). SGT was more self vs. other-related (paired t-test, $t(39) = 4.57$, $p < .001$). SGT was also more directed towards the future vs. past (paired t-test, $t(39) = 5.81$, $p < .001$). In addition, SGT was in general considered as positive rather than negative (average Emotion ratings: $M = 61.21$, $SE = 2.10$). These results are in line with previously published findings (Iijima & Tanno, 2012; Ruby, Smallwood, Sackur, et al., 2013; Smallwood, Nind, et al., 2009; Song & Wang, 2012; Stawarczyk, Cassol, et al., 2013).

Regarding the phenomenology of SGT, we did not find a significant bias towards thinking in images or thinking in words (paired t-test, $t(39) = -.48$, $p > .6$; Figure 5-1). In addition, participants did not consider their SGT as intrusive ($M = 20.87$, $SE = 2.62$) or particularly vague ($M = 40.66$, $SE = 3.35$).

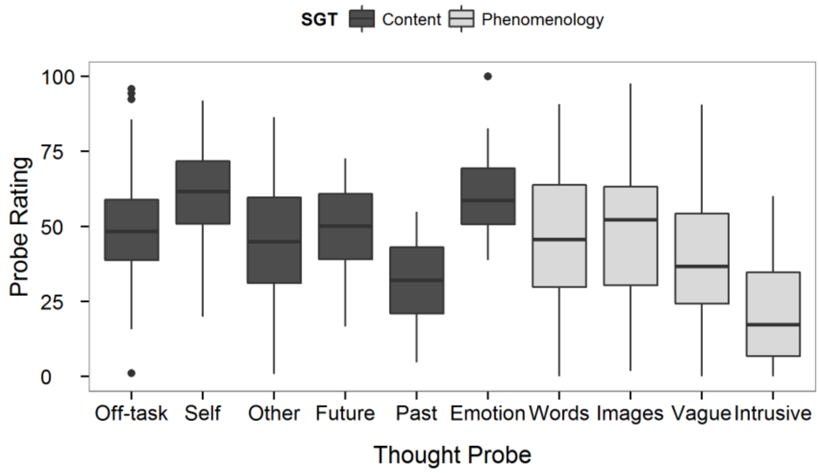


Figure 5-1. Boxplots of average content and phenomenology ratings
Self-generated thought (SGT) was rated as more self- than other-related and was more directed towards the future than the past. There was no significant difference between images and words ratings.

5.3.1.2 Principal Component Analysis of SGT content

Next, we used PCA with Varimax rotation to determine how the ratings from the different content questions related to each other (n = 351 probes, 40 participants, 6 probe questions: Off-task, Self, Other, Past, Future, Emotion; see Chapter 2 for more details). We obtained 3 principal components (PC) that explained 68% of variance in our data (Figure 5-2a; Table 5-1). The first PC loaded positively on Off-task, Self, Other and Future (*Future SGT*). The second loaded positively on Off-task, Other and Past as well as negatively on Future (*Past SGT*). Finally, the third PC loaded positively on Emotion, Future and Other, and negatively on Off-task (*Emotion SGT*). These results broadly replicate previous findings (Chapter 3; Chapter 4; Engert et al., 2014; Ruby, Smallwood, Engen, et al., 2013). SGT scores were computed based on the PC loadings, therefore allowing us to describe how much each thought was future-related, past-related and negative or positive (see Chapter 2 for more details).

5.3.1.3 Principal Component Analysis of SGT phenomenology

We also used PCA to determine how the different phenomenology ratings (Words, Images, Vague, Intrusive) related to each other. The PCA revealed three PC that explained 80% of variance in our data (Figure 5-2b; Table 5-2). The first PC represented SGT's *Modality,* and loaded positively on Words and negatively on Images. The second represented *Intrusiveness* (loading on Intrusive and on Images) and the last one represented *Vagueness* (loading positively on Vague). These data suggest that thoughts are rarely in the form of images *and* in the form of words (replicating Stawarczyk et al., 2013) and that intrusive thoughts may be more in the form of images rather than words. Based on the PCA results, we computed three phenomenology scores in order to determine how much each thought was in the form of words or images, intrusive and vague.

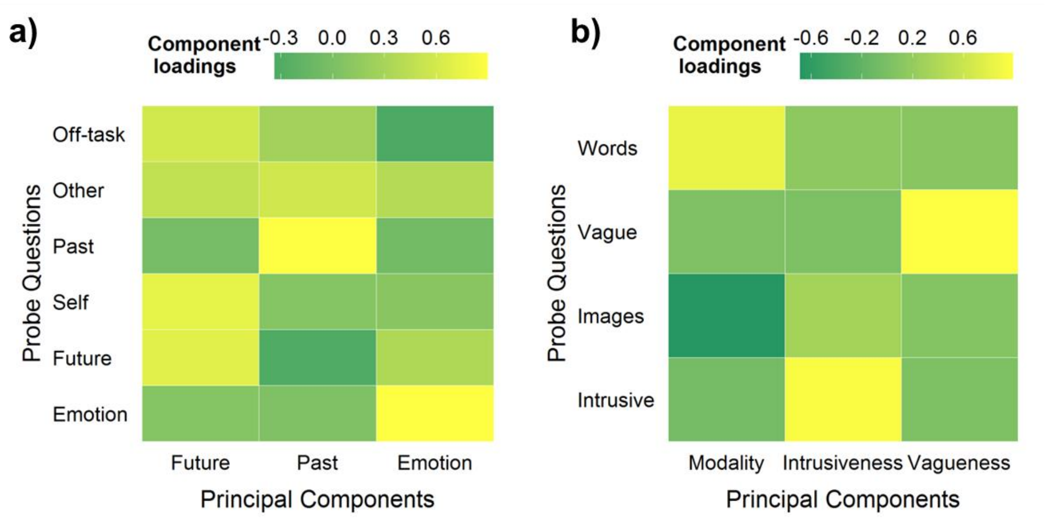


Figure 5-2. Principal Component Analyses of probe data
a) The PCA on the 6 content questions revealed three PC, explaining 68% of variance in the probe data. Future SGT loaded positively on future, self, other and off-task ratings. Past SGT loaded positively on past and other, and negatively on future ratings. Finally, Emotion SGT loaded positively on emotion ratings and negatively on off-task ratings. b) The PCA on the 4 phenomenology questions revealed three PC explaining 80% of variance in our data. The Modality PC loaded positively on the words ratings and negatively on the images ratings. The Intrusiveness PC loaded positively on the intrusive and images ratings. Finally, the Vagueness PC loaded positively on vague ratings. Abbreviations: PC: principal components, PCA: principal component analysis, SGT: self-generated thought.

Table 5-1. Results of the Principal Component Analysis computed on content ratings
The table presents the loadings of each probe question on the three principal components (PC) generated using principal component analysis. 68% of variance in the probe data was explained by the three PC. See Figure 5-2a for a graphical representation of the loadings.

	Principal Components		
	Future	Past	Emotion
Off-task	0.59	0.26	-0.34
Other	0.48	0.58	0.39
Past	-0.04	0.89	-0.06
Self	0.72	0.07	0.09
Future	0.69	-0.31	0.35
Emotion	0.07	0.03	0.89
Eigen values	1.88	1.26	.93

Table 5-2. Results of the Principal Component Analysis computed on phenomenology ratings
The table presents the loadings of each probe question on the three principal components (PC) generated using principal component analysis. 80% of variance in the probe data was explained by the three PC. See Figure 5-2b for a graphical representation of the loadings.

	Principal Components		
	Modality	Intrusiveness	Vagueness
Words	0.83	0.14	0.1
Vague	0.03	0.02	0.99
Images	-0.69	0.31	0.07
Intrusive	-0.05	0.96	0.01
Eigen values	1.26	1.06	.88

5.3.2 Relation between Content and Phenomenology of SGT

Altogether, PCA identified three types of SGT content (Future, Past, Emotion SGT) and three types of phenomenological properties (Modality, Intrusiveness and Vagueness). We first investigated the relation between the content and the phenomenology of the thoughts. The first set of analyses aimed at examining this link at the thought probe level, for example whether future-focused thoughts tended to rely on a specific modality. The second set of analyses investigated the link at the participant level i.e. examining whether individual differences in SGT content relate to individual differences in SGT phenomenology.

5.3.2.1 Thought probe level

In order to examine the link between SGT content and phenomenology at the probe level, we used linear mixed models (LMMs). LMMs allow estimating both fixed effects (i.e. effects that one is interested in, such as the relation between Intrusiveness and Future SGT) while controlling for random effects (effects arising due to the presence of groups within the data e.g. repeated sampling within participants). Each LMM predicted a single SGT type (e.g. Future SGT) from the three phenomenological properties (Modality, Intrusiveness, Vagueness) and one random effect (the intercept of each participant) and was fitted using maximum likelihood (Field, Miles, & Field, 2012).

Content. We first investigated whether Future SGT was predicted by SGT phenomenology. To estimate whether an independent variable had a significant effect on Future SGT, we ran several LMMs, adding one fixed effect at a time (see Table 5-3). We then compared each new model to the previous one, using the likelihood ratio test. This consists in a Chi-square test that determines whether the log-likelihood (-2LL) of the new model is significantly lower than the -2LL from the previous model (i.e. whether adding an independent variable to the model significantly increases the fit of the model). A significant result indicates that the newly added independent variable has a significant effect on the dependent variable. For example, our initial model predicting Future SGT only contained one random effect (the intercept of each subject, Model 1). Model 2 contained one fixed effect (Intrusiveness). As it can be seen in Table 5-3, adding Intrusiveness to Model 1 significantly decreased the log-likelihood ($X^2(1) = 29.69$, $p < .001$), therefore showing that Intrusiveness significantly predicted Future SGT. Next, we added Vagueness as independent variable. Because the log-likelihood of Model 3 was not significantly lower than the log-likelihood of Model 2 ($X^2(1) = 0$, $p > .9$), we can conclude that Vagueness is not a significant predictor of Future SGT. As can be seen in Table 5-3, the best-fitted LMM contained 5 fixed effects and revealed a significant effect of Intrusiveness and two significant interactions (Intrusive x Vagueness and Intrusive x Modality, Table 5-4[3]). To understand the interaction effect between Intrusiveness and Vagueness, we computed a median split of Vagueness scores. As can be seen in Figure 5-3a, Future SGT was linked to increased Intrusiveness, especially when the thoughts were more specific (left panel; LMM for specific thoughts: t = 6.78, coefficient c = .41, SE = .06; LMM for vague thoughts: t = .1.81, c = .12, SE = .07). When computing a median split of Modality scores, we observed that Future SGT was more intrusive, especially when the thoughts were in the form of images (left panel; LMM: t = 8.0, coefficient c = .47, SE = .06) rather than in the form of words (right panel, Figure 5-3b; LMM: t = .48, c = .03, SE = .07).

A similar LMM was computed to investigate the relation between Past SGT and phenomenology. Both Intrusiveness and Modality had significant effects (respectively, $X^2(1) = 15.97$, $p < .001$ and $X^2(1) = 5.24$, $p = .02$). As it can be seen in Table 5-5, thoughts that were more past-related were also more intrusive (Figure 5-4) and more in the form of images rather than words.

[3] Note that we do not report p-values for our best-fitted LMMs because controversies persist with regard to the best way of estimating these p-values and as a consequence, R functions do not generally provide them. We determined whether the fixed effects were significant using the Chi-square tests (Bates, Mächler, Bolker, & Walker, 2014).

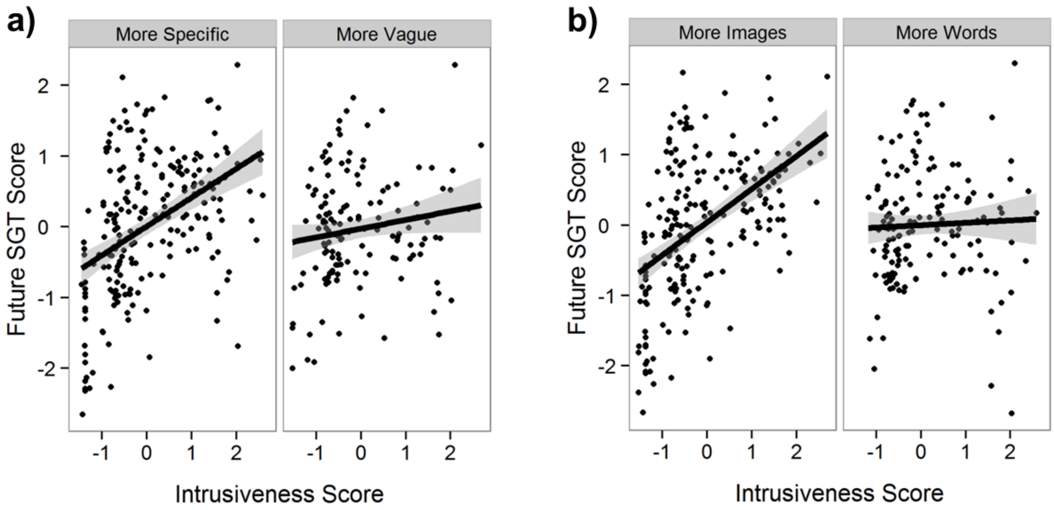


Figure 5-3. Relation between Future SGT and phenomenology (probe level)
a) Self-generated thoughts (SGT) that were more intrusive were also more future-related, especially when the thoughts were more specific (left panel) rather than vague (right panel). b) This relation was also observed when thoughts were in the form of images (left panel) rather than in the form of words (right panel).

Table 5-3. Log-likelihood and Chi-squares for LMMs predicting Future SGT from phenomenology (probe level)
"+" indicates the addition of a fixed effect, "*" indicates full-factorial effects between two independent variables. The best-fitted LMM is indicated in bold and is described in Table 5-4.

Models	Log-likelihood	X^2	X^2 df	p-value
1. Intercept Subject	-491.34			
2. Intrusiveness	-476.49	29.69	1	0.000
3. Intrusiveness + Vagueness	-476.49	0.00	1	0.988
4. Intrusiveness * Vagueness	-472.52	7.94	1	0.005
5. Intrusiveness * Vagueness + Modality	-470.90	3.24	1	0.072
6. Intrusiveness * Vagueness + Intrusive * Modality	**-466.41**	**8.98**	**1**	**0.003**
7. Intrusiveness * Vagueness + Intrusiveness * Modality + Vagueness * Modality	-466.40	0.03	1	0.872
8. Intrusiveness * Vagueness * Modality	-466.09	0.61	1	0.435

Table 5-4. Best-fitted LMM predicting Future SGT from phenomenology (probe level)

	Coefficient	CI (95%)	SE	t value
Mean Future SGT	0.02	-0.13; 0.16	0.07	0.23
Intrusiveness	0.29	0.18; 0.40	0.05	5.32
Vagueness	-0.05	-0.15; 0.06	0.05	-0.84
Modality	-0.09	-0.20; 0.02	0.06	-1.58
Intrusiveness x Vagueness	-0.16	-0.26; -0.06	0.05	-3.08
Intrusiveness x Modality	-0.15	-0.25; -0.05	0.05	-3.04

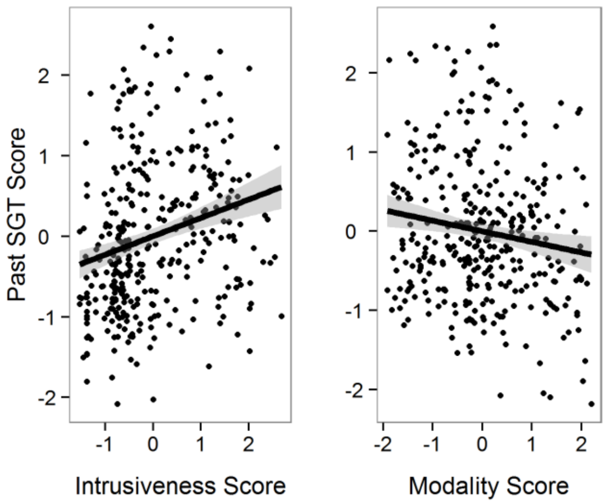


Figure 5-4. Relation between Past SGT and phenomenology (probe level)
Self-generated thoughts (SGT) directed towards the past were more intrusive (left panel) and were more in the form of images than words (right panel). Note that a positive modality score indicates that SGT was more in the form of words than images.

Table 5-5. Best fitted LMM predicting Past SGT from phenomenology (probe level)

	Coefficient	CI (95%)	SE	t value
Mean Past SGT	0.00	-0.14; 0.14	0.07	0.00
Intrusiveness	0.23	0.12; 0.34	0.06	4.14
Modality	-0.13	-0.25; -0.02	0.06	-2.38

We also computed a LMM to predict Emotion SGT from SGT phenomenology (Table 5-6). We observed a significant effect of Vagueness ($X^2(1) = 7.75$, p = .005) and of Modality ($X^2(1) = 8.19$, p = .004) as well as a significant triple interaction between Vagueness, Modality and Intrusiveness ($X^2(1) = 6.08$, p = .01). As seen in Figure 5-5a, positive SGT was more specific and in the form of images. Moreover, positive SGT was specific especially when in the form of images and when intrusive (Figure 5-5b; bottom left panel; LMM for intrusive thoughts in images: t = -4.11, e = -.48, SE = .12; LMM for other thoughts: t = -1.29, e = -.05, SE = .04).

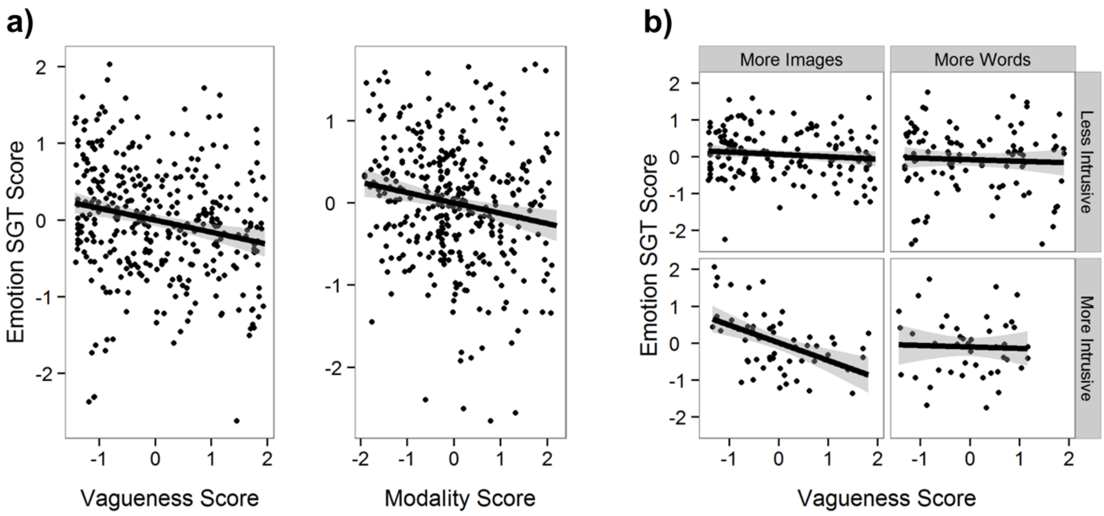


Figure 5-5. Relation between Emotion SGT and phenomenology (probe level)
a) Positive self-generated thoughts (SGT) were more specific (left panel) and were more in the form of images than in the form of words (right panel). In addition, positive thoughts were especially specific if they were intrusive and in the form of images (b, bottom left panel). Note that a positive modality score indicates that SGT was more in the form of words than images; a positive emotion score indicates that SGT was more positive.

Table 5-6. Best fitted LMM predicting Emotion SGT from phenomenology (probe level)

	Coefficient	CI (95%)	SE	t value
Mean Emotion SGT	0.05	-0.16; 0.25	0.10	0.44
Vagueness	-0.16	-0.26; -0.05	0.05	-3.03
Modality	-0.13	-0.24; -0.02	0.06	-2.25
Intrusiveness	-0.02	-0.12; 0.08	0.05	-0.38
Modality x Intrusiveness	-0.01	-0.11; 0.09	0.05	-0.18
Modality x Vagueness	0.06	-0.03; 0.15	0.05	1.28
Vagueness x Intrusiveness	-0.06	-0.16; 0.03	0.05	-1.29
Modality x Vagueness x Intrusiveness	0.12	0.02; 0.21	0.05	2.48

In summary, these analyses revealed that Future SGT was more intrusive, especially when the thoughts were more specific or were in the form of images rather than words. We also found that Past SGT was more in the form of images and more intrusive, and positive SGT was more in the form of images and more specific. The analyses described above shed light on the phenomenological properties of each SGT type. However, because the LMMs only predict one dependent variable, they cannot ascertain the shared variance between the different types of SGT with regard to phenomenology scores. The next set of analyses will explore how each phenomenological property is predicted by the three SGT types in order to determine whether different types of SGT explain distinct or overlapping variance in SGT phenomenology scores.

