Directing the conscious flow: two nested executive control mechanisms

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1. Scientific question and brief review of the literature

1.1 Introduction

Mind wandering – or thinking about something else than what you are doing – is a subjective experience, and as such presents many challenges in its study. What is known about it is often summed up this way: "Mind wandering is an experience common to all, that occupies our minds 25 to 50% of our waking time[3], and seems to have deleterious consequences on attentional and memory performances[4], but likely positive ones on creativity[5,6] and long term goal achievements". Our project is to introduce a new classification of the dimensions of mind wandering participants are asked to report; and to investigate a new aspect – agency –, that we think better match the actual features of the process.

1.2 Methods

The main paradigm used in most studies is the sustained-attention-to-response task[10] (SART; Figure 3). The SART is a go/no-go task with infrequent no-go targets, designed so that it's easy and boring, and people are therefore more likely to mind wander. During this task, we collect reports of mind wandering with "thought probes" that appear pseudo-randomly. Participants are then asked to answer on a Likert scale or in a binary way :"Were you focused on the task or mind wandering?"[11–13], and other question about the nature of the experience (content and temporality of thought[3], intention[9], vividness[12], awareness[14], form[15]…). Another common and more ecological way to investigate mind wandering is through experience sampling with mobile applications[3,13,15]. At random moments during the day, people get a notification on their phone and are asked similar thought probes, along with questions about what they are doing at the moment.

Unfortunately, there isn't a real objective marker of mind wandering yet. The more objective way to use the contrastive method is to compare the rate of different types of mind wandering (for instance deliberate versus spontaneous) in different version of the SART[9]. Some explore the possibility that pupillometry (phasic and tonic responses) could reflect the focus of attention (internal versus external)[12,16,17], but this hasn't borne robust results yet. Neuroimaging hasn't shown a distinctive signature of mind wandering either, only correlating some aspects of the experience to BOLD signal, like lack of meta-awareness with frontal activations[18]. The most promising marker is reaction time (RT) variability[12,19–21] (RTV) in the SART task: the variability in RT of trials preceding the probe is higher when people report that they are mind wandering. Seli[20] used it for instance to assess the validity of reports: when participants were more confident that they were mind wandering, they indeed had larger RT variability.

1.3 Results

Certain aspects of cognition are affected by mind wandering, and the way we mind wander is mediated by our cognitive abilities. One classical result is that people who mind wander more during a task, tend to have worse performance and RT[1,4,5]. Mind wandering is indeed sometimes accounted for by executive failure[1,7,10], but it is also thought to be central in episodic memory encoding[8], future planning[22], creativity[6] and addressing "current concerns"[23,24] in general. Being able to mind wander at the right time can then be a sign of good executive control: mind wandering 'efficiency' (more mind wandering when the task is easy than when it is hard) is correlated with working memory capacity[25] and meta-cognitive abilities[26].

Moreover, the different phenomenal features of mind wandering seem to interact and affect us differently. For instance, mind-wandering is associated with lower mood, especially when thoughts are past-oriented[3,27]. It is also proportionally more deliberate than spontaneous when the task is easy than when it is hard[9]. Besides, verbal mind wandering, as opposed to visual, auditory or multimodal, is more likely to be (meta-)aware. And the intensity of the thought seems to increase awareness only in the verbal modality[15].

1.4 Definition

The original definition of task-unrelated thoughts[2,3,12,15] (TUT) is often perceived as insufficient, so researchers sometimes dissociate stimulus-independent and dependent (or self-generated versus perceptually-guided) TUTs [1,24,28]. This dissociates TUTs that relate to a distractor of the environment, rather than to internal representations. Then some argue that it is not task-relatedness, or even perceptual-relatedness that matters, but rather the deliberateness[9], the awareness[18], or the freedom of movement[7,8,13] of the thought that defines mind wandering.

The term mind wandering is used to describe a variety of phenomena occurring in our stream of thought. To reconcile everybody, some propose to rather use "self-generated" or "spontaneous" thought, of which mind wandering – along with day dreaming and rumination – is a subtype[7,29]. Seli proposed to use a family resemblance framework to define mind wandering[30], meaning that many different concepts are grouped under this label, the whole of them having many common characteristics (e.g. task-independence) but two uses of the words might not refer to overlapping concepts. Considering this, it is necessary that one clearly describes what aspects one wants to inquire in an experiment.

Another consequence of this diversity of definitions is the reliability of results[30]. What is true for TUTs might not be for "free" mind wandering[13]. Furthermore, even when investigating the same phenomenal aspects, experimenters use different sentences in their probes ("Were your thoughts related to the task ?" and "Was your attention focused on the task?" can produce different results), and different instructions for their subjects[31]. A way to get around the definition problem is to ask several questions (about different aspects of the experience) in the probes, in order to do covariance analysis, to determine which aspects are independent and relevant to predict performance, RTV, …[27,29]

1.5 Models and neural correlates

The component process account[1,32] dissociates three components of mind wandering: perceptual decoupling (disengagement of attention from external processing), self-generation of thought (through episodic and affective processes), and executive monitoring (regulation of mind wandering). It is not surprising either that the Default Mode Network[1,7,33] (DMN), which is the network of resting-state activation, is often linked to occurrence of mind wandering. Less obviously, fMRI studies have shown a frontal executive network activity in spontaneous (or self-generated) thought[7,34,35], especially when mind wandering lacks awareness[18].