Phenomenology. The previous analyses revealed that both Future and Past SGT are significantly predicted by Intrusiveness. To determine whether the two types of SGT explain shared or distinct variance in Intrusiveness, we ran a LMM predicting Intrusiveness from the three SGT scores. As can be seen in Table 5-7, both Future and Past SGT were significant predictors of Intrusiveness (respectively, $X^2(1) = 30.74$, $p < .001$ and $X^2(1) = 19.79$, $p < .001$). Thoughts that were considered as more intrusive were also more future and more past-related (Figure 5-6). This result suggests that both Future and Past SGT explain distinct aspects of Intrusiveness variance.

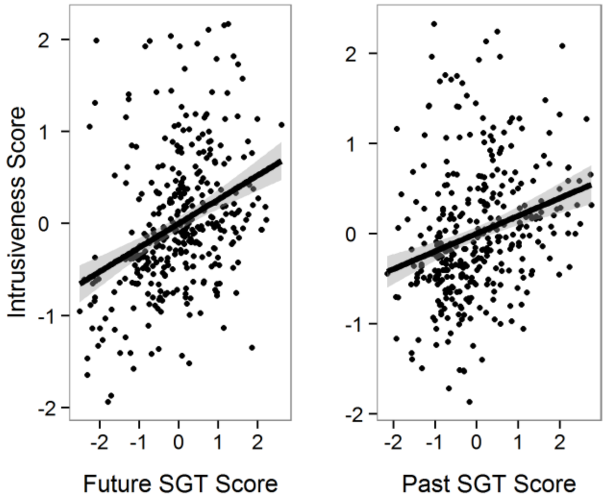


Figure 5-6. Relation between Intrusiveness and SGT content (probe level)
Self-generated thoughts (SGT) that were rated as more intrusive were also more future-related (left panel) and more past-related (right panel).

Table 5-7. Best fitted LMM predicting Intrusiveness from SGT scores (probe level)

	Coefficient	CI (95%)	SE	t value
Mean Intrusiveness	0.02	-0.18; 0.22	0.10	0.17
Future SGT	0.26	0.18; 0.35	0.04	5.99
Past SGT	0.20	0.11; 0.28	0.04	4.52

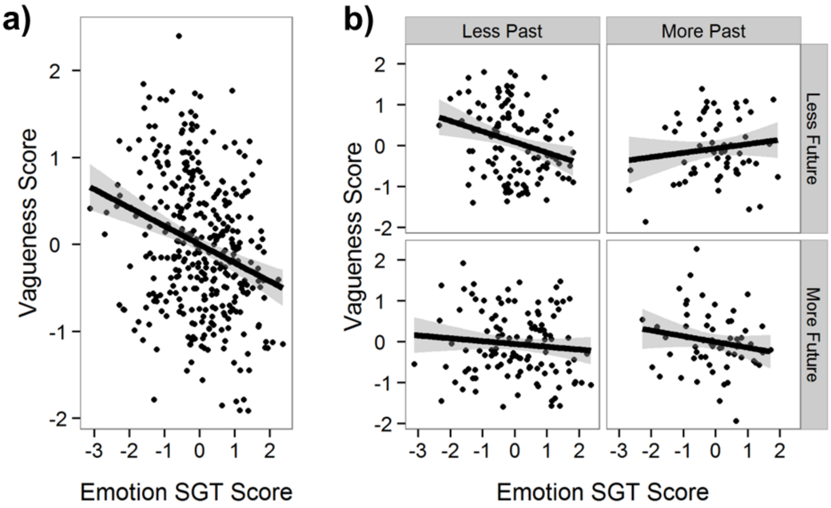


Figure 5-7. Relation between Vagueness and SGT content (probe level)
Vague thoughts were also more negative (a). This relation was especially true for self-generated thoughts (SGT) that were neither focused on the past nor on the future (b, top left panel). Note that a positive emotion score indicates that SGT was more positive.

Table 5-8. Best fitted LMM predicting Vagueness from SGT scores (probe level)

	Coefficient	CI (95%)	SE	t value
Mean Vagueness	0.00	-0.20; 0.20	0.10	0.00
Emotion SGT	-0.21	-0.32; -0.10	0.06	-3.71
Future SGT	-0.04	-0.14; 0.07	0.05	-0.70
Past SGT	-0.06	-0.15; 0.04	0.05	-1.15
Emotion x Future SGT	-0.04	-0.15; 0.07	0.06	-0.77
Emotion x Past SGT	0.08	-0.01; 0.18	0.05	1.74
Future x Past SGT	-0.07	-0.19; 0.04	0.06	-1.27
Emotion x Future x Past SGT	-0.20	-0.29; -0.10	0.05	-3.94

Next, we investigated the relation between Vagueness and SGT types (Table 5-8). We observed a main effect of Emotion SGT ($X^2(1) = 7.66$, p = .006) as well as a triple interaction between Emotion, Future and Past SGT ($X^2(1) = 15.09$, p < .001). Thoughts rated as vague were also negative in tone (Figure 5-7a), especially if they were neither future nor past-focused (Figure 5-7b, top left panel; LMM for top left panel: t = -2.93, e = -.26, SE = .09; LMM for other thoughts: t = -.95, e = -.05, SE = .05).

Finally, we investigated whether Modality was linked to the content of the thoughts (Table 5-9). The best-fitted LMM included a main effect of Emotion SGT ($X^2(1) = 9.12$, p = .003) and a triple interaction (Emotion x Future x Past, $X^2(1) = 4.04$, p = .04). Figure 5-8 indicates that thoughts in the form of images were more positive (a), especially if they were future-related (Figure 5-8b, bottom panels; LMM for future and past-related SGT: t = -2.1, c = -.19, SE = .09; LMM for future and non-past-related SGT: t = - 2.65, c = -.15, SE

= .06; LMM for non-future related thoughts: t = -.11, c = .0, SE = .06)[4]. This model also highlights that, when controlling for the emotional aspect of the thoughts, Past SGT alone is not a significant predictor of Modality anymore.

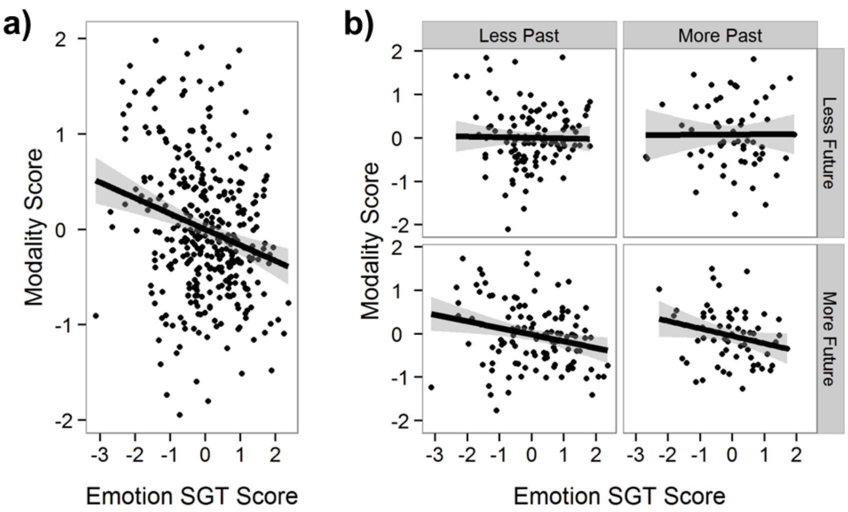


Figure 5-8. Relation between Modality and SGT content (probe level)
a) Self-generated thoughts (SGT) that were in the form of images were also more positive. b) Thoughts were in the form of images especially if they involved future thinking and if they were positive (bottom panels). Note that a positive modality score indicates that SGT was more in the form of words than images; a positive emotion score indicates that SGT was more positive.

Table 5-9. Best fitted LMM predicting Modality from SGT scores (probe level)

	Coefficient	CI (95%)	SE	t value
Mean Modality	0.01	-0.21; 0.22	0.11	0.05
Emotion SGT	-0.16	-0.27; -0.06	0.05	-3.11
Future SGT	-0.04	-0.14; 0.05	0.05	-0.91
Past SGT	-0.07	-0.16; 0.03	0.05	-1.42
Emotion x Future SGT	-0.07	-0.17; 0.03	0.05	-1.39
Emotion x Past SGT	0.01	-0.08; 0.09	0.04	0.14
Future x Past SGT	-0.05	-0.16; 0.05	0.05	-0.98
Emotion x Future x Past SGT	-0.09	-0.18; 0.00	0.05	-2.02

Altogether, our analyses show that both Future and Past SGT are more intrusive. In addition, thoughts that are more positive are also more specific and more in the form of

[4] Note that although the LMM revealed a triple interaction, Figure 5-8 illustrates that the interaction Emotion x Future SGT was significant whether thoughts were less past-related (bottom left) or more past-related (bottom right). This may be due to the fact that we employed a median split to visualize the data whereas the triple interaction is based on continuous variables.

images rather than words. These analyses provide evidence that different types of SGT can have similar and distinct phenomenological properties.

5.3.2.2 Differences between Future and Past SGT

Although the previous set of analyses are important to identify the potential relations between the content and the phenomenology of SGT, they do not provide insight into potential differences between Future and Past SGT. For example, Stawarczyk and colleagues found that Future SGT was overall more in the form of words than images compared to non-future oriented thoughts (Stawarczyk, Cassol, et al., 2013). To investigate these differences, we first categorized the 351 probes into either Future SGT or Past SGT. As the PC are z-scores, a thought was considered as either: i) Future, if it had a Future score equal or above 1 or ii) Past, if it had a Past score equal or above 1; thought probes that were neither Future or Past SGT ($n = 241$) and thoughts that could be considered as both future and past-oriented ($n = 3$) were discarded from the subsequent analyses. A total of 51 future-directed and 59 past-directed thoughts remained.

LMM predicting Modality scores from SGT temporal direction (Future, Past) did not reveal any significant effect ($X^2(1) = .48$, $p > .4$). Likewise, there was no significant effect on Vagueness ($X^2(1) = 0$, $p > .9$) or on Intrusiveness ($X^2(1) = .11$, $p > .7$). Overall these results suggest that future and past-directed thoughts did not differ in terms of modality, vagueness or intrusiveness.

5.3.2.3 Participant level

The next set of analyses was designed to investigate the relation between individual differences in the content and phenomenology of SGT. For example, these may help answer questions such as “Do future thinkers also have more intrusive thoughts?”. To this end, we employed average SGT scores and to parallel the LMMs computed at the probe level (i.e. one dependent variable predicted by several independent variables), we computed one hierarchical linear regression predicting the average scores of one SGT type (e.g. Future SGT) from the three other measures (e.g. Intrusiveness, Vagueness and Modality).

Content. When predicting Future SGT from phenomenology, we observed a main effect of Modality ($X^2(1) = 6.07$, $p = .019$) and an effect of Intrusiveness at trend level ($X^2(1) = 3.55$, $p = .07$). Table 5-10 indicates that future thinkers thought in general more in images than in words, and that their thoughts tended to be more intrusive (Figure 5-9a). A similar hierarchical regression predicting Past SGT revealed that past thinkers also thought more in images than in words ($X^2(1) = 9.77$, $p = .004$; Table 5-11; Figure 5-9b). Finally, we did not find any significant relation between Emotion SGT and the phenomenology of the thoughts at the participant level.

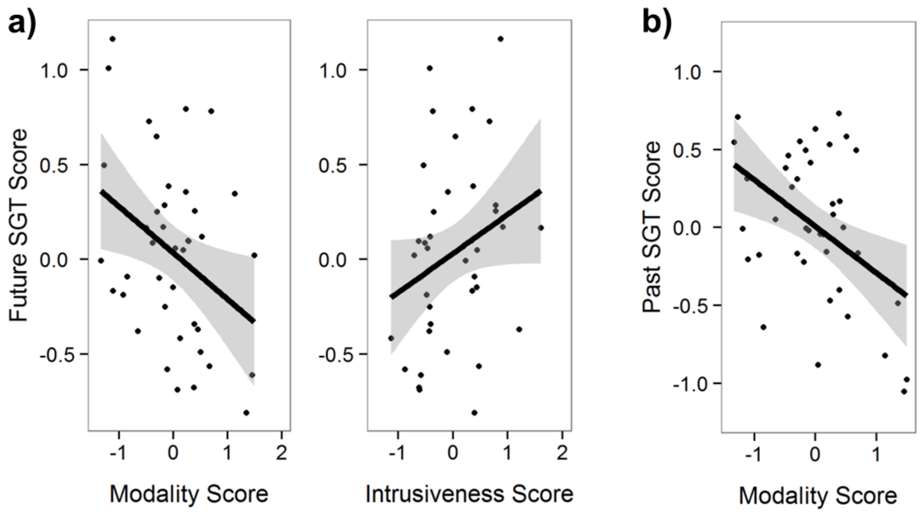


Figure 5-9. Relation between Content SGT and phenomenology (participant level)
a) Future thinkers used more frequently visual imagery than inner speech (left panel) and rated their thoughts as more intrusive (right panel). b) Past thinkers also used visual imagery more frequently than inner speech. Note that a positive modality score indicates that individuals used inner speech more than visual imagery to generate their thoughts. Abbreviation: SGT: self-generated thought.

Table 5-10. Best-fit linear regression predicting Future SGT from phenomenology (participant level)
$F(2,37) = 4.95$, $p = .01$, $R^2 = .21$.

	Coefficient	SE	t value	p-value
Constant	.03	.07	.41	.685
Modality	-.24	.10	-2.45	.019
Intrusiveness	.20	.10	1.91	.064

Table 5-11. Best-fit linear regression predicting Past SGT from phenomenology (participant level)
$F(1,38) = 4.95$, $p = .004$, $R^2 = .20$.

	Coefficient	SE	t value	p-value
Constant	.01	.07	.09	.693
Modality	-.30	.10	-3.05	.004

Phenomenology. Similar analyses were computed to predict each SGT phenomenology scores from the content SGT. In particular, we explored whether Future and Past SGT explained separate or overlapping variance in Modality. Table 5-12 indicates that both Future and Past SGT significantly predicted Modality, suggesting that these two types of content explain separate variance. The hierarchical regression predicting

Vagueness from content SGT did not reveal any significant effect, and the regression predicting Intrusiveness only confirmed the trending relation to Future SGT ($X^2(1) = 3.08$, $p = .09$; Table 5-13).

Table 5-12. Best-fit linear regression predicting Modality from SGT content (participant level)
$F(2,37) = 7.42$, $p = .002$, $R^2 = .29$.

	Coefficient	SE	t value	p-value
Constant	.01	.10	.12	.908
Future SGT	-.45	.21	-2.15	.038
Past SGT	-.59	.21	-2.82	.008

Table 5-13. Best-fit linear regression predicting Intrusiveness from SGT scores (participant level)
$F(1,38) = 3.43$, $p = .07$, $R^2 = .08$.

	Coefficient	SE	t value	p-value
Constant	.02	.10	.17	.863
Future SGT	.40	.22	1.85	.072

In summary, this set of linear regressions highlight that participants experiencing more mental time travel (either towards the past or towards the future) also had more thoughts in the form of images rather than words. In addition, future thinkers also experienced their thoughts as being more intrusive. No significant relation was observed between the overall valence of individuals' thoughts and their phenomenology. Altogether, these analyses reveal similarities between future and past thinkers in terms of phenomenological properties.

5.3.3 Relation between SGT and task performances

5.3.3.1 <u>CRT task efficiency</u>

As previous chapters highlight a link between SGT content and task performance, we investigated whether different types of SGT predicted CRT task performance. We computed a measure of task efficiency by z-scoring the error rate and RT, computing an average of the two measures and reversing this score (so that higher scores would indicate higher efficiency). The multivariate ANOVA predicting SGT Content scores (Future, Past, Emotion) from task efficiency did not reveal any significant effect ($F(3,36) = .14$, $p > .9$). No significant effect was found between the phenomenology of SGT and task efficiency either ($F(3,36) = 1.12$, $p > .3$).

5.3.3.2 Stop signal response task

We were also interested in investigating the link between individual differences in SGT and performance at the Stop Signal Response Task (SSRT, Verbruggen & Logan, 2009). For each participant, we computed a measure of SSRT efficiency as following (SSD: Stop Signal Delay (ms); RT: Reaction Time (ms); Accuracy: percentage of correct stop-signal trial responses):

$$SSRT\ Efficiency = ((SSD - RT)/Accuracy)x100$$

One participant was excluded from the analysis due to a technical error during the performance of the task. We found no evidence that individual differences in SGT content or phenomenology related to individual differences in SSRT efficiency (multivariate ANOVA predicting three SGT content scores: $F(3,35) = .29$, $p > .8$; Multivariate ANOVA predicting three phenomenology scores: $F(3,35) = .55$, $p > .6$).

5.3.3.3 Self-reference task

Previous studies report that self-referential processes may be preferentially involved during Future vs. Past SGT (Chapter 4 and Smallwood, Schooler, et al., 2011) and we explored this question using the Self Reference Task (SRT, Rogers et al., 1977). First, we computed: i) for each condition, the sum of "old" items correctly identified as "old" and ii) the total number of "new" items falsely identified as "old". This latter score was then divided by three and subtracted from each accuracy score in order to control for participants tendency to falsely recognise items. Data from two participants were excluded from the analysis as their accuracy scores in the "best friend" conditions were extremely low (i.e. below 4.5, with an average sample score of 10.2).

Replicating previous findings, participants displayed a self-reference effect i.e. their memory for adjectives was higher in the Self condition (Repeated measures ANOVA predicting accuracy from referent (Self, Best friend, David Cameron), $F(2,74) = 25.25$, $p < .001$, Self: $M = 11.80$, $SE = .3$; Best friend: $M = 10.54$, $SE = .28$; David Cameron: $M = 9.32$, $SE = .34$). We explored how SGT content and SRT performance were linked by computing a multivariate ANOVA predicting SGT content scores from the three accuracy scores. We found a main effect of Self accuracy ($F(1,32) = 4.88$, $p = .007$). Post-hoc analyses revealed that Future SGT was significantly predicted by memory for Self items ($F(1,36) = 15.54$, $p < .001$; Figure 5-10). We did not find an effect for either Past or Emotion SGT. Finally, a multivariate ANOVA predicting phenomenology scores from SRT scores did not yield any significant effect. Altogether, our data replicate previous findings showing that self-referential processes preferentially relate to Future SGT rather Past or Emotion SGT (Chapter 4 and Smallwood, Schooler, et al., 2011).

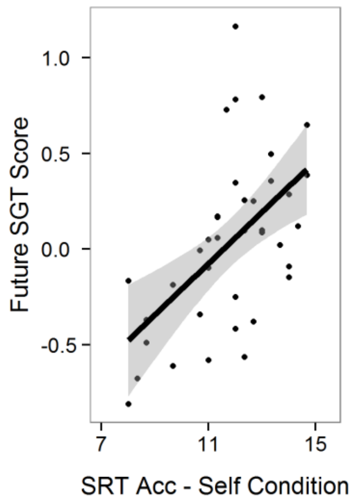


Figure 5-10. Relation between Future SGT and self-reference task performance
Participants who generated more SGT about the future during the CRT task were better able to remember self-related words presented during the SRT. Abbreviations: Acc: Accuracy, CRT: choice reaction time, SGT: self-generated thought, SRT: self-reference task.

5.3.4 Relation between SGT and questionnaires

5.3.4.1 CESDR

The mind-wandering literature highlights a link between SGT tendencies and well-being (Killingsworth & Gilbert, 2010; Ruby, Smallwood, Engen, et al., 2013; Smallwood, Fitzgerald, et al., 2009; Smallwood & O'Connor, 2011). Although some studies report that tendencies to mind-wander is associated with low mood levels (Killingsworth & Gilbert, 2010), other studies highlight that this relationship depends on the content of the thoughts (Poerio et al., 2013; Ruby, Smallwood, Engen, et al., 2013; Smallwood & O'Connor, 2011). The following analysis explored whether a relationship existed between depressive symptoms (as assessed using the Centre for Epidemiologic Studies Depression Scale Revised [CESDR], Eaton et al., 2004) and the content as well as the phenomenology of SGT. Two participants were excluded due to extremes score on the CESDR (above 30, with a sample median of 11.5).

A multivariate ANOVA predicting the three types of SGT Content from CESDR scores revealed an effect of CESDR at trend level ($F(3,34) = 2.59$, $p = .07$). Post-hoc univariate ANOVAs revealed that depressive tendencies were associated with more negative thoughts ($F(1,36) = 7.48$, $p = .009$; Figure 5-11a), replicating previous findings (Andrews-Hanna et al., 2013; Ruby, Smallwood, Engen, et al., 2013). No significant effect was observed for either Past or Future SGT.

We also explored whether individual differences in the phenomenology of thoughts were related to depressive symptoms. We computed a multivariate ANOVA predicting the three phenomenology scores from CESDR scores but no significant relation was observed ($F(3,34) = .17$, $p > .9$).

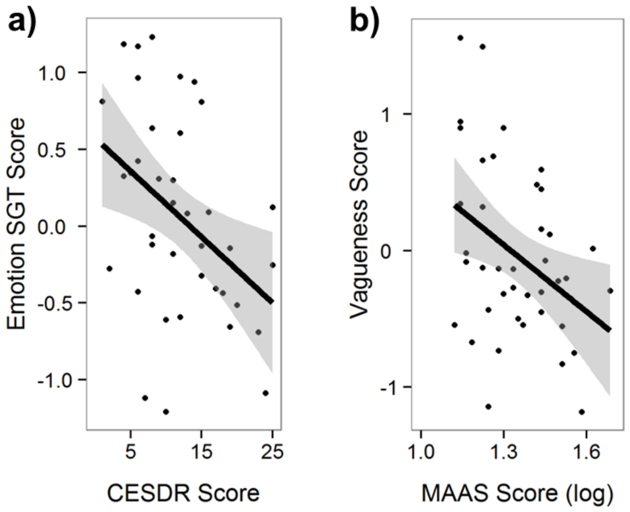


Figure 5-11. Relation between SGT content and questionnaires
a) Individuals reporting more negative thoughts also had higher depressive symptoms as measured using the CESDR. b) Individuals reporting more specific thoughts also had larger MAAS scores, indicating that they had more mindful tendencies. Note that a positive emotion score indicates that individuals generated more positive SGT. Abbreviations: CESDR: Centre for Epidemiologic Studies Depression Scale Revised, MAAS: Mindful Attention Awareness Scale, SGT: self-generated thought.

5.3.4.2 Mind-wandering questionnaires

We also investigated whether mind-wandering tendencies (as assessed using questionnaires) related to either the content or the phenomenology of SGT (as measured under laboratory conditions). Two Multivariate ANOVAs predicting the content of SGT were computed, one with Daydreaming Frequency Scale (DDFS, Singer & Antrobus, 1970) and one with Mind Wandering Spontaneous (MWS) and Mind Wandering Deliberate (MWD, Seli et al., 2014) as covariates. Neither analysis revealed a significant relationship. Similarly, we ran multivariate ANOVAs predicting the three types of phenomenology from i) MWD and MWS, and ii) from DDFS scores. Again, no significant effect was observed.

5.3.4.3 MAAS

Finally, we investigated whether mindfulness tendencies, as measured using the Mindful Attention Awareness Scale (MAAS, Brown & Ryan, 2003) related to SGT. We log-transformed MAAS scores prior to performing analyses as they did not follow a normal distribution. The multivariate ANOVA predicting three types of SGT Content from the MAAS score did not reveal any significant effect. Regarding the phenomenology of SGT, we found an effect at trend level ($F(3,38) = 2.77$, $p = .06$). Follow-up univariate ANOVAs separate for each phenomenology type revealed that higher MAAS scores were associated with more specific thoughts ($F(1,38) = 6.47$, $p = .02$; Figure 5-11b).

5.4 Discussion

The aim of the study was to investigate the phenomenological properties of Future, Past and Emotion SGT in order to highlight potential similarities and differences. First, by computing two separate PCAs for the content and phenomenological ratings, we gained insight into the organization of the different features of the mind-wandering experience. We replicated the pattern of SGT types observed in previous chapters and studies (Engert et al., 2014; Ruby, Smallwood, Sackur, et al., 2013), with three PC corresponding to Future, Past and Emotion SGT. Overall, the pattern of SGT content was observed across 5 independent datasets, confirming that our approach for defining types of thought content is reliable. In addition, the resemblance between the current SGT pattern and previous findings also suggests that individuals were equally able to introspect on the features of their thoughts, whether we assessed 5 (Chapter 3), 7 (Chapter 4) or 10 dimensions. It also suggests that replacing the two Negative and Positive questions by a single one has no detrimental consequence on the PCA outcomes.

Performing a separate PCA on the Words, Images, Intrusive and Vague ratings allowed us to determine the shared variance between different phenomenological properties of SGT. One PC represented the modality employed to represent the thoughts (i.e. whether SGT was in the form of words or images), indicating that thoughts are generally represented in a single modality and replicating Stawarczyk et al. (2013b). In addition, our data also suggest that intrusiveness and visual imagery share overlapping variance. Although this result is preliminary, it hints at the possibility that the relation between intrusive thoughts and visual imagery observed in debilitating conditions such as Post-Traumatic Stress Disorder (PTSD) and depression (Brewin, Gregory, Lipton, & Burgess, 2010) may be extreme forms of a phenomenon that is naturally present in healthy populations.

By investigating the relation between the content and phenomenological qualities of the thoughts (using data from 351 probes), we gained a better understanding of the common and distinct properties of Future, Past and Emotion SGT. Our set of LMMs revealed that Future and Past SGT (i.e. mental time travel, MTT) were both considered as more intrusive. However, we did not find evidence for a link between negative thinking and Intrusiveness. Although speculative, this suggests that participants did not consider MTT as negative intrusions but rather as involuntary or spontaneous experiences, perhaps interfering with the performance of the task at hand. This result may have implications for the investigation of the neural correlates of SGT (Chapter 6), as previous studies have found that distinct neural processes support the generation of voluntary and involuntary MTT (Berntsen, 2010). In particular, involuntary future and past thoughts involve associative processes supported by the hippocampus and the medial temporal lobe, whereas voluntary simulations rely on additional goal-directed and executive processes (involving regions of the prefrontal cortex). Our result also provides insight into the results obtained in Chapter 3, where we observed that both Future and Past SGT were related to individual differences in the creative aspect of social problem solving (i.e. generating steps to reach a given solution). Arguably, the generation of involuntary MTT may be related to the creation of steps to resolve a problem because of the shared involvement of associative processes necessary to generate creative mental content.

We also observed that Emotion SGT was characterised by distinct phenomenological properties. Positive thoughts were more in the form of images and negative thoughts more in the form of words. This is in line with early daydreaming studies showing a link between positive thoughts and vivid imagery (Singer, 1974). In addition, results obtained from a Multi-level Exploratory Factor analysis published by Stawarczyk and colleagues revealed one factor loading positively on inner speech, and negatively on imagery as well as affective content (Stawarczyk, Cassol, et al., 2013). Evidence also suggests that certain types of inner speech are linked to anxiety (McCarthy-Jones & Fernyhough, 2011) and that visual mental imagery is impaired during worry (Hirsch, Hayes, Mathews, Perman, & Borkovec, 2012). LMMs also revealed that positive thoughts were considered as more specific, which is consistent with findings highlighting a relation between depressive symptoms and a tendency to generate non-specific and over-general memories or prospections (O'Connor & Cassidy, 2007; Sumner, Griffith, & Mineka, 2010).

Our data also highlight potential similarities between Future and Emotion SGT. As mentioned above, positive thoughts relied on visual imagery and were in general more specific. Paralleling these findings, we observed that Future SGT was especially intrusive when the thoughts were specific or in the form of images. Our PCA results also show that data obtained from future and emotion probe questions shared variance, as indicated by the fact that the Emotion SGT loaded positively on future ratings. These results suggest a link between prospective cognition and positive thinking, in line with a growing body of evidence (Finnbogadóttir & Berntsen, 2013; Plimpton, Patel, & Kvavilashvili, 2015; Rasmussen & Berntsen, 2012; Ruby, Smallwood, Engen, et al., 2013).

Additional analyses were also computed to investigate the relation between individual differences in SGT content and in SGT phenomenology. We observed that individuals who frequently experienced MTT also tended to represent their thoughts using imagery rather than inner speech. This suggests an overlap in the cognitive processes involved in MTT and visual mental imagery, and is consistent with (D'Argembeau & Van der Linden, 2006). In addition, this result also shows that common cognitive processes support Future and Past SGT, and provides additional evidence for the claim that simulations of the past and the future rely on shared cognitive processes (Addis et al., 2009; Schacter et al., 2007).

Finally, two others results replicated previous findings. First, we observed that negative thinking predicted depressive symptoms, in line with (Andrews-Hanna et al., 2013; Ruby, Smallwood, Engen, et al., 2013; Smallwood & O'Connor, 2011). Note that we did not observe a significant relation between the CESDR and Past SGT (on the contrary to previous studies e.g. Ruby, Smallwood, Engen, et al., 2013; Smallwood & O'Connor, 2011) and this may be due to the difference in questionnaires employed (CESDR vs. Beck Depression Inventory, Beck, Steer, & Brown, 1993). Second, we also found that individual differences in Future SGT (but not other types of thoughts) was related to self-referential processing, in line with Chapter 4 and Smallwood, Schooler, et al. (2011). These results confirm that our approach for operationalizing SGT content is reliable and replicable, and therefore provides a solid basis for the investigation of its neural correlates.

To conclude, the current chapter provides evidence that distinct types of SGT possess heterogeneous phenomenological properties and may therefore recruit differences cognitive correlates. Similarities were observed between Future and Past SGT (e.g. they were both considered as more spontaneous), whereas mental time travel and Emotion SGT had distinct properties (e.g. Emotion SGT but not MTT was considered more specific). These similarities and differences support the theoretical approach employed throughout the thesis, whereby we consider Future and Past SGT as more similar to each other than to Emotion SGT (see Chapter 2 for more details). Moreover, they provide evidence for our prediction that distinct types of SGT recruit heterogeneous cognitive correlates. Although preliminary, our findings also hint at the possibility that these heterogeneous cognitive correlates may support SGT heterogeneous functional outcomes and future studies will be required to examine this relationship in more detail.

Chapter 6.

Neural Correlates of SGT

6.1 Introduction

The studies presented throughout this thesis provide evidence that distinct types of SGT can be identified based on the interaction between the temporal, social and emotional dimensions of SGT and represent Future, Past and Emotion SGT. Our studies as well as published findings highlight that different SGT types can have heterogeneous functional outcomes (Chapter 3; Chapter 4; Chapter 5 and e.g. Baird, Smallwood, & Schooler, 2011; Smallwood & O'Connor, 2011) as well as heterogeneous phenomenological properties (Chapter 5; Cole & Berntsen, 2015; Stawarczyk, Cassol, & D'Argembeau, 2013). Altogether, these provide support for our predictions that i) distinct types of thoughts can be identified based on their content and ii) that they possess heterogeneous functional outcomes. The present chapter will test our last prediction i.e. distinct types of SGT rely on specific neural correlates. Evidence in favour of this prediction will provide final support for our claim that SGT is a heterogeneous phenomenon.

We will adopt the *component process hypothesis* as a theoretical framework to guide the examination of the neural mechanisms supporting SGT (Andrews-Hanna et al., 2014; Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015; Smallwood, 2013a; Stawarczyk & D'Argembeau, 2015). The model states that the large range of SGT that individuals can experience (e.g. planning, worry, rumination, reminiscence and so on) may emerge via the flexible selection and recruitment of a variety of neurocognitive processes, including episodic memory, emotion or executive processes (see Chapter 1 for more details). Rather than a single common neural mechanism supporting all forms of SGT, the component process hypothesis postulates that specific sub-processes may be recruited depending on the specificities of the SGT generated.

Throughout the PhD, we have focused on the role of thought content in gaining a better understanding of SGT heterogeneities. Likewise, the current chapter will investigate how the content may shape the neural processes related to distinct types of thoughts. For example, autobiographical planning (i.e. projecting oneself into the future and planning means to achieve one's goals) may require different processes compared to rumination (i.e.

focussing one's attention on negative past experiences) and may therefore rely on distinct neurocognitive substrates to be generated. In addition, we also suggest that the context in which these different SGT types occur may influence the processes recruited. The *context regulation hypothesis* states that individuals regulate their SGT tendencies depending on the demands dictated by the external environment (Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015; Smallwood, 2013a). In particular, SGT is more frequent when the environment is less demanding (e.g. during the Choice Reaction Time (CRT) task comparted to the Working Memory (WM) task) and this effect is preferentially observed for future-focused rather than past-focused thoughts (Chapter 3; Chapter 4; Iijima & Tanno, 2012; Levinson, Smallwood, & Davidson, 2012; Mason, Norton, et al., 2007; Ruby, Smallwood, Sackur, & Singer, 2013; Smallwood, Nind, & O'Connor, 2009; Smallwood, Brown, et al., 2011; Smallwood, Schooler, et al., 2011). This suggests that individuals are able to suppress SGT tendencies under more demanding conditions, and this capacity may require additional control and inhibitory processes. In the current study, we will explore how the neural correlates of SGT vary according to the content of thoughts and the context in which they occur, with the aim to provide support for the component process hypothesis and for our prediction that SGT can have heterogeneous neural correlates.

Role of DMN and non-DMN regions in SGT

An extensive body of research has investigated the neural mechanisms of SGT and highlights the role of the Default Mode Network (DMN[5]) in supporting spontaneous internal mentation. For example, Christoff et al. (2009) probed participants' SGT while they performed a non-demanding task in the scanner. Functional magnetic resonance imaging (fMRI) revealed that DMN regions, including the posterior cingulate cortex (PCC), medial prefrontal cortex (mPFC) and angular gyrus (AG), were more active prior to off-task vs. on-task reports. This study and others demonstrate the ubiquitous role the DMN plays in SGT (Allen et al., 2013; Andrews-Hanna et al., 2010, 2014; Mason, Norton, et al., 2007; Smallwood & Schooler, 2015; Smallwood, Tipper, et al., 2013; Stawarczyk, Majerus, Maquet, et al., 2011).

[5] The DMN is a large-scale brain network more active at rest or when individuals are performing non-demanding tasks. The main hubs of the DMN are the posterior cingulate cortex (PCC) and the anterior medial prefrontal cortex (mPFC). Additional regions include the hippocampus and parahippocampus, ventromedial and dorsomedial PFC (dmPFC and vmPFC), retrosplenial cortex (RSC), posterior inferior parietal cortex (pIPL), temporal pole, lateral temporal cortex (LTC), and temporo-parietal junction (TPJ). See (Andrews-Hanna et al., 2014; Raichle et al., 2001) for reviews.

Additional brain areas not traditionally considered as part of the DMN are also recruited during SGT. For example, future planning (which frequently occurs during SGT) relies on the interaction between the DMN and regions of the Frontoparietal Network (FPN), in particular the anterior cingulate cortex (ACC), dorsolateral prefrontal cortex (dlPFC) and insula (Gerlach, Spreng, Gilmore, & Schacter, 2011; Gerlach, Spreng, Madore, & Schacter, 2014; Spreng et al., 2010). Similar findings have been observed in studies investigating SGT. For example, Christoff et al. (2009) observed activations in the ACC and dlPFC in addition to activations within the DMN (in line with Bernhardt et al., 2014; D'Argembeau et al., 2005; Mason, Norton, et al., 2007; Wang et al., 2009) and Mason, Norton, et al. (2007) also reported activations in the insula and the cingulate alongside activations in the PCC and mPFC. Altogether, these studies highlight that non-DMN regions also support SGT.

Although these studies have shed light on the neural correlates of SGT, little is known regarding SGT heterogeneities emerging due to SGT content. Using fMRI, Mason, Bar, & Macrae (2007) observed that individual differences in future-directed thought were linked to increased fMRI activity in several regions including the mPFC and hippocampus, whereas individual differences in past-directed thought were linked to increased activity in regions such as the insula and cingulate gyrus, providing preliminary evidence for potential differences in neural correlates. In another study, Gorgolewski et al. (2014) employed resting state fMRI (rsfMRI[6]) to examine variations in intrinsic brain activity depending on individual differences in SGT content and phenomenology. Their results highlight heterogeneities, with certain thought types associated with within-DMN regions (e.g. visual imagery recruiting the mPFC) and others associated with non-DMN regions (e.g. social cognition linked to the insula). The current study builds on these studies and aims to provide further evidence for differences in the neural substrates of SGT depending on thought content.

Taking into account the component process hypothesis, and based on the findings demonstrating the ubiquitous role of the DMN in SGT as well as the importance of non-DMN areas, the current study proposes that *interactions* between the DMN and non-DMN regions may support SGT varieties, in line with Andrews-Hanna et al. (2014). In particular, we propose that the DMN hubs (PCC and mPFC) are essential to all types SGT and that additional regions may be recruited according to the specific requirements of the SGT

[6] RsfMRI is a neuroimaging technique which estimates brain activity at rest based on spontaneous fluctuations in the blood-oxygen-level dependent (BOLD) signal.

generated. Our study will test the hypothesis that the interaction between DMN and non-DMN regions may vary for different types of thoughts and according to the context in which they occur.

Current experiment

To assess the interaction between the DMN and non-DMN regions, we used rsfMRI and seed-based whole-brain functional connectivity (FC). FC can be measured by correlating the time courses of the BOLD signal between one region (the seed) and all the other voxels measured. A positive correlation indicates that the seed and the voxel examined are functionally connected (i.e. they are part of the same network) whereas a negative correlation indicates that they may be part of anti-correlated networks. Thus FC provides a quantitative description of how the seed interacts with other brain regions. Previous studies have shown that individual differences in FC can be predicted by individual differences in behavioural and subjective measures e.g. task performance or self-reports (Hampson, Driesen, Skudlarski, Gore, & Constable, 2006; Smallwood, Gorgolewski, et al., 2013). The current study will take advantage of this technique in order to examine how the DMN and other regions interact, and how this interaction is predicted by SGT.

Whole-brain FC of the two mains hubs of the DMN (PCC and mPFC) will be computed and we will examine how individual differences in these FC patterns relate to individual differences in SGT tendencies. In particular, the current experiment will determine how the content and context of SGT influences the FC patterns. To this end, we probed the temporal, social and emotional content of SGT while participants performed the CRT / WM cognitive task and we identified distinct SGT types using Principal Component Analysis (PCA; see Chapter 2 for more details). Following previous findings, we expected that SGT, in particular directed towards the future, would be reduced during the WM compared to the CRT task (Chapter 3; Chapter 4; Iijima & Tanno, 2012; Smallwood et al., 2009; Smallwood, Schooler, et al., 2011).

The main aim of the study was to provide evidence for the component process hypothesis, as instantiated by the proposition that the interaction between the DMN and other non-DMN regions vary according to the content and context of SGT. *Hypothesis 1* states that the individual differences in SGT types will predict individual differences in the FC of the DMN. To this end, our analyses will explore whether differences exist between Future, Past and Emotion SGT. *Hypothesis 2* states that the context in which SGT occurred will be related to individual differences in DMN's FC patterns. Our analyses will therefore test whether generating SGT during easier and harder conditions rely on different neural processes. Finally, *hypothesis 3* will test whether an interaction exists between the content and context in relation to the DMN FC. For example, as previous studies have shown that Future but not Past SGT is reduced during WM vs. CRT task, it is possible that the generation of Future SGT during the WM task may be associated with particular DMN FC patterns compared to CRT. Altogether, evidence in favour of these hypotheses will demonstrate that the content and context of SGT influence the neural processes involved in SGT, thus supporting the component process hypothesis and our general claim that SGT is a heterogeneous phenomenon.

6.2 Materials and Methods

6.2.1 Participants

The study was approved by the Ethics Commission of the Medical Faculty of the University of Leipzig (Ref # 360-10-13122010). 49 right-handed individuals were recruited from the database of the Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany (Mean age = 28 years, Age range 19–46, 30 females). All of them were native German speakers, had normal or corrected-to-normal vision, no history of psychiatric or radiological conditions and no history of substance abuse. Participants provided written informed consent prior to their participation.

6.2.2 Experimental session

Prior to the behavioural experiment, all participants had taken part in various neuroimaging studies during which at least one resting-state scan had been recorded and was accessible from the database. During the experimental session, participants performed three computer tasks in a counter-balanced order. One task consisted of the CRT / WM cognitive task; data from the two other tasks have been described elsewhere and will not be described in the current study (Baird, Smallwood, Gorgolewski, & Margulies, 2013; Smallwood, Gorgolewski, et al., 2013). The information regarding task order will be included as a covariate in behavioural and rsfMRI analyses in order to control for potential order effects.

6.2.3 Cognitive task

Participants performed both the CRT and WM tasks (see Chapter 2 for more details). Each task lasted 14 min and the order of the conditions was counterbalanced. Again, this information will be included as a covariate in statistical analyses in order to control for potential order effects.

6.2.4 Experience sampling

Participants were probed about the content of their thoughts while performing the cognitive task. Intermittently throughout the task, participants were interrupted and asked to rate how much their thoughts were unrelated to the current task (i.e., "off-task"), future-focused, past-focused, self-focused, other-focused, negative and positive. To answer these seven questions, participants used a slider ranging from "Not at all" (0) to "Completely" (100). In total, 613 probes were recorded in 49 participants (average number of probes per participant: CRT, M = 6.3, SE = 0.2; WM, M = 6.2, SE = 0.2).

6.2.5 Functional MRI data acquisition

The rsfMRI scans of the 49 participants were retrieved from the existing Max Planck Institute for Human Cognitive and Brain Sciences database. The data from 8 participants were subsequently excluded because one or more scanning parameters were too extreme compared to the other scans, leaving data from 41 participants. The remaining scans were collected on either a 3.0 Tesla Siemens Tim Trio (n = 26) or a Siemens Vario scanner (n = 15), several months up to a few weeks before the behavioural testing session. Scan duration varied from 360 to 600 seconds and two different slice order acquisitions were employed (ascending, n = 37, interleaved, n = 4). We controlled for differences in scan type, slice order and scan duration by including these variables as nuisance covariates in group-level whole-brain FC analyses. For all participants, the remaining scan parameters were the same (TR = 2000 ms; TE = 30 ms; flip angle = 90°; acquisition matrix = 64×64; FOV = 192 mm; acquisition voxel size = 3×3×4 mm). Participants were instructed to relax, to hold as still as possible, and to keep their eyes open. High-resolution T1-weighted anatomical scans were also acquired for all participants (MPRAGE, TR = 2300 ms; TE = 2.96 ms; TI = 900 ms; flip angle = 9°; FOV = 256 mm; acquisition voxel size = 1×1×1 mm).

6.2.6 fMRI pre-processing

Cortical surface reconstruction was performed on the T1 scans using FreeSurfer (Behzadi, Restom, Liau, & Liu, 2007; Dale, Fischl, & Sereno, 1999; Fischl et al., 2002; Fischl, Liu, & Dale, 2001; Reuter, Rosas, & Fischl, 2010). For each subject, nonlinear transformation from T1 to MNI template (created from 152 subjects, resampled at 2mm, provided with FSL) was calculated using ANTs (Avants et al., 2011). To remove scanner instability effects the first four volumes of each EPI sequence were removed. Slice-timing and motion correction using 4DRealign was implemented in nipy (http://nipy.org/nipy; Roche 2011). Affine transformation from mean EPI image to T1 volume was calculated using BBRegister (Greve & Fischl, 2009). Brain, cerebrospinal fluid (CSF) and white matter masks were extracted from FreeSurfer parcellation and transformed into EPI space (thresholded at 0.5 after interpolation). Realigned time series were masked using the brain mask. Principal components of physiological noise were estimated using the CompCor (Behzadi et al., 2007). Joined white matter and CSF masks and voxels of highest variance were used to extract two sets of principal components (a.k.a. aCompCor and tCompCor). Using both of those strategies ensured robust estimation of physiological noise. Outliers in the EPI sequence were discovered based on intensity and motion parameters (ArtDetect - http://www.nitrc.org/projects/artifact_detect/). This was followed by denoising of the time series using a GLM model with motion parameters, CompCorr components, and outliers as regressors (note that global signal was not regressed). Time series were also smoothed using SUSAN with 5mm full width half minimum (FWHM) kernel (Smith S.M, 1992). Finally high-pass (0.1 Hz) and low-pass (0.01Hz) filters were applied using FSL. Quality of scans and pre-processing was assessed visually by looking at EPI to T1 coregistration overlay, motion parameters plots and temporal signal to noise ratio volumes (tSNR). Pre-processing was performed with a workflow from Brain Imaging Pipelines (https://github.com/INCF/BrainImagingPipelines) and all data processing integrated using Nipype (Gorgolewski et al., 2011).

6.2.7 Functional connectivity analysis

Based on the graph theoretical analysis of the DMN from Andrews-Hanna et al. (2010), spherical ROIs of 6 mm radius were computed for left and right mPFC and left and right PCC, centred at the following MNI coordinates (x,y,z): left mPFC: -6, 52, -2; right mPFC: 6, 52, -2; left PCC: -8, -56, 26; right PCC: 8, -56, 26. These correspond to the major hubs of the DMN in the left hemisphere and we transformed them to the right hemisphere to reflect the fact that the DMN has a complex bilateral structure in healthy individuals (Swanson et al., 2011).

ROI masks were transformed back to each subject's EPI space using combined inverse nonlinear MNI to T1 transform and affine T1 to EPI (thresholded after interpolation at 0.5). Translated ROIs were restricted within the brain mask. ROIs time-series were estimated by averaging voxels within each ROI. Full brain connectivity (correlation) maps were calculated using AFNI. Connectivity maps were Fisher's r-to-z transformed and spatially transformed to MNI space for group-level analysis. Finally, maps were averaged across hemispheres separately for each seed region to provide averaged FC maps. These averaged maps were used in subsequent analyses. Data processing pipelines were put together using Nipype (Gorgolewski et al., 2011) and the code is available at https://github.com/NeuroanatomyAndConnectivity/pipelines/tree/reading_by_default/src/reading_by_default.

6.3 Results

6.3.1 Definition of SGT types

6.3.1.1 Thought probe descriptives

We first investigated whether the current data had similar characteristics to previously published datasets. Note that we included the task order and CRT / WM task order as covariates in all analyses to control for potential order effects. We found that participants reported more off-task thinking during the CRT vs. WM task (Figure 6-1, paired sample t-test, $t(48) = 4.76$, $p < .001$), similar to previous findings (Levinson et al., 2012; Mason, Norton, et al., 2007; Smallwood, Brown, et al., 2011; Teasdale et al., 1995).

Next, we investigated whether the temporal dimension of the thought varied according to the cognitive task. A repeated measures ANOVA predicting ratings from probe type (Future, Past), cognitive task (CRT, WM) and controlling for task order revealed a main effect of probe type ($F(1,48) = 22.97$, $p < .001$). Post-hoc paired t-test revealed that thoughts were in general more future than past-related ($t(48) = 4.79$, $p < .001$). However, unlike Chapter 2, Chapter 3 and previous studies, we did not observe that thoughts were more future-related during the CRT vs. WM task (main effect cognitive task, $F(1,48) = .57$, $p > .4$; interaction probe type x cognitive task, $F(1,48) = .26$, $p > .6$). This may be due to the fact that participants performed the CRT and WM conditions one after the other (in counterbalanced order), whereas participants in previous experiments performed twice each condition, therefore providing them the chance to adapt their SGT tendencies according to task demands.

Regarding the social dimension of thoughts, we observed a main effect of cognitive task ($F(1,48) = 5.49$, $p = .02$). A paired t-test indicated that ratings were higher during the CRT vs. WM task ($t(48) = 2.34$, $p = .02$), in line with previous findings. However, contrary to Chapter 3, Chapter 4 and Ruby, Smallwood, Engen, et al. (2013), we did not observe any significant difference between self and other ratings (main effect of probe type, $F(1,48) = .48$, $p < .5$).

Finally, we also explored the emotional content of participants' thoughts. A repeated measures ANOVA with probe type (negative, positive) and cognitive task (CRT, WM) revealed that thoughts were in general more positive than negative (main effect of probe type, F(1,48) = 58.47, p < .001; paired sample t-test, t(48) = 7.65, p < .001). However, we did not observe an effect of cognitive task (F(1,48) = 1.80, p = .19).

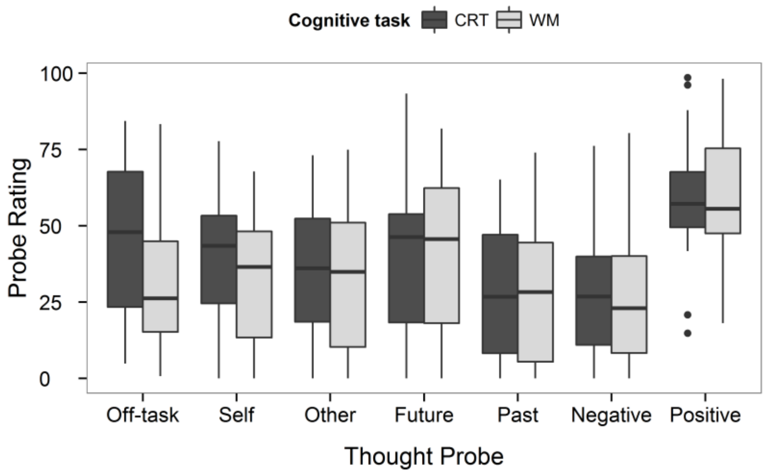


Figure 6-1. Boxplots of average probe ratings
Participants reported significantly more off-task thinking during the CRT vs. WM task. In addition, thoughts were also significantly more future than past-related, and social ratings (self, other) were significantly higher during the CRT vs. WM task. Abbreviations: CRT: Choice Reaction Time, WM: Working Memory.

6.3.1.2 Principal Component Analysis

Similarly to previous chapters, we investigated the shared variance between different probe types using PCA. We computed PCA with Varimax rotation on 613 probes and obtained 3 principal components (PC) explaining 70% of the variance in our data (Figure 6-2a; Table 6-1). The first PC, *Future SGT*, loaded positively on future, self, other and off-task ratings. The second, *Emotion SGT*, loaded positively on negative ratings and negatively on positive ratings. The third PC, *Past SGT*, loaded positively on past, other and off-task ratings. These three types of thoughts are highly similar to the results obtained from previous datasets (Chapter 3; Chapter 4; Chapter 5; Engert et al., 2014; Ruby, Smallwood, Engen, et al., 2013). Using the PC loadings, we averaged the SGT scores for each participant (see Chapter 2 for more details). We also reversed the average scores for the Emotion SGT so that a higher score would reflect more positive SGT.

We then investigated whether SGT types were influenced by the cognitive task (Figure 6-2b). A repeated measures ANOVA with SGT type (Future, Emotion, Past), cognitive task (CRT, WM) and controlling for task order revealed a main effect of cognitive task (F(1, 48) = 5.83, p = .02). Post-hoc paired sample t-test showed that SGT scores were overall higher during the CRT vs. WM task (t(48) = 3.34, p = .001). Although we did not observe a significant interaction between SGT types and cognitive task, our data are in line with previous studies showing that SGT is reduced during the WM vs. CRT task (Mason, Norton, et al., 2007; Smallwood, Brown, et al., 2011; Teasdale et al., 1995).

Table 6-1. Results of the Principal Component Analysis
The table presents the loadings of each probe question on the three principal components (PC) generated by Principal Component Analysis. 70% of variance in the probe data was explained by the three PC. See Figure 6-2 for a graphical representation of the loadings.

	Principal Components		
	Future	Emotion	Past
Off-task	0.63	0.07	0.31
Other	0.54	0.07	0.58
Past	0.12	0.06	0.92
Self	0.70	0.04	0.25
Future	0.86	0.05	-0.06
Negative	0.21	0.85	0.14
Positive	0.06	-0.91	0.02
Eigen values	2.53	1.40	.89

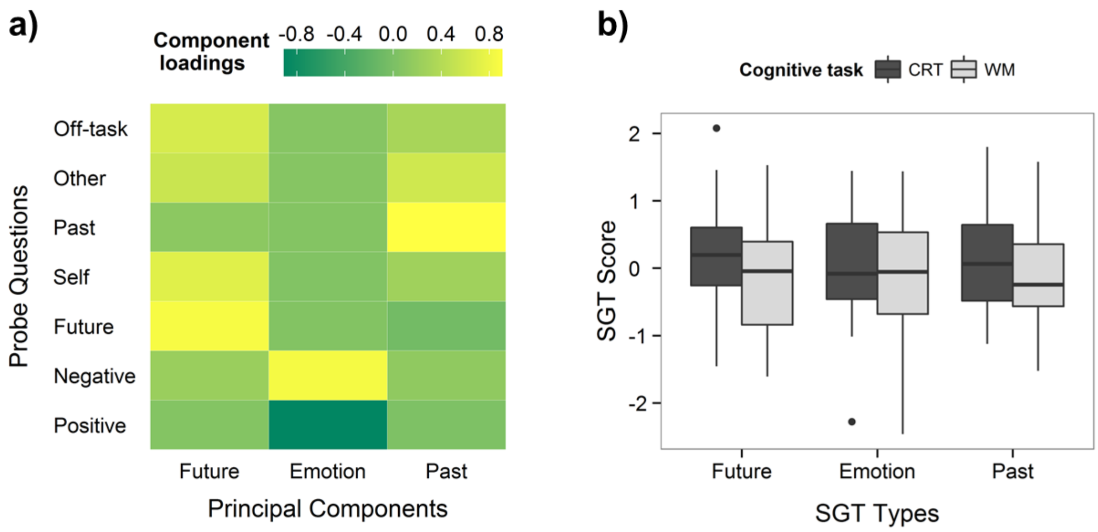


Figure 6-2. Principal Component Analysis of probe data and SGT task differences
a) The principal component analysis on the seven questions revealed three principal components, explaining 70% of variance in the probe data (n = 613 probes). Future SGT loaded positively on future, self, other and off-task ratings. Emotion SGT loaded positively on negative ratings and negatively on positive ratings. Finally, Past SGT loaded positively on off-task, past and other ratings. b) SGT scores were overall higher during the CRT task vs. the WM task but we did not observe any significant difference between the SGT types. Note that Emotion SGT scores were reversed so that higher scores indicate more positive thoughts. Abbreviations: CRT: choice reaction time, SGT: self-generated thought, WM: working memory.

6.3.2 Functional connectivity analyses

We computed FC group-level analyses using SPM8 (Wellcome Trust Department of Imaging Neuroscience, University College London). A voxelwise multiple regression was computed separately for each seed and included 6 SGT covariates (3 from CRT, 3 from WM task) as well as 5 nuisance covariates (scan type, slice order, scan duration, CRT / WM order, and task order). We report results obtained from whole-brain analyses computed with a cluster forming threshold *k* of $p = .005$ and corrected for false discovery rate FDR at $q < .05$ (Chumbley, Worsley, Flandin, & Friston, 2010).

6.3.2.1 Whole brain functional connectivity analysis

Prior to examining the relationship between FC and the patterns of thought, we examined the intercept of the multiple regression models for the PCC and mPFC seeds to confirm that they are both embedded in the DMN. Figure 6-3a and Figure 6-3c show the results for PCC (cluster forming threshold, positive FC: $k = 160$, negative FC: $k = 138$) and for mPFC (positive FC: $k = 411$, negative FC: $k = 191$). Both seeds are part of a large scale network composed of the main regions of the DMN, including PCC, mPFC and bilateral AG, hippocampus and anterior temporal lobe (ATL). Both seeds are also anti-correlated with regions such as the bilateral supra-marginal gyrus (SMG), bilateral inferior frontal gyrus (IFG), bilateral precuneus and left posterior middle temporal gyrus (pMTG), replicating previous findings (e.g. Fox et al., 2005; Raichle et al., 2001).

Figure 6-3 also illustrates that PCC is significantly anti-correlated with the ACC, bilateral middle-lateral PFC (mlPFC) and bilateral Insula, whereas the mPFC does not display significant negative FC to these regions. These results are in line with previous findings highlighting differences in anti-correlations between the main hubs of the DMN (Uddin, Kelly, Biswal, Castellanos, & Milham, 2009).

For each seed, we transformed the positive and negative FC maps into two masks, a positive network (N^+) and a negative network (N^-) mask (PCC masks: Figure 6-3b; mPFC masks: Figure 6-3d). These masks will be used to guide the interpretation of the subsequent results. In particular, the following analyses will investigate how individual differences in SGT scores predict individual differences in PCC and mPFC FC, and the masks will be used to identify whether SGT is related to changes in FC within the DMN (N^+), outside the DMN (N^-) or at the junction between the two.

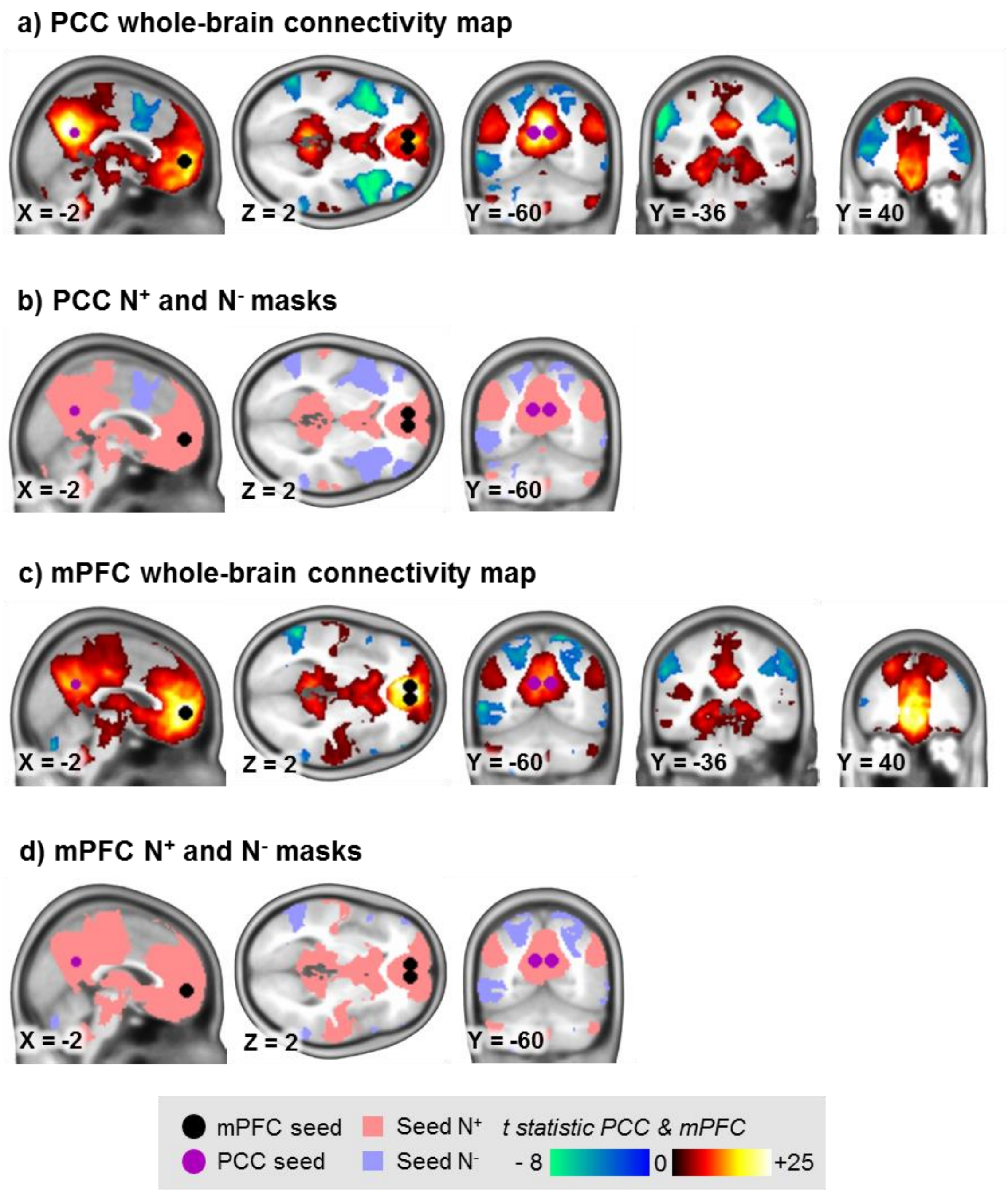


Figure 6-3. Whole brain functional connectivity patterns for PCC and mPFC
Whole-brain FC analyses for the PCC (a) and mPFC (c) confirmed that both seeds were embedded in a network composed of the main DMN regions, including midline regions and bilateral hippocampus, retrosplenial cortex, angular gyrus, dorsorostral PFC and striatum (hot colours). Although positive correlation patterns were similar across DMN seeds, spatial differences can be observed for the anti-correlation patterns (cool colours). PCC was negatively correlated to the ACC, bilateral insula and middle-lateral PFC, whereas we did not observe significant negative correlations between the mPFC and these areas. The masks generated from the whole-brain FC maps can be seen in (b) and (d). These masks represent the positive (N^+) and negative networks (N^-) of each seed. Significant clusters were obtained with a cluster forming threshold *k* of p = .005 and FDR-corrected at q < .05 (PCC, positive FC: *k* = 160, negative FC: *k* = 138; mPFC, positive FC: *k* = 411, negative FC: *k* = 191). Abbreviations: ACC: anterior cingulate cortex, DMN: default mode network, FC: functional connectivity, FDR: false discovery rate, mPFC: medial prefrontal cortex, N^-: negative network mask, N^+: positive network mask, PCC: posterior cingulate cortex, PFC: prefrontal cortex.

6.3.2.2 Hypothesis 1: Role of the content in SGT neural correlates

The first set of analyses will test the hypothesis that the interaction between the DMN and other regions vary according to the content of SGT. These analyses will identify whether individual differences in SGT content (measured across both CRT and WM tasks) are linked to individual differences in PCC and mPFC FC.

Mental time travel. We first examined the similarities between Future and Past SGT (i.e. mental time travel, MTT, Table 6-2). As can be seen in Figure 6-4 we observed that individuals reporting more MTT had increased FC between PCC and vmPFC (k = 540), suggesting that MTT was associated with a more cohesive DMN. In addition, MTT was also associated with decreased FC between mPFC and bilateral lingual gyrus and cuneus (k = 2777). As shown in Figure 6-4, the negative FC pattern was located at the junction between mPFC N^+ and mPFC N^-. This suggests that, although individuals generally display negative FC between mPFC and lateral occipital at rest (Figure 6-4, pale blue), MTT may be accompanied by additional decreases in FC to visual areas (Figure 6-4, dark green).

Table 6-2. Functional connectivity peaks for PCC and mPFC for Mental Time Travel
See Figure 6-4 for abbreviations.

Relation	Seed	Code	Brain Region	Peak region		Peak voxel	MNI Coordinates		
				p(FDR-corr)	cluster size (k)	(z-value)	x	y	z
Mean increase	PCC	A	vmPFC	< .001	540	4.25	-10	44	-8
Mean decrease	mPFC	B	lingual gyrus	< .001	2777	4.56	8	-62	8

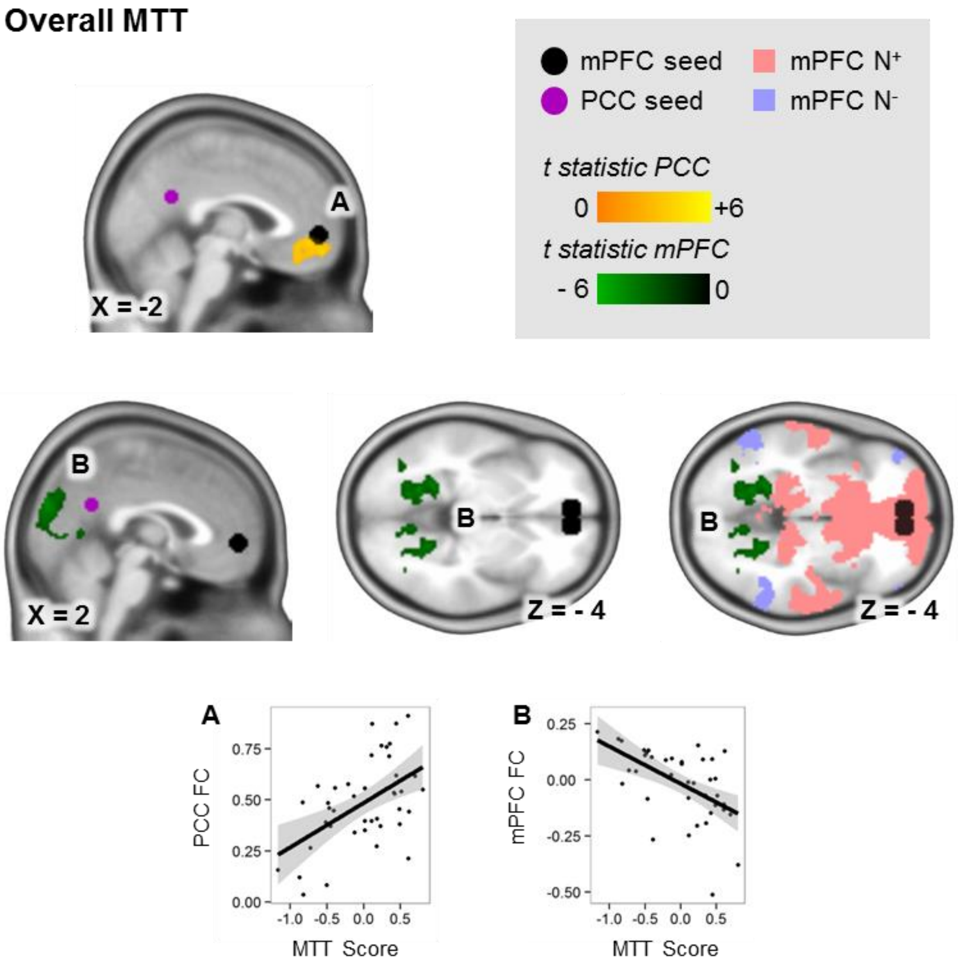


Figure 6-4. Mental Time Travel functional connectivity patterns

Increases in overall MTT were linked to significant changes in FC between the PCC seed (purple) and vmPFC (A). Decreases in overall MTT were related to reduction in FC between the mPFC seed (black) and visual areas, including bilateral lingual gyrus and cuneus (B). When overlapping the mPFC FC pattern on mPFC N^+ and N^-, we found that the visual cluster was located between the two. Significant clusters were obtained with a cluster forming threshold *k* of p = .005 and FDR-corrected at q < .05, see Table 6-2 for more details. Scatterplots represent the averaged PCC and mPFC FC for the two significant clusters (A, B) according to individual differences in MTT scores. Abbreviations: FC: functional connectivity, FDR: false discovery rate, mPFC: medial prefrontal cortex, MTT: mental time travel, N^-: negative network mask, N^+: positive network mask, PCC: posterior cingulate cortex, SGT: self-generated thought, vmPFC: ventromedial prefrontal cortex.

Future > Past SGT. Next, we investigated whether Future and Past SGT were linked to distinct FC patterns. The Future > Past contrast revealed a significant cluster for PCC in a region of the left superior frontal cortex (Brodmann Area BA8, *k* = 258, Table 6-3). As can be seen on Figure 6-5a, the area was located between PCC N^- (pale blue) and PCC N^+ areas (pale red). Post-hoc analyses revealed that this effect was due to Past SGT significantly predicting decreased FC between PCC and BA8 (*k* = 320, Figure 6-5b). On the contrary, overall increase in Future SGT was linked to increased FC between PCC and vmPFC (*k* = 472) i.e. the DMN was more integrated for future thinkers (Figure 6-5c).

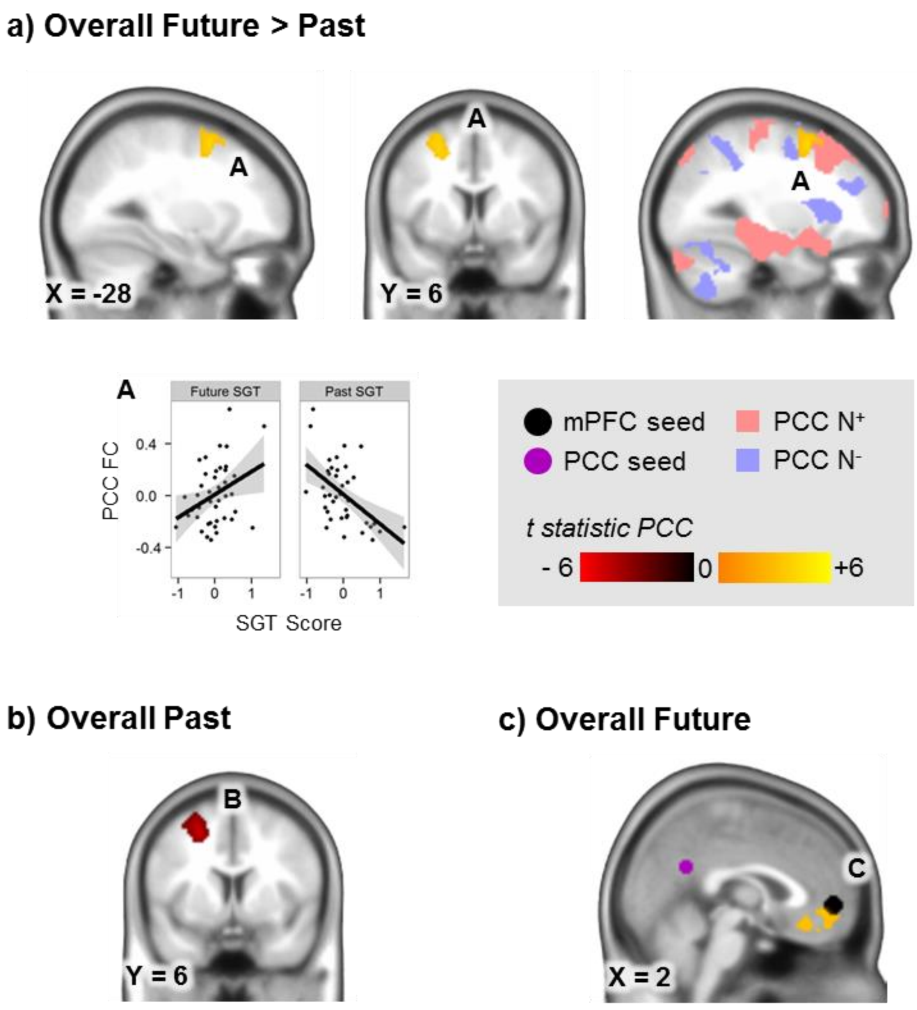


Figure 6-5. Future > Past SGT functional connectivity patterns
a) The Future > Past SGT contrast revealed one significant PCC cluster located in BA8 (A). When overlapping the significant cluster on PCC N^+ and N^- masks, we found that it was located at the junction between the two. b) Overall Past SGT scores significantly predicted decreases in FC between PCC and BA8 (B). c) Future SGT scores significantly predicted increases in PCC FC to the vmPFC (C). Significant clusters were obtained with a cluster forming threshold *k* of p = .005 and FDR-corrected at q < .05, see Table 6-3 for more details. The scatterplot represents the averaged PCC FC for the significant cluster (A) according to individual differences in Future and Past SGT scores. Abbreviations: BA: Brodmann Area, FC: functional connectivity, FDR: false discovery rate, mPFC: medial prefrontal cortex, N^-: negative network mask, N^+: positive network mask, PCC: posterior cingulate cortex, SGT: self-generated thought, vmPFC: ventromedial prefrontal cortex.

Table 6-3. Functional connectivity peaks for PCC and mPFC for Future > Past SGT
See Figure 6-5 for abbreviations.

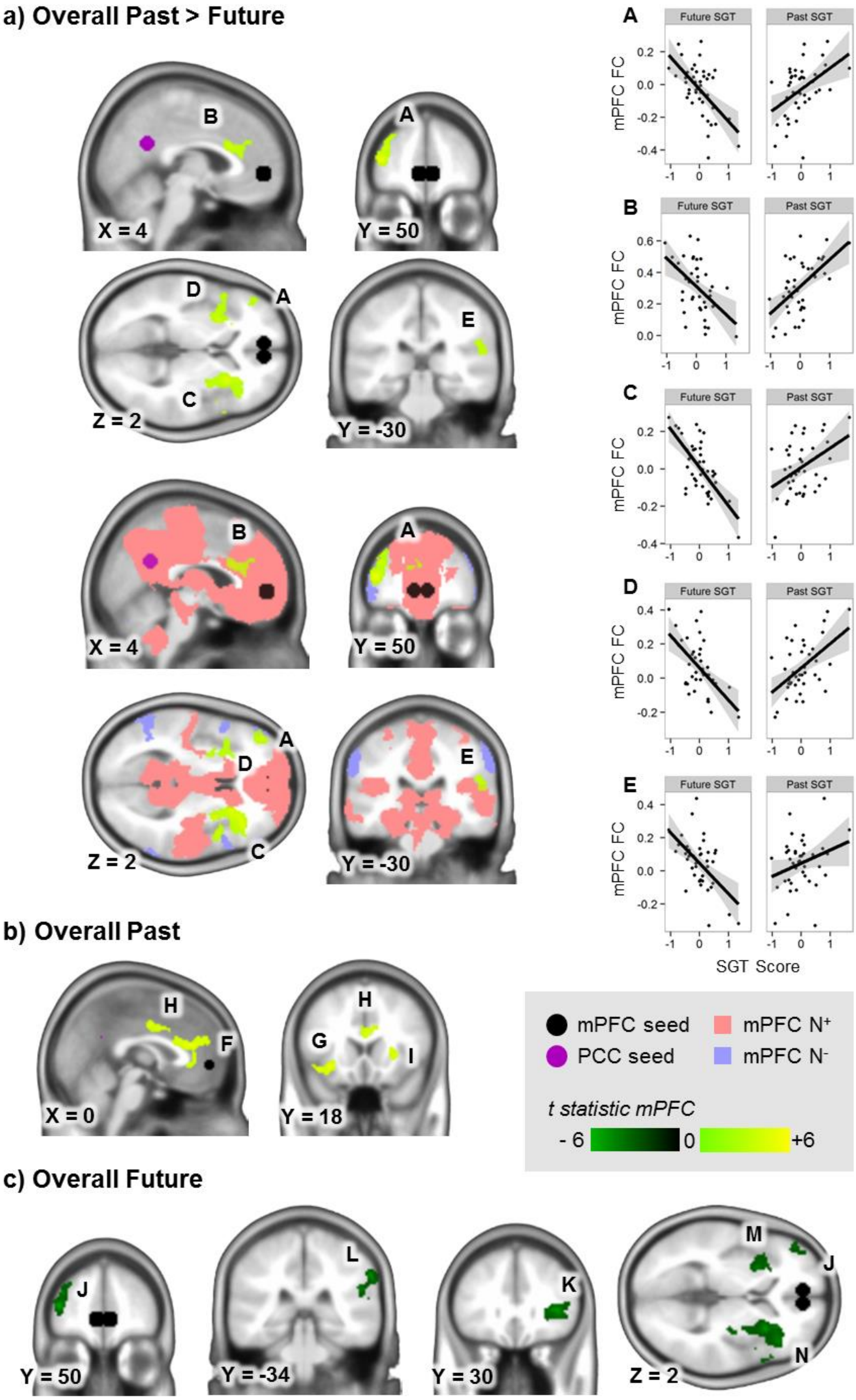
Relation	Seed	Code	Brain Region	Peak region		Peak voxel (z-value)	MNI Coordinates		
				p(FDR-corr)	cluster size (k)		x	y	z
Future > Past	PCC	A	BA8	0.034	258	3.93	-26	8	54
Mean Past decrease	PCC	B	BA8	0.014	320	4.24	-26	8	54
Mean Future increase	PCC	C	vmPFC	0.001	472	3.88	-10	46	-8

Past > Future SGT. Next, we observed that individuals reporting overall more Past than Future SGT had increased FC between mPFC and regions of the frontal lobe (*k* = 179), including bilateral anterior insula, mlPFC and ACC, as well as right SMG (Figure 6-6; Table 6-4). Post-hoc analyses revealed that this effect was related to both increases in FC with Past SGT (*k* = 225, Figure 6-6b) as well as decreases in FC for Future SGT (*k* = 205, Figure 6-6c). Figure 6-6a illustrates that the ACC cluster was located within mPFC N^+. Other clusters were located either at the junction between mPFC N^- and mPFC N^+ (mlPFC, right SMG) or overlapping with both mPFC N^- and mPFC N^+ (bilateral Insula). Taken together, these results suggest that Past SGT is linked to increases in FC between mPFC and regions not traditionally considered as part of the DMN.

Table 6-4. Functional connectivity peaks for PCC and mPFC for Past > Future SGT
See Figure 6-6 for abbreviations.

Relation	Seed	Code	Brain Region	Peak region		Peak voxel (z-value)	MNI Coordinates		
				p(FDR-corr)	cluster size (k)		x	y	z
Past > Future	mPFC	A	vlPFC	< .001	493	4.63	-42	48	12
		B	ACC	< .001	499	4.33	10	30	22
		C	right anterior insula	< .001	1778	4.32	30	18	2
		D	left anterior insula	< .001	775	4.31	-30	18	-10
		E	right SMG	0.041	179	3.63	56	-32	16
Mean Past increase	mPFC	F	dmPFC	< .001	694	4.01	-8	38	0
		G	left anterior insula	0.002	386	3.88	-40	16	-12
		H	ACC	0.021	225	3.68	4	-8	38
		I	right putamen	0.021	234	3.66	28	16	0
Mean Future decrease	mPFC	J	vlPFC	0.001	411	4.5	-42	48	12
		K	right frontal operculum	< .001	1746	4.43	46	20	-8
		L	right SMG	< .001	472	4.03	62	-34	38
		M	left anterior insula	0.001	420	3.79	-30	18	-10
		N	right pars opercularis	0.025	205	3.29	62	16	18

Figure 6-6. Past > Future SGT functional connectivity patterns (next page)
a) The Past > Future SGT contrast revealed five significant mPFC clusters, located in vlPFC (A), ACC (B), right anterior insula (C), left anterior insula (D) and right SMG (E). When overlapping the significant clusters on mPFC N^+ and N^-, we found that cluster B was located within mPFC N^+, whereas clusters A, C – E were all located at the N^+ and N^- junction. b) Overall Past SGT scores significantly predicted increases in mPFC FC to dmPFC (F), left anterior insula (G), ACC (H) and right putamen (I). c) Overall Future SGT scores significantly predicted decreases in FC between mPFC and vlPFC (J), right frontal operculum (K), right SMG (L), left anterior insula (M) and right pars opercularis (N). Significant clusters were obtained with a cluster forming threshold *k* of p = .005 and FDR-corrected at q < .05, see Table 6-4 for more details. Scatterplots represent the averaged mPFC FC for the significant clusters (A – E) according to individual differences in Future and Past SGT scores. Abbreviations, ACC: anterior cingulate cortex, dmPFC: dorsomedial PFC, FC: functional connectivity, FDR: false discovery rate, mPFC: medial prefrontal cortex, N^- : negative network mask, N^+: positive network mask, PCC: posterior cingulate cortex, SGT: self-generated thought, SMG: supramarginal gyrus, vlPFC: ventrolateral prefrontal cortex.



a) Overall Past > Future
b) Overall Past
c) Overall Future
X = 4
Y = 50
Z = 2
Y = -30
X = 0
Y = 18
Y = -34
Y = 30
Future SGT
Past SGT
mPFC FC
SGT Score
mPFC seed
PCC seed
mPFC N+
mPFC N-
t statistic mPFC
- 6
0
+6

Emotion SGT. Finally, we observed a main effect of Emotion SGT on PCC FC (k = 505, Figure 6-7, Table 6-5), indicating that individuals who reported more positive thoughts had increased FC between the PCC and the orbitofrontal cortex (OFC) / vmPFC.

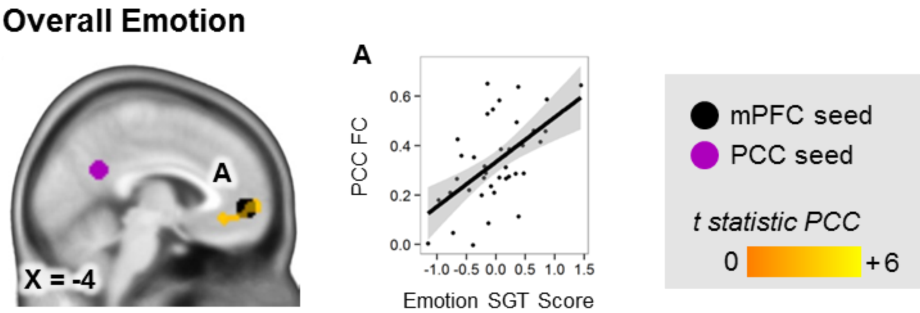


Figure 6-7. Emotion SGT functional connectivity patterns
Emotion SGT was related to significant increases in FC between PCC and OFC / vmPFC (A). The significant cluster was obtained with a cluster forming threshold *k* of p = .005 and FDR-corrected at q < .05, see Table 6-5 for more details. The scatterplot represents the averaged PCC FC for the cluster A according to individual differences in Emotion SGT. Abbreviations, FC: functional connectivity, FDR: false discovery rate, mPFC: medial prefrontal cortex, OFC: orbitofrontal cortex, PCC: posterior cingulate cortex, SGT: self-generated thought, vmPFC: ventromedial prefrontal cortex.

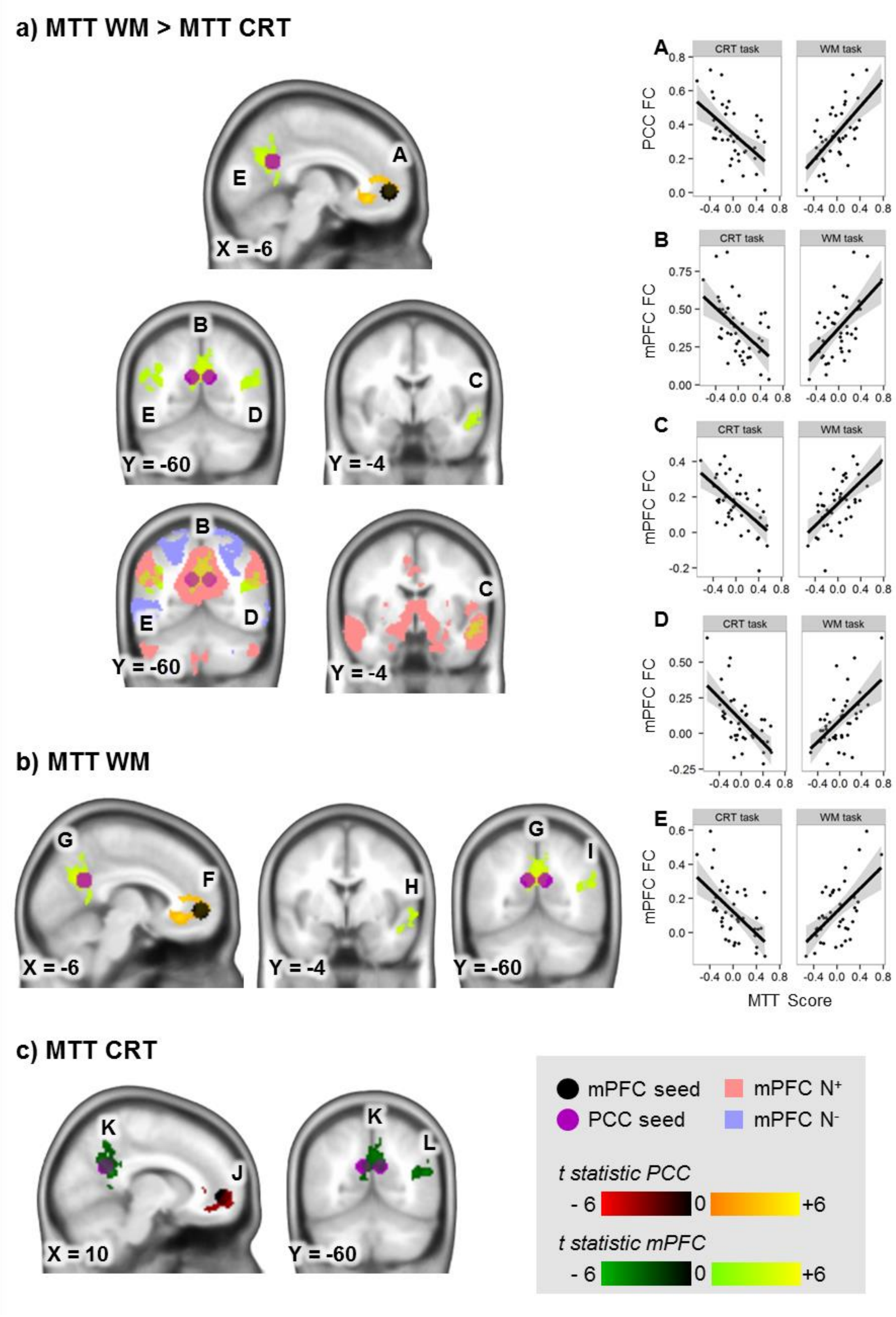
Table 6-5. Functional connectivity peaks for PCC and mPFC for Emotion SGT
See Figure 6-7 for abbreviations.

Relation	Seed	Code	Brain Region	Peak region		Peak voxel (z-value)	MNI Coordinates		
				p(FDR-corr)	cluster size (k)		x	y	z
Mean increase	PCC	A	vmPFC	0.001	505	4.34	10	36	-14

6.3.2.3 Hypothesis 2: Role of the context in SGT neural correlates

We also investigated whether the FC patterns of the seeds varied according to the cognitive task being performed. To this end, we explored whether PCC and mPFC FC patterns were predicted by SGT recorded in the CRT and WM task. We ran one set of analyses for MTT and one set for Emotion SGT.

Figure 6-8. MTT WM > CRT task functional connectivity patterns (next page)
a) The MTT WM > MTT CRT contrast revealed one significant PCC cluster located in mPFC (A) and 4 significant mPFC clusters, located in PCC (B), right ATL (C), right TPJ (D) and left TPJ (E). When overlapping the significant clusters on mPFC N^+ and N^-, we found that all clusters were located within mPFC N^+, i.e. within the DMN. b) MTT WM scores significantly predicted increases in PCC FC to the mPFC (F) and increases in mPFC FC to the PCC (G), right ATL, (H) and right TPJ (I). c) MTT CRT scores significantly predicted decreases in FC between the PCC and vmPFC (J), and decreases in FC between mPFC and PCC (K) as well as the right TPJ (L). Significant clusters were obtained with a cluster forming threshold *k* of p = .005 and FDR-corrected at q < .05, see Table 6-6 for more details. Scatterplots represent the averaged PCC or mPFC FC for the significant clusters (A – E) according to individual differences in MTT CRT and MTT WM scores.



Abbreviations: ATL: anterior temporal lobe, CRT: choice reaction time, DMN: default mode network, FC: functional connectivity, FDR: false discovery rate, mPFC: medial prefrontal cortex, MTT: mental time travel, N^-: negative network mask, N^+: positive network mask, PCC: posterior cingulate cortex, TPJ: temporoparietal junction, WM: working memory.

Mental time travel. As can be seen in Figure 6-8a and Table 6-6, the contrast MTT WM > MTT CRT revealed significant effects for PCC (*k* = 921) and for mPFC (*k* = 174). Post-hoc analyses revealed that MTT was associated with increased FC within DMN regions during the WM task (PCC, mPFC, right TPJ, right ATL, Figure 6-8b) and decreased FC between DMN regions during the CRT task (PCC, mPFC, right TPJ, Figure 6-8c). This pattern of results suggests that the generation of MTT during a harder task is supported by the strengthening of the DMN integrity. The contrast MTT CRT > MTT WM did not reveal any significant effect.

Table 6-6. Functional connectivity peaks for PCC and mPFC for MTT, WM > CRT task
See Figure 6-8 for abbreviations.

<table>
<tr><th rowspan="2">Relation</th><th rowspan="2">Seed</th><th rowspan="2">Code</th><th rowspan="2">Brain Region</th><th colspan="2">Peak region</th><th rowspan="2">Peak voxel (z-value)</th><th colspan="3">MNI Coordinates</th></tr>
<tr><th>p(FDR-corr)</th><th>cluster size (k)</th><th>x</th><th>y</th><th>z</th></tr>
<tr><td rowspan="5">WM > CRT</td><td>PCC</td><td>A</td><td>mPFC</td><td>< .001</td><td>921</td><td>5.06</td><td>-6</td><td>52</td><td>0</td></tr>
<tr><td rowspan="4">mPFC</td><td>B</td><td>PCC</td><td>< .001</td><td>1476</td><td>4.55</td><td>10</td><td>-50</td><td>20</td></tr>
<tr><td>C</td><td>right ATL</td><td>0.047</td><td>174</td><td>4.17</td><td>50</td><td>-8</td><td>-18</td></tr>
<tr><td>D</td><td>right TPJ</td><td>< .001</td><td>489</td><td>3.86</td><td>52</td><td>-60</td><td>20</td></tr>
<tr><td>E</td><td>left TPJ</td><td>0.017</td><td>234</td><td>3.78</td><td>-52</td><td>-54</td><td>34</td></tr>
<tr><td rowspan="4">WM increase</td><td>PCC</td><td>F</td><td>mPFC</td><td>< .001</td><td>1240</td><td>5.1</td><td>-6</td><td>52</td><td>0</td></tr>
<tr><td rowspan="3">mPFC</td><td>G</td><td>PCC / Precuneus</td><td>< .001</td><td>1367</td><td>4.48</td><td>-4</td><td>-66</td><td>34</td></tr>
<tr><td>H</td><td>right ATL</td><td>0.03</td><td>218</td><td>4.1</td><td>50</td><td>-8</td><td>-18</td></tr>
<tr><td>I</td><td>right TPJ</td><td>0.009</td><td>302</td><td>3.68</td><td>38</td><td>-58</td><td>18</td></tr>
<tr><td rowspan="3">CRT decrease</td><td>PCC</td><td>J</td><td>mPFC</td><td>< .001</td><td>525</td><td>4.69</td><td>-6</td><td>52</td><td>0</td></tr>
<tr><td rowspan="2">mPFC</td><td>K</td><td>PCC</td><td>< .001</td><td>1251</td><td>4.36</td><td>-4</td><td>-68</td><td>34</td></tr>
<tr><td>L</td><td>right TPJ</td><td>< .001</td><td>551</td><td>4.08</td><td>52</td><td>-50</td><td>20</td></tr>
</table>

Emotion SGT. Regarding Emotion SGT, we found a significant task effect on the FC of PCC (*k* = 325) and mPFC (*k* = 350, Figure 6-9, Table 6-7). PCC was significantly more connected to the mPFC; mPFC was significantly more connected to the PCC and right TPJ[7]. The PCC cluster was overlapping with the PCC seed and the TPJ cluster was located within mPFC N^+, suggesting that both clusters are part of the DMN (Figure 6-9a). Subsequent post-hoc analyses revealed that positive thinking during the CRT task was linked to increased FC between i) PCC and mPFC and ii) between mPFC and PCC as well as right TPJ (Figure 6-9b). No significant effect was observed for Emotion WM.

[7] To ensure that the extreme data point from one participant (i.e. low Emotion SGT score in the CRT task) was not driving the positive correlations, we ran the analyses again excluding the participant's data and confirmed that results were still significant (mPFC: cluster forming threshold at p = .01, *k* = 372; PCC: cluster forming threshold at p = .005, *k* = 284).

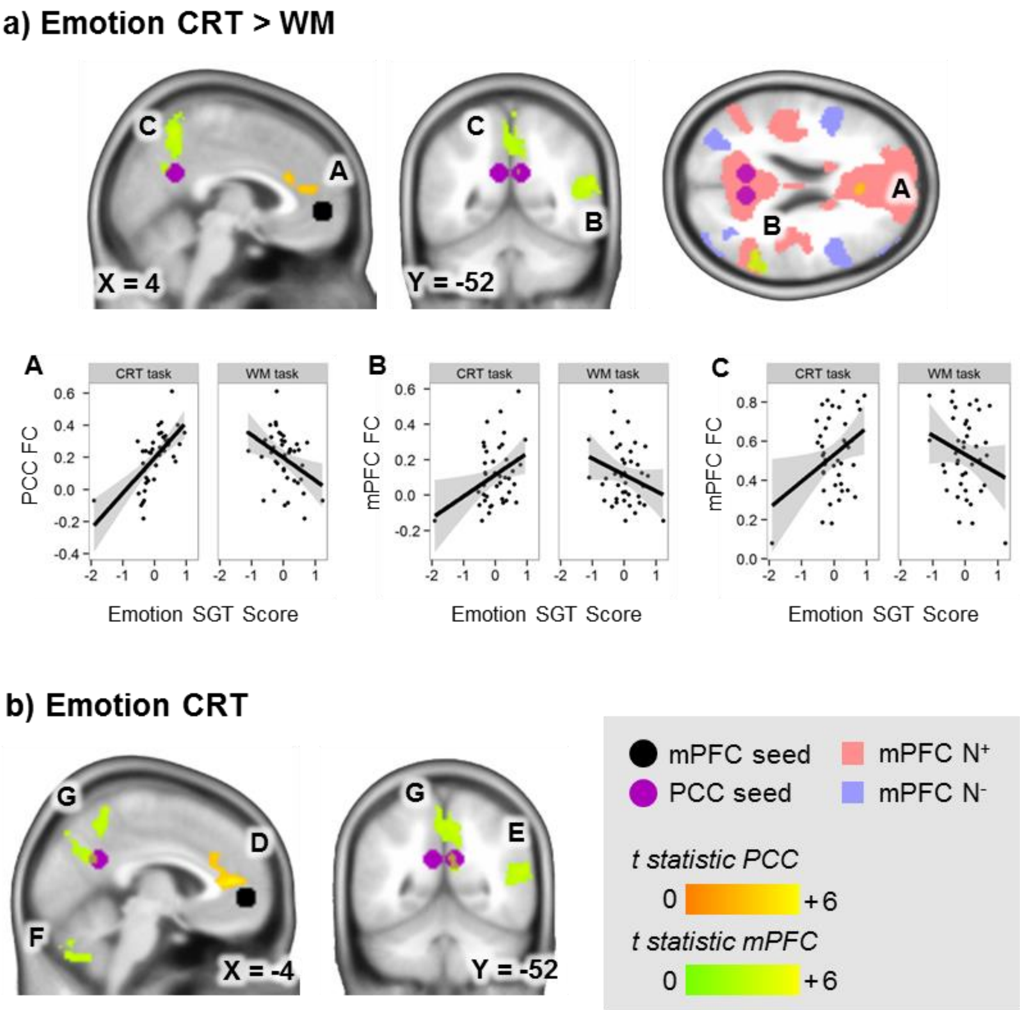


Figure 6-9. Emotion CRT > WM functional connectivity patterns
a) The Emotion CRT > WM contrast revealed increased FC between PCC and mPFC (A), and increased FC between mPFC and PCC (B) as well as right TPJ (C). The significant mPFC clusters (B, C) all overlapped with mPFC N^+, highlighting that they are part of the DMN. b) Emotion CRT was linked to increased FC between PCC and mPFC (D). It was also related to increases in FC between mPFC and right TPJ (E), cerebellum (F) and PCC / precuneus (G). Significant clusters were obtained with a cluster forming threshold *k* of p = .005 and FDR-corrected at q < .05, see Table 6-7 for more details. Scatterplots represent the averaged PCC or mPFC FC for the significant cluster (A – C) according to individual differences in Emotion CRT and Emotion WM. Abbreviations: CRT: choice reaction time, DMN: default mode network, FC: functional connectivity, FDR: false discovery rate, mPFC: medial prefrontal cortex, N^-: negative network mask, N^+: positive network mask, PCC: posterior cingulate cortex, SGT: self-generated thought, TPJ: temporoparietal junction, WM: working memory.

Table 6-7. Functional connectivity peaks for PCC and mPFC for Emotion SGT, CRT > WM task
See Figure 6-9 for abbreviations.

Relation	Seed	Code	Brain Region	Peak region		Peak voxel (z-value)	MNI Coordinates		
				p(FDR-corr)	cluster size (k)		x	y	z
CRT > WM	PCC	A	mPFC	0.01	325	4.33	-4	42	10
	mPFC	B	right TPJ	0.005	350	4.69	54	-48	18
		C	PCC	0.001	489	3.94	4	-56	56
CRT increase	PCC	D	mPFC	< 0.001	591	4.37	-6	36	8
	mPFC	E	right TPJ	0.013	312	4.8	54	-48	18
		F	cerebellum	0.034	243	4.6	-10	-62	-48
		G	precuneus	< .001	991	4.33	4	-56	56

6.3.2.4 Hypothesis 3: Interaction between content and context in SGT neural correlates

Finally, we investigated the role of the interaction between the content and context in the relation between SGT and FC patterns. In particular, we explored whether Future and Past SGT had distinct neural correlates when generated during the CRT and WM tasks (Table 6-8). We found a significant interaction between SGT type (Past > Future) and cognitive task (CRT > WM) for the mPFC seed, with increased FC to the right SMG (k = 321, Figure 6-10a). When overlapping the significant cluster on mPFC N^+ (pale red) and N^- (pale blue), we found that it was located at the junction between the two. As can be seen on the scatterplots showing the relation between individual differences in SGT and in FC, Future SGT generated in both the CRT and WM tasks predicted a negative correlation between mPFC and right SMG, whereas Past SGT in the CRT task was linked to a positive correlation and Past SGT in the WM with a negative correlation. Post-hoc analyses indeed revealed that increases in Past SGT during CRT were related to more FC between mPFC and right SMG, as well as with bilateral insula and dlPFC (Figure 6-10b). On the contrary, Past SGT during the WM task was linked to significant decreases in FC between mPFC and cuneus (Figure 6-10c).

Table 6-8. Functional connectivity peaks for PCC and mPFC for Past > Future SGT, CRT > WM task
See Figure 6-10 for abbreviations.

Relation	Seed	Code	Brain Region	Peak region		Peak voxel (z-value)	MNI Coordinates		
				p(FDR-corr)	cluster size (k)		x	y	z
Past > Future x CRT > WM	mPFC	A	right SMG	0.016	321	4.1	52	-32	24
Past CRT increase	mPFC	B	right anterior insula	< .001	941	4.43	30	26	10
		C	right SMG	< .001	722	4.42	52	-32	24
		D	dlPFC	0.018	229	4.1	-24	46	30
		E	left anterior insula	0.002	374	3.61	-44	12	-4
Past WM decrease	mPFC	F	lingual gyrus	< .001	822	3.93	-4	-92	18

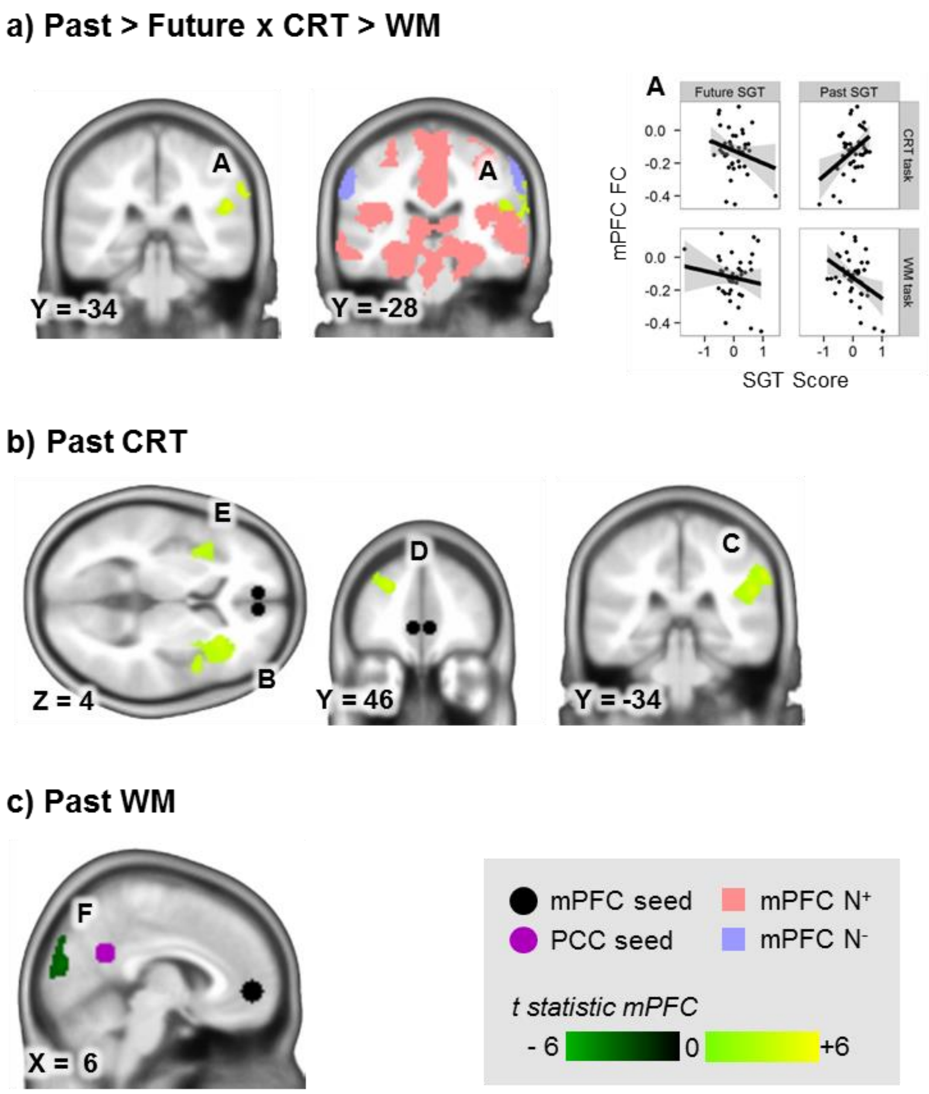


Figure 6-10. Past > Future x CRT > WM functional connectivity patterns

a) The Past > Future x CRT > WM contrast revealed one significant mPFC cluster located in right SMG (A). When overlapping the significant cluster on mPFC N^+ and N^-, we found that it was located at the junction between the two. The scatterplots indicate that Future SGT generated in both the CRT and WM tasks predicted a negative correlation between mPFC and right SMG, whereas Past SGT in the CRT task was linked to a positive correlation and Past SGT in the WM to a negative correlation. b) Past CRT scores significantly predicted increases in mPFC FC to the right anterior insula (B), right SMG (C), dlPFC (D) and left anterior insula (E). c) Past WM scores significantly predicted decreases in FC between mPFC and cuneus (F). Significant clusters were obtained with a cluster forming threshold *k* of p = .005 and FDR-corrected at q < .05, see Table 6-8 for more details. Scatterplots represent the averaged mPFC FC for the significant cluster (A) according to individual differences in Past CRT, Past WM, Future CRT and Future WM scores. Abbreviations: CRT: choice reaction time, dlPFC: dorsolateral prefrontal cortex, FC: functional connectivity, FDR: false discovery rate, mPFC: medial prefrontal cortex, N^-: negative network mask, N^+: positive network mask, PCC: posterior cingulate cortex, SGT: self-generated thought, SMG: supramarginal gyrus, WM: working memory.

6.4 Discussion

The current study aimed to test the hypothesis that different types of SGT are related to different neurocognitive substrates, as proposed by the component process hypothesis (Andrews-Hanna et al., 2014; Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015). To this end, we used rsfMRI and seed-based whole-brain FC in order to explore whether the content and context of SGT were associated with individual differences in DMN FC patterns.

6.4.1 DMN and perceptual decoupling in SGT

The PCA computed on the current dataset allowed us to identify three distinct types of SGT (Future, Past and Emotion SGT), thus replicated previous findings (Chapter 3; Chapter 4; Chapter 5 and Engert et al., 2014; Ruby, Smallwood, Engen, et al., 2013). First, we observed that MTT was related to increases in within-DMN FC. These results add to a growing body of evidence showing that the DMN is involved in SGT (Allen et al., 2013; Andrews-Hanna et al., 2010, 2014; Christoff et al., 2009; Mason, Norton, et al., 2007; Smallwood & Schooler, 2015; Smallwood, Tipper, et al., 2013; Stawarczyk & D'Argembeau, 2015; Stawarczyk, Majerus, Maquet, et al., 2011) and this pattern is also consistent with studies highlighting the role of the DMN in episodic processes (Addis et al., 2007; Buckner & Carroll, 2007). Our data also show that MTT was associated with reduced FC between the mPFC and visual areas (including the cuneus and lingual gyrus). Although mPFC and PCC are generally anti-correlated with visual areas, our data indicate that SGT may require a supplementary dissociation between sensory areas and the DMN. These data are consistent with the perceptual decoupling hypothesis, which states that SGT requires the decoupling of attentional processes from externally-generated information in order to insulate the stream of thought (Smallwood & Schooler, 2015; Smallwood, 2013a; Smallwood, Brown, et al., 2011). In addition, these results also support the component process hypothesis and in particular the claim that specific sub-processes are selected and other inhibited during the generation of SGT (Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015). Taken together, these findings highlight that our seed-based FC approach yields results that are consistent with previously published studies.

6.4.2 Role of content and context in SGT neural correlates

In support for hypothesis 1, our results show that individual differences in SGT types were related to individual differences in PCC and mPFC FC patterns. In particular, Emotion SGT was associated with the specific recruitment of the OFC / vmPFC. This is in line with previous studies showing that the OFC is involved in the spontaneous generation of emotional thoughts (Tusche, Smallwood, Bernhardt, & Singer, (2014), as well as in emotion processing and emotion regulation (Berridge & Kringelbach, 2013; Etkin, Egner, & Kalisch, 2011; Roy, Shohamy, & Wager, 2012). In addition, we observed that Past SGT, compared to Future SGT, was associated with an increase in FC between the mPFC and frontal regions (ACC, bilateral Insula and mlPFC) as well as a decrease in FC between PCC and BA8. These results are in line with Mason, Bar, et al. (2007) who reported that brain activity in these regions was predicted by past thinking tendencies. Previous studies have reported the involvement of the ACC in SGT (Bernhardt et al., 2014; Christoff et al., 2009; Wang et al., 2009) and our data suggest that the ACC may be particularly relevant for past-related SGT rather than other types of thoughts. Taken together, our findings provide support for the hypothesis that individual differences in thought content is related to variations in SGT neural correlates and therefore, that different types of SGT may rely on different neural processes.

Note that although these results are consistent with previous neuroimaging studies, discrepancies can also be observed between the current data and findings published by Gorgolewski et al. (2014). Using rsfMRI and a retrospective questionnaire to assess SGT content, they observed that past thinking was related to increased fractional amplitude of low frequency fluctuations (fALFF) in visual areas; they also found that both past and positive thinking were linked to decreases in fALFF in the mPFC. Although these results are at odds with our findings, it is possible that differences in the methodological approaches employed may have led to inconsistencies (e.g. use of FC vs. fALFF, and use of experience sampling vs. a retrospective questionnaire).

Next, our data also provide evidence for the hypothesis that the context of SGT influences its neural correlates. We found that MTT was related to an increase in within-DMN FC when SGT was generated during the WM task. This indicates that the strengthening of the DMN integrity may support the generation of MTT under more constraining external conditions. On the contrary, Emotion SGT was associated with increased within-DMN FC during the CRT task. This may be related to the observation that individuals generally experience more positive thoughts when performing an easy vs. harder task (e.g. Chapter 3; Chapter 4 and current data). Altogether, this set of results show that the neural correlates of SGT also varied according to the context in which they occurred, therefore supporting our second hypothesis.

Finally, our results also hint at a possible interaction between the content and context of SGT. We observed that Past SGT (but not Future SGT) occurring during the CRT vs. WM task predicted increased FC between mPFC and right SMG, an area located within the somatosensory cortex and overlapping with the ventral-attention network (Fox, Corbetta, Snyder, Vincent, & Raichle, 2006). One potential explanation for this finding can be provided using data published by D'Argembeau and colleagues, who found that memories are more vividly experienced and possess more sensory details compared to prospective simulations. In addition, evidence suggests that performing a concurrent task can impact the vividness of visual mental images (Baddeley & Andrade, 2000). Taken together, we speculate that Past SGT might be experienced more vividly when task demands are low (i.e. in the CRT task) and this may be supported by the specific recruitment of the SMG. Although future studies will be required to better understand the role of the right SMG in Past SGT, these data suggest that the content and context of SGT may interact and conjointly influence SGT neural patterns.

In summary, our results support the three hypotheses we tested and illustrate that different neural correlates are related to SGT depending on the content and context of the thoughts. These findings are in favour of the component process hypothesis and indicate that specific neural processes may be recruited in order to support the variety of SGT experiences.

6.4.3 Interaction between DMN and others networks in Past SGT

In addition to supporting the component process hypothesis, our data show that some types of thought (in particular Past SGT) may rely on the recruitment of regions not traditionally considered as part of the DMN. Compared to Future SGT, Past SGT was linked to increased FC between mPFC and ACC, mlPFC and bilateral Insula, in line with results published by Mason, Bar, et al. (2007). The regions are located between the mPFC N^+ and mPFC N^-, and are anti-correlated with the PCC seed. In addition, PCC FC to BA8 (a region of the FPN) was also reduced for Past SGT compared to Future SGT. Two potential explanations are provided to clarify these results.

The first possibility is that the DMN integrity may be compromised for individuals with past-thinking tendencies. Indeed, Past SGT was associated with changes in FC between the mPFC and regions located at the junction between DMN and non-DMN areas, suggesting that the common segregation between DMN and other networks may be diminished for past thinkers. In addition, this pattern of results was observed for mPFC but not for PCC seed. Previous studies as well as data presented here show that the PCC is negatively correlated with frontal regions (including the ACC, Insula and mlPFC), whereas mPFC does not display significant anti-correlations (Figure 6-3; Uddin, Kelly, Biswal, Castellanos, & Milham, 2009). The FC between mPFC and frontal areas may therefore be more easily modulated than PCC FC, facilitating the disorganization of the DMN based on mPFC FC changes.

In addition, Past SGT may also rely on the interaction between the DMN and the salience / ventral-attention network. By examining the position of the areas involved in Past SGT (ACC, mlPFC, Insula), we observed that these are all overlapping with regions of the ventral-attention network, as defined by Yeo et al. (2011). This network is involved in the detection of salient stimuli and supports the subsequent redirection of attention (Seeley et al., 2007). Despite having been traditionally linked to externally-driven cognitive processes, Andrews-Hanna et al. (2014) suggest that this network may support the switching between externally- and internally-driven cognition, in particular during the occurrence of salient internally-generated information. Although preliminary, our data provide initial evidence for this hypothesis. Following this view, it is therefore possible that Past SGT may be particularly salient. Indeed, our behavioural data showing that Past SGT is considered as intrusive are in line with this interpretation (Chapter 5). Although future research will be required to shed light on the potential role of the salience network in Past SGT, our data provide evidence that certain types of SGT rely on the recruitment of additional regions outside the DMN, as previously reported (Bernhardt et al., 2014; Christoff et al., 2009; D'Argembeau et al., 2005; Gorgolewski et al., 2014; Mason, Bar, et al., 2007; Mason, Norton, et al., 2007; Wang et al., 2009).

6.4.4 Conclusions

To conclude, the current study provides evidence that the content and context of SGT predict differences in neural correlates as assessed using rsfMRI. The data presented here support the component process hypothesis and show that different types of thoughts may rely on a variety of sub-processes to be generated. Investigating the neural correlates of separate types of SGT or under different contexts therefore provides a more refined characterisation of the neural processes involved in SGT. In line with previous chapters, the present dataset highlights that SGT is a heterogeneous phenomenon and that considering SGT characteristics allows a better understanding of the neurocognitive substrates supporting this subjective experience.

Chapter 7.
General Discussion

7.1 Recap of research questions

Self-generated thought (SGT) has been traditionally considered as a homogeneous phenomenon although evidence described in the literature challenges this perspective. In particular, SGT has been associated with both advantages and disadvantages (i.e. heterogeneous functional outcomes) and has been linked to both increases and decreases in executive functions (i.e. heterogeneous cognitive correlates). To reconcile these conflicting findings, the current PhD proposed the hypothesis that SGT is in fact a heterogeneous phenomenon. In particular, we sought to test whether considering SGT as heterogeneous allows a better understanding of the cognitive and neural processes involved in this subjective experience.

To explain how SGT heterogeneities may emerge, we proposed that different types of SGT exist and are characterised by differences in thought content. In addition, these different types may rely on distinct cognitive and neural processes, following the component process hypothesis (Andrews-Hanna et al., 2014; Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015). The current PhD aimed to test three predictions emerging from the view that SGT is a heterogeneous phenomenon:

i. Different types of SGT can be statistically identified based on the content of the thoughts. This prediction was tested across all five empirical chapters.
ii. Different types of SGT have heterogeneous functional outcomes. To this end, Chapter 3 examined the relation between SGT and social problem solving and Chapter 4 explored its relation to self-concept.
iii. Different types of SGT have heterogeneous cognitive and neural correlates. This prediction was investigated in Chapter 5, where the phenomenological properties of SGT were examined. Finally, Chapter 6 investigated the neural correlates of SGT using resting state fMRI (rsfMRI).

The following sections will highlight the evidence accumulated throughout the empirical chapters in favour of each prediction and will demonstrate the importance of the component process hypothesis for understanding SGT heterogeneities. The discussion will conclude by presenting avenues for future research.

7.2 Identification of SGT types using Principal Component Analysis

Throughout the PhD, we have adopted a holistic approach to SGT content by taking into account the temporal, social and emotional dimensions of SGT when investigating thought content. The studies we have conducted aimed to provide novel evidence that distinct types of SGT could be identified based on the interaction between these three dimensions.

7.2.1 Identification of types of thoughts

Across the five empirical chapters, we found evidence that Principal Component Analysis (PCA) can be used to statistically identify different types of SGT according to the content of the thoughts. Using the covariance between the probe questions, PCA assessed how the temporal, social and emotional dimensions interacted and in each dataset, three principal components (PC) were obtained[8]. These PC represent three independent types of thoughts, namely Future SGT, Past SGT and Emotion SGT.

As can be seen in Figure 7-1, Emotion SGT mainly loads on negative and positive questions. It consists of a continuous dimension with negative and positive questions as its two extreme anchors. Loadings for the temporal and social questions are low for Emotion SGT, highlighting that the emotional dimension does not interact with the temporal and social dimensions. These findings therefore support previous approaches which have considered the emotional content of SGT as a continuous dimension (Andrews-Hanna et al., 2013; Song & Wang, 2012; Stawarczyk, Cassol, et al., 2013; Tusche et al., 2014). In addition, because Emotion SGT does not load on temporal and social questions, this suggests that the emotional content of SGT and other aspects such as mental time travel (MTT) are independent and can easily interact. An example of this interaction has been observed when predicting individuals' mood levels (Ruby, Smallwood, Engen, et al., 2013).

[8] Note that only two PC were obtained in Chapter 3 as the emotional dimension of SGT was not measured.

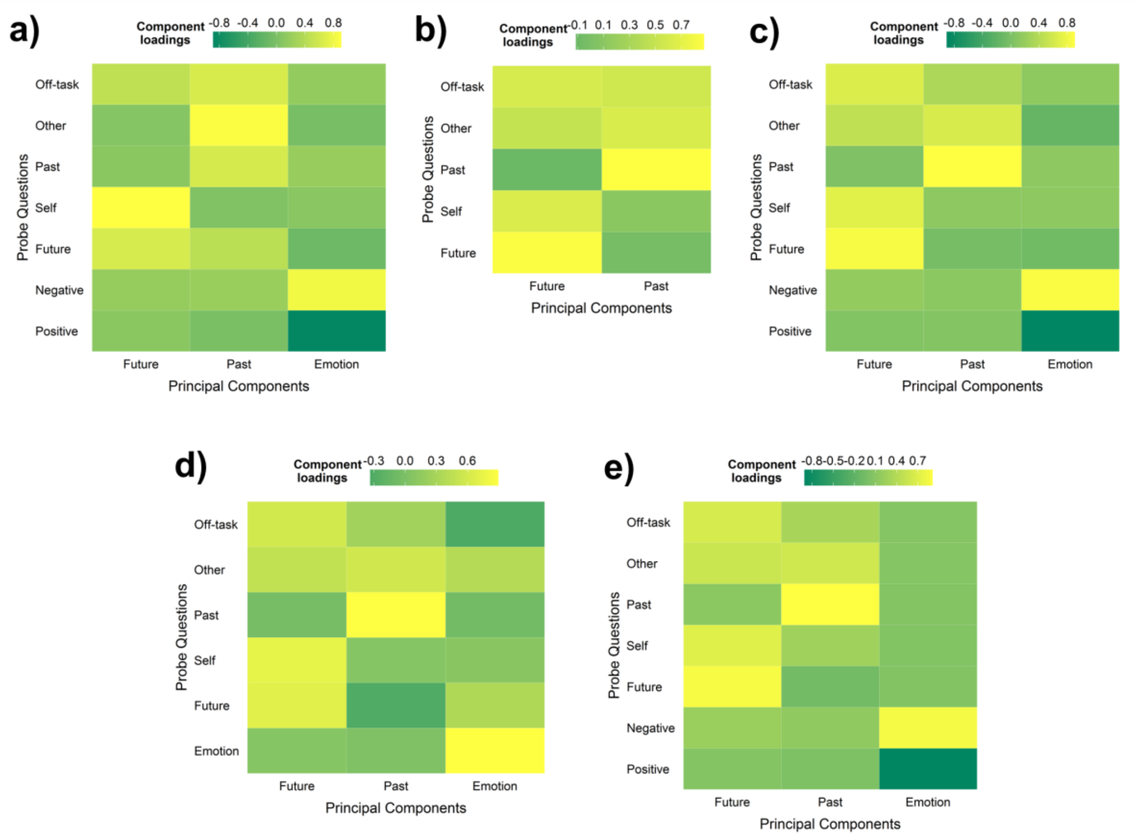


Figure 7-1. Heat maps generated from the five datasets employed in the current thesis
Heat maps obtained from five independent datasets are regrouped (a – e, respectively data from Chapters 2 – 6). Very similar patterns are observed across the different heat maps. In particular, Emotion SGT constitutes a separate PC, not interacting with the temporal and social dimensions. Future and Past SGT are defined by two distinct PC, and both consist of interactions between the temporal and social dimensions of SGT. Note that the PC have been reordered to reflect similarities across datasets. Abbreviations: PC: principal component, SGT: self-generated thought.

The two other PC revealed by PCA relied on the interaction between the temporal and social dimensions. Future SGT loaded on future as well as self and other questions, and Past SGT loaded on past as well as other questions. The fact that PCA revealed two independent PC may seem surprising as one might expect that future and past constitute the two extremes of a single temporal dimension (Andrews-Hanna et al., 2013; McVay, Unsworth, McMillan, & Kane, 2013; Smallwood, Nind, et al., 2009; Song & Wang, 2012; Stawarczyk, Cassol, et al., 2013). However, this approach implies that SGT can be either future or past-directed, but not simultaneously both. Contrary to this assumption, the PCA results show that Future and Past are in fact independent e.g. thoughts that have a high score on Future SGT do not necessarily have a low score on Past SGT. Indeed, thoughts directed towards the future require individuals to simulate potential events using previously acquired knowledge stored as semantic or episodic memory. We suggest that individuals may sometimes be aware of the past events they are using to build their simulation of the future (therefore leading to SGT with both high Future and Past scores), and sometimes may generate Future SGT without being conscious of the source of the information they are manipulating (leading to SGT with high Future scores but low Past scores). Thus, our findings contradict traditional experience sampling approaches which consider Future and Past as opposite or categorical constructs (Andrews-Hanna et al., 2013; McVay et al., 2013; Smallwood, Nind, et al., 2009; Song & Wang, 2012; Stawarczyk, Cassol, et al., 2013). Our results should therefore be taken into account when designing thought probes targeting the temporal dimension of SGT.

Our data also show that Future and Past SGT both involve the interaction between temporal and social dimensions. Based on these findings, we suggest that considering the temporal and social dimensions separately does not take into account the complexities of SGT content and as a consequence, may limit the understanding of this subjective experience. Previous studies have commonly considered separately different aspects of SGT content e.g. investigating the characteristics and functional outcomes of temporal thoughts (Baird et al., 2011; McVay et al., 2013; Song & Wang, 2012) or social thoughts (Poerio et al., 2015) but not both simultaneously. Our PCA data however suggest that taking into account the covariance among different aspects of SGT content allows a better understanding of this experience. As a consequence, future investigations should adopt a more holistic approach by considering different aspects of SGT simultaneously.

Altogether, our findings show that using a statistical approach such as PCA allows a more objective characterisation of different types of SGT and avoids assumptions commonly made in the literature. Subsequent sections will provide evidence that the types of SGT identified using PCA are replicable and can be validated using independent measures.

7.2.2 Replication of PCA patterns

Applying PCA to five independent datasets revealed consistent SGT patterns despite several differences across the samples (Figure 7-1). In particular, SGT was measured in two different countries (the UK and Germany) and the populations tested had varied demographics. The UK dataset consisted primarily of young undergraduate students, whereas the German datasets were obtained from individuals with a larger age range and more diverse occupations. Despite these population differences, similar PCA patterns were obtained, which suggests that the types of SGT identified using PCA are robust.

Thoughts were also measured across different conditions and using different probes. SGT was assessed while participants performed an easy non-demanding Choice Reaction

Time (CRT) task or a more demanding Working Memory (WM) task. Nevertheless, similar patterns were observed across both conditions and when only one condition was implemented (Chapter 5). In addition, similar types of SGT were obtained despite substantial changes in the probing questions employed. For example Chapter 2, Chapter 4 and Chapter 6 assessed the emotional dimension of SGT using 2 questions (negative and positive), whereas Chapter 5 employed a single question and Chapter 3 did not include this dimension. Moreover, similar thought types were obtained even when increasing the number of probe questions (e.g. in Chapter 5, a total of 10 questions probed SGT content as well as its phenomenological properties). Altogether, the studies presented in the current PhD show that the SGT types were replicated despite methodological changes and population differences, providing evidence that the thought patterns identified using PCA are robust.

7.2.3 Validation using independent measures

We validated the PCA patterns using independent measures. In particular, we found that Emotion SGT was related to emotion processes and individuals' well-being. For example, Chapter 4 showed that Emotion SGT predicted individuals' self-esteem and Chapter 5 replicated the findings that Emotion SGT was linked to depressive symptoms. Regarding the other types of SGT, we found that Future but not Past SGT was linked to the temporal dimension of self-concept and predicted individual differences in the self-reference effect, therefore replicating previous findings (Smallwood, Schooler, et al., 2011).

In addition to behavioural data, neuroimaging data provide further evidence validating the types of SGT obtained using PCA. Chapter 6 shows that Emotion SGT was related to increased functional connectivity (FC) between the posterior cingulate cortex (PCC) and the orbitofrontal cortex (OFC), a region previously identified as playing a role in Emotion SGT (Tusche et al., 2014) and involved in valence and reward processing (Berridge & Kringelbach, 2013; Kringelbach, 2005). In addition, our results show that individual differences in MTT predicted FC within the Default Mode Network (DMN). These findings are in line with an extended body of literature highlighting the role of the DMN in SGT and in episodic processes (Addis et al., 2007; Andrews-Hanna et al., 2010, 2014; Mason, Norton, et al., 2007; Schacter et al., 2007; Smallwood, Tipper, et al., 2013). Taken together, these findings provide further evidence that the types of SGT obtained using PCA are valid and reflect objective individual differences in thought content.

7.2.4 Manipulation of SGT

In addition to replicating and validating SGT types, our data also show that SGT occurrence and content can be manipulated by changing the experimental conditions. In particular, SGT was measured while participants performed a cognitive task under two conditions: a non-demanding CRT and a more demanding WM task. As a consequence of task difficulty, SGT scores were overall reduced during the WM compared to the CRT task, in particular Future and Emotion SGT whereas levels of Past SGT did not significantly change (Chapter 3; Chapter 4, Chapter 6). Altogether these results are in line with previous findings (Smallwood, Nind, et al., 2009; Smallwood, Ruby, et al., 2013; Smallwood, 2013b; Smallwood, Brown, et al., 2011) and highlight that the PC generated by PCA are sensitive to task manipulations.

In Chapter 4, we also found that priming individuals to adopt a more independent or more interdependent mind-set influenced the functional outcomes of different types of SGT. For example, Past SGT was linked to lower mood levels and poorer task performance only following interdependent priming. Although we did not observe significant differences in SGT occurrence across priming conditions, our results suggest that interdependent priming manipulated SGT properties and perhaps its cognitive correlates, therefore leading to changes in functional outcomes. This result provides further evidence that the SGT scores generated using PCA can capture changes induced by experimental manipulations.

7.2.5 Summary of findings

In summary, all empirical chapters provide evidence that different types of SGT can be identified using a statistical approach. PCA allowed us to determine how the temporal, social and emotional dimensions of SGT interact to make up three distinct types of thoughts. We replicated the PCA patterns across five independent datasets. In addition, the three SGT types were validated using independent measures and evidence shows that they were sensitive to experimental manipulations. Altogether, this demonstrates that different types of SGT can be identified based on the content of the thoughts, therefore supporting the first prediction the PhD set out to test. Next, we will review the findings in favour of the predictions that different types of SGT have heterogeneous functional outcomes and heterogeneous neurocognitive correlates.

7.3 Heterogeneities of SGT

Chapter 3 to Chapter 6 explored whether the different types of SGT identified using PCA possessed heterogeneous functional outcomes and relied on heterogeneous correlates.

Chapter 3, Chapter 4 and Chapter 5 focused on the functional outcomes of SGT, and Chapter 5 and Chapter 6 investigated the cognitive and neural processes of SGT in order to test the component process hypothesis.

7.3.1 Heterogeneities in SGT functional outcomes

7.3.1.1 Differences across SGT types

Evidence accumulated in Chapter 3, Chapter 4 and Chapter 5 provide evidence that Future, Past and Emotion SGT have heterogeneous functional outcomes. In particular, we found that Emotion SGT (but not other types of SGT) was preferentially linked to emotion-related outcomes. Positive thinking predicted increased mood levels and higher self-esteem (Chapter 4) as well as lower depressive symptoms (Chapter 5). These results are in line with previous findings and highlight that the emotional content of SGT is strongly related to individuals' general well-being (Andrews-Hanna et al., 2013; Poerio et al., 2013; Ruby, Smallwood, Engen, et al., 2013).

More interestingly, we found that Future and Past SGT were associated with different functional outcomes. For example, Future but not Past SGT predicted increased task performance (Chapter 3, Chapter 4). Next, we replicated the observation that Future but not Past SGT is linked to self-referential processes; Chapter 4 revealed that the temporal direction of individuals' self-concept was predicted by their tendencies to generate Future SGT but not Past SGT; Chapter 5 confirmed that only Future SGT was related to increases in the self-referential effect (i.e. the bias individuals display towards remembering self-related compared to other-related words). Finally, we also found that Past SGT but not Future SGT was linked to decreased mood levels following interdependent priming. Altogether, these findings show that SGT can have heterogeneous functional outcomes when the content of the thoughts is taken into account, therefore supporting our second prediction and the claim that the content of SGT plays a significant role in SGT heterogeneities.

7.3.1.2 Similarities across SGT types

In addition to observing differences in functional outcomes across SGT types, the studies described in the PhD also show that Future and Past SGT can have similar functional outcomes under some circumstances. For example, we found that both Future and Past SGT had a similar relation to social problem solving as assessed using the Means Ends Problem Solving task (MEPS, Platt & Spivack, 1975; Svaldi, Dorn, & Trentowska, 2011). Both types of SGT predicted significant increases in relevant means (i.e. the number of steps individuals generated to reach the solution to a given problem) but decreases in overall efficiency (i.e. how efficient the story provided by the participant was at solving the given problem). In Chapter 4, we also observed that both types were linked to decreased task performance following interdependent priming. These results suggest that, although Future and Past thinking can have heterogeneous properties, similar functional outcomes can also be observed in certain cases.

7.3.1.3 Interaction between SGT content and context

Both Chapter 3 and Chapter 4 provide evidence that the functional outcomes of SGT were modulated by the context in which SGT occurred. For example, Future SGT predicted increased performance at the CRT but not the WM task. In addition, the link between Future SGT and self-concept was also compromised when individuals performed the WM task. However, other outcomes do not seem to be influenced by task conditions. For example, SGT predicted individual differences in social problem solving skills whether the thoughts were measured during the CRT or the WM task (Chapter 3). Similarly, interdependent priming led to a negative relation between Past SGT and CRT as well as WM task performance (Chapter 4). Although a thorough investigation of the interaction between content and context of SGT was beyond the scope of the current PhD, these results replicate previous findings and provide additional evidence that the context in which SGT occur may modulate the relation between SGT and its functional outcomes (Levinson et al., 2012; Rummel & Boywitt, 2014; Smallwood & Andrews-Hanna, 2013; Smallwood & Schooler, 2015).

7.3.1.4 Component process hypothesis

The previous sections highlight that different types of SGT (in particular Future and Past SGT) can have similar or different functional outcomes, and that these functional outcomes may be influenced by the context in which SGT occurred. To explain this complex pattern of results, we use the component process hypothesis and propose that specific processes are recruited according to the demands of each type of SGT (Andrews-Hanna et al., 2014; Smallwood & Schooler, 2015).

The tasks we employed to examine SGT's functional outcomes assess specific cognitive processes. For example, the Twenty Statement Test used in Chapter 4 to measure individuals' self-concept relies on self-referential processes. When two types of SGT have a similar relation to a task, this suggests that the cognitive process assessed by that task is involved in both types of thoughts. On the contrary, when Future and Past SGT have a heterogeneous relation to a task, this suggests that that process is not ubiquitously recruited in these two types of SGT. Finally, when the relation between SGT and a task is only observed in one context but not the other (e.g. CRT or WM), this suggests that the process is recruited differently according to the demands of the external environment. Altogether, we propose that distinct types of SGT may rely on shared or distinct processes to be generated and that this may be modulated by the context in which SGT occurred. The following section will review evidence in favour of this interpretation.

7.3.2 Cognitive and neural correlates of SGT types

The last two studies conducted during the PhD aimed to test the component process hypothesis and more particularly, the prediction that different types of SGT rely on heterogeneous neurocognitive substrates. To this end, Chapter 5 investigated the phenomenological properties of SGT and Chapter 6 explored its neural correlates using rsfMRI.

7.3.2.1 Cognitive correlates of SGT

In Chapter 5, we investigated the phenomenological properties of different types of SGT in order to shed light on their cognitive correlates. Applying PCA to the four phenomenological questions revealed three PC: modality of SGT (whether thoughts were in the form of words or in images), intrusiveness (whether they were considered intrusive by individuals) and vagueness (whether thoughts were rather vague or specific). Our results revealed that positive thoughts were in general more specific and more in the form of images than in the form of words. In addition, we observed that both Future and Past SGT were considered as more intrusive or more spontaneous. Although speculative, this suggests that associative rather than controlled episodic processes may be recruited during MTT. This may therefore explain why both Future and Past SGT were linked to the creative component of social problem solving (i.e. relevant means). Indeed, creativity relies on the spontaneous generation of new ideas and benefits from associative rather than controlled processes. Thus, the relation between episodic SGT and problem solving may be observed because of shared associative processes. We also explored the relation between individual differences in SGT content and in SGT phenomenology. We found that individuals who had a tendency to generate episodic SGT also tended to use visual imagery rather than inner speech, suggesting that these individuals may rely more on imagery processes rather than semantic processes to generate their thoughts.

Taken together, these findings reveal similarities and differences in terms of phenomenological properties between different types of SGT. This therefore provides preliminary evidence that the cognitive correlates of SGT may vary according to the content of the thoughts. Nevertheless, the study focused on four phenomenological properties (intrusiveness, inner speech, visual imagery and specificity) and we believe that subsequent studies should be conducted to assess the role of additional phenomenological features in SGT heterogeneities.

7.3.2.2 Neural correlates of SGT

In Chapter 6, we assessed the neural correlates of SGT using rsfMRI. In particular, we investigated whether the FC of the two mains hubs of the DMN varied according to individual differences in SGT content. We observed that Emotion SGT was linked to increased FC between the PCC and OFC, a region traditionally involved in emotion processing as well as valence and reward appraisal (Berridge & Kringelbach, 2013; Kringelbach, 2005). In addition to replicating Tusche et al. (2014) findings, this highlights that emotion processes occurring spontaneously or triggered by external information (e.g. during a task) share similar neural correlates. Thus, these results are in favour of the component process hypothesis.

Next, we also found that Past and Future SGT had distinct neural correlates. Past SGT was linked to increased FC between the mPFC and frontal regions (e.g. anterior cingulate cortex, ventromedial prefrontal cortex, bilateral insula), in line with Mason, Bar, et al. (2007). Although these results support the prediction that different types of SGT rely on specific neural processes, future studies are required to shed light on the role these regions play in Past SGT and how they may influence its functional outcomes.

Finally, similarities between Past and Future SGT were also observed. We found that both types of thoughts were associated with increased FC within the DMN. These findings are consistent with previous studies showing that MTT relies on the DMN (Buckner & Carroll, 2007; Spreng, Mar, & Kim, 2009) and that prospection and memory share neural correlates (Addis et al., 2007; Buckner, 2010; Schacter et al., 2007). We also observed that both types of SGT were linked to reduced FC between mPFC and the visual cortex. This result supports the *perceptual decoupling hypothesis*, which suggests that SGT requires a reduction in sensory information processing in order to insulate the stream of thought (Barron et al., 2011; Smallwood & Schooler, 2015; Smallwood, Brown, et al., 2011). Taken together, these findings suggest that both types of SGT share neural correlates, with the episodic system providing the content of SGT and perceptual decoupling allowing insulation from external distraction.

7.3.2.3 Summary of findings

In summary, the findings described in Chapter 5 and Chapter 6 show that different types of SGT can rely on shared or distinct cognitive and neural correlates. In addition, our findings suggest that these differences and similarities may underlie SGT heterogeneous functional outcomes. Taken together, these findings illustrate the component process hypothesis and indicate that the content of SGT plays a role in determining the processes involved in SGT. These results provide strong evidence in favour of our hypothesis that SGT is a heterogeneous phenomenon. We hope that future studies will build on our findings and to this end, we will describe potential avenues for future research in the following section.

7.4 Avenues for future research

7.4.1 Identification of other types of SGT

The current PhD focused on the identification of distinct types of SGT based on the interaction between the temporal, social and emotional dimensions of SGT. We found that the three types of SGT identified possessed heterogeneous functional outcomes and heterogeneous correlates, therefore supporting our hypothesis that SGT is a heterogeneous phenomenon. Although the dimensions we focused on explained significant amount of variance in independent variables (e.g. task performance, neural correlates and so on), we acknowledge that additional dimensions may also be important to explain SGT heterogeneities, and future studies investigating different dimensions of SGT will likely find additional types of SGT. Our studies highlight that PCA was able to generate meaningful types of SGT based on probe data assessing a variety of features (including the content and the phenomenology of SGT), suggesting that this technique can be applied to a wide range of variables assessing SGT and is not limited to the ones we examined. To this end, we hope that the statistical technique we have employed throughout this PhD will be used in the future to identify additional types of SGT and further the understanding of this subjective experience.

7.4.2 Exploration of SGT neural correlates

As described in Chapter 6, individual differences in SGT related to individual differences in neural correlates as assessed using rsfMRI. These data as well as previous findings confirm that the subjective reports individuals provide about their thoughts can be corroborated by objective neuroimaging measures (Andrews-Hanna et al., 2010; Christoff et al., 2009; Gorgolewski et al., 2014; Mason, Norton, et al., 2007). In addition, these findings as well as other studies (Gorgolewski et al., 2014; Schaefer et al., 2014) provide preliminary evidence that distinct types of SGT possess specific neural signatures. These findings therefore provide a strong basis for further exploration of the similarities and differences between thought types.

In particular, although the spatial resolution provided by rsfMRI and task-based fMRI have allowed the identification of key brain regions involved in SGT (Andrews-Hanna et al., 2010; Christoff et al., 2009; Gorgolewski et al., 2014; Mason, Norton, et al., 2007), their slow time resolution have limited the understanding of the thoughts' dynamics (e.g. onset, development and termination). We believe that employing neuroimaging techniques which possess higher temporal resolution (e.g. electroencephalography and magnetoencephalography) will provide a fruitful avenue for future research. In particular, knowledge about the brain regions involved in different types of SGT can be used to understand the dynamics of SGT. For example, recording the dynamical activations and deactivations of networks that have been shown to support types of SGT may allow the detection of switches between one type and another type of SGT at a ms time scale, or the onset of specific types of SGT, which is not easily identifiable using subjective reports. Altogether, we believe that gaining a better understanding of the neural mechanisms and dynamics of SGT is an exciting avenue for future research.

7.4.3 Better understanding of clinical disorders

Finally, we hope that our research findings will have a positive impact on the understanding of mental health disorders. These disorders (e.g. depression, anxiety, schizophrenia, bipolar disorders and so on) are characterised by deleterious thought and behavioural patterns causing individuals to poorly function in daily life (American Psychiatric Association, 2013). We suggest that a better understanding of SGT in healthy individuals allows a better comparison with clinical populations and as a consequence, may lead to improvements in the treatment and handling of these deleterious conditions.

7.4.3.1 Comparing SGT between healthy and clinical populations

A more thorough identification of different types of SGT and their functional outcomes in healthy populations provides a baseline on which to compare thought patterns in clinical populations and therefore allows an easier identification of deleterious tendencies (e.g. exacerbation in one type of SGT). In addition, data from healthy populations can also be used to formulate and test clearer predictions regarding psychopathological changes (e.g. "depression may be characterized by overall increases in negative and Past SGT, but decreases in Future SGT").

7.4.3.2 Investigating differences in SGT between healthy and clinical populations

We propose two ways in which SGT may change between healthy individuals and individuals suffering from mental health disorders: the occurrence of certain types of SGT may vary, or the types of SGT experienced may be different.

Changes in SGT occurrence. Investigations of mental health disorders highlight that these illnesses are characterised by deleterious thought patterns. For example, depression involves the exacerbation of ruminative thoughts (i.e. negative thoughts focused on the past) whereas suicidal tendencies involve a lack of future-directed thoughts. These two examples illustrate how the occurrence of certain types of SGT may vary compared to baseline levels in healthy populations.

Changes in SGT types. Additional differences may emerge in terms of the thought types identified. In particular, we suggest that the temporal, social and emotional dimensions of SGT may interact differently in clinical populations compared to healthy individuals. For example, PCA computed on data obtained from individuals suffering from depression might reveal one "ruminative" PC loading on past and negative ratings, rather than two distinct PC (Past SGT, Emotion SGT) observed in healthy individuals. To estimate differences in SGT patterns, other statistical approaches than PCA may be employed. In particular, Multiple Group Confirmatory Factor Analysis (MGCFA, Hirschfeld, Datteln, Brachel, & Bochum, 2014) can be used to compare the patterns obtained across different populations. Using structural equation modelling, MGCFA estimates regression parameters for each variable and computes latent variables. For example, population differences may be identified when the parameters' loadings or intercept are significantly different. Using MGCFA to identify similarities and differences in SGT patterns may shed light on SGT changes in deleterious conditions.

7.4.3.3 Improving the diagnosis and treatments of mental health disorders

It is possible that applying the experience sampling approach to a clinical context may prove beneficial. Clinical assessments usually consist of self-assessment questionnaires and interviews, which may lead to overlooking certain symptoms and as a consequence, may bias the evaluations of clinicians towards one or another diagnosis. As experience sampling allows the repeated measures of different features of SGT, thought patterns can be assessed in a broader and unbiased way, therefore potentially improving the diagnosis of mental disorders.

We hope that a better characterisation of the changes in SGT patterns between healthy and clinical populations will in turn improve the diagnosis and treatments of mental health disorders. In particular, disorders which share similar symptoms are often misdiagnosed as one another and inappropriate treatments are administered to patients. For example, bipolar spectrum disorders are frequently misdiagnosed as unipolar depression because manic symptoms are overlooked by patients and clinicians. As a consequences, patients are prescribed with anti-depressants which lead to increases in manic symptoms rather than improvements (Ghaemi, Ko, & Goodwin, 2002; Matza, Rajagopalan, Thompson, & de Lissovoy, 2005). We hope that a better description of patients' thought patterns will improve their diagnostic and the administration of treatments.

7.5 General conclusions

The current thesis tested the hypothesis that SGT is a heterogeneous phenomenon, with the aim to gain a better understanding of SGT's functional outcomes and neurocognitive substrates. Using PCA, we systematically identified distinct types of SGT based on the temporal, social and emotional dimensions of thought content. We observed that Future, Past and Emotion SGT possess heterogeneous functional outcomes. In addition, we provide initial evidence that distinct SGT types rely on specific cognitive and neural processes, therefore supporting the component process hypothesis. Altogether, the empirical findings described in the current thesis strongly support our hypothesis that SGT is a heterogeneous phenomenon. Although subsequent investigations will be required to further the characterisation of the neurocognitive substrates supporting spontaneous cognition, the current thesis highlights that considering distinct types of thoughts allows a better description of SGT and advances the general understanding of this subjective experience.

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