Furthermore, in Christoff's dynamic framework[7], two different kinds of constraints are brought by two different executive networks (Figure 2). Attentional networks (of salience and relevance) bring automatic constraints, whereas a fronto-parietal control network brings deliberate constraints by coupling with attentional networks. Moreover, the subparts of the DMN have different roles: the core one (including the medial prefrontal cortex and posterior cingulate cortex) and the temporo-frontal one (including the lateral temporal cortex, the dorsomedial prefrontal cortex and inferior frontal gyrus) seem to direct the thoughts internally.The DMN part centered on the medial temporal lobe (MTL; including the hippocampus) would be more related to the self-generation and the variability of the train of thought (the freedom in Mills' view[13]). In a related manner, Mittner[16] proposes that transient input from the locus coeruleus norepinephrine system to the MTL, promotes a disengagement from the external input and an engagement towards internal representations.

What we would like to do is to try and synthesize the different models of mind wandering, and clarify what is indeed inquired in the probes. We would also like to propose an updated component account based on this, and test its validity.

2. Reference paper (Seli et al., 2016): On the Necessity of Distinguishing Between Unintentional and Intentional Mind Wandering

2.1 Introduction

Paul Seli and his colleagues' main goal in the last decade has been to bring more precision and standards in the field of research on mind wandering[20,30,36,37]. He is especially known to have brought the idea that mind wandering can be intentional, while it was before conceptualized as mostly automatic or involuntary. The

authors acknowledge that, as both deliberate and spontaneous mind wandering involve self-generated thoughts and perceptual decoupling, the distinction might not be so important.

However, their hypothesis is that it is important: they want to show that not making the distinction will make us miss some aspects of mind wandering, and misinterpret others. Specifically, in this paper, they believe that "a manipulation can have opposing effects on unintentional and intentional mind wandering.". This follows previous papers showing that subject's traits and states of mind can affect differently intentional and unintentional mind wandering. In 2013, they showed that only deliberate mind wandering was correlated with certain mindfulness traits[11,38]. In 2015, they showed that motivation affected the proportion of intentional and unintentional mind wandering (more intentional for participants less motivated), but failed to show that both types had a different effect on participant's performance[39].

2.2 Methods

The procedure is simple: they had a first group of participants do the classic SART. More precisely, blocks of digits from 1 to 9 were presented in a random order, in a random font size (from 5 possible). Participants had to press the space bar for every number except "3" (no-go trial). Participants had 2 of those blocks as practice, then 100 for the real experiment (900 trials, approx. 20 minutes). During the experiment, 20 thought probes were presented at pseudo-random interval, asking the participant to characterize their thoughts as: "(1) On task, (2) Intentionally mind wandering, and (3) Unintentionally mind wandering".

Another group of participants did an easier version of the task, where the numbers appeared in ascending order, thus making it possible to predict the next trial. Their hypothesis was that the number of reported mind wandering episodes would vary with task difficulty, and differently for each type of mind wandering.

2.3 Results

They controlled the new task was easier by comparing performances of subjects in both conditions, with an independent-sample t-test (n=56 & 57, $t(66.201) = 8.36$, $p < .001$). Likewise, overall mind wandering report rate didn't vary as a function of difficulty (p=.429).

They tested their main hypothesis with a mixed ANOVA (with difficulty as between subject, mind-wandering type as within subject, and rate as dependent variable). In addition to a main effect of mind-wandering type (more unintentional reported), the interaction effect was significant. T-tests confirmed that the intentional mind wandering rate decreased with difficulty (p=.034), whereas unintentional increased (p=.005; See Fig1).

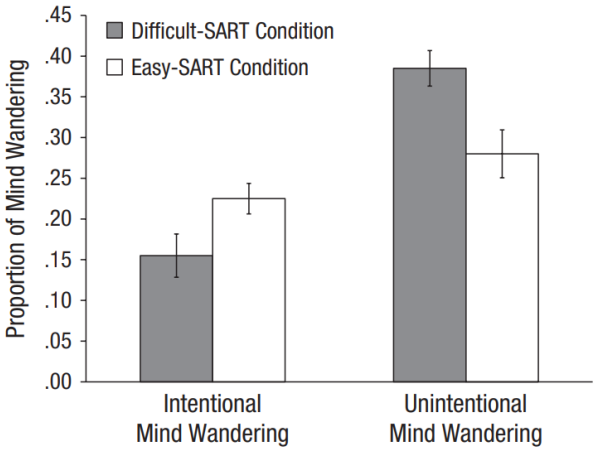


Figure 1 *(from Seli et al., 2016): Proportion of mind wandering as a function of mind wandering type (intentional and unintentional), presented separately for the easy-SART and difficult-SART conditions. Error bars represent +-1 SEM.*

2.4 Discussion

Distinction between unintentional and intentional mind wandering revealed a different influence of task difficulty on the rate of each of subtypes of mind wandering, whereas a researcher looking only at general mind wandering rate wouldn't have found anything. This result is particularly relevant, because previous studies that found higher mind wandering rates in easier tasks, accounted for it by an increase in unintentional mind wandering[40]. The excess resources available in the easy task seems to actually be more voluntarily used to mind wander than previously thought.

Seli et al. also raise the issue of the many aspects experimenters study, and how they relate or not to each other. The difference between awareness and intentionality could be explained by the process-occurrence framework[32]: a mind wandering episode is deliberate if one is aware of the onset of mind wandering, the "ignition point". So, as queries about intention relate to the occurrence, those about awareness relate to the process. They also show that this aspects are not identical because they don't show the same consequences: awareness brings slower RT[14], but intention does not (p=.660).

This dissociation makes sense, because the awareness of the episode isn't too dependent on the onset: you

can catch yourself unintentionally mind wandering[15], or you can lose awareness as you mind wander. It is also very important because introspective access to occurrence and process might differ.

Moreover, Seli and colleagues refer to previous results that showed increased future-orientation of mind wandering in easier tasks[41]. This could suggest that when mind wandering is deliberate, it is more often used strategically to prepare for the future. As intentional mind wandering requires more engagement, and could be more future-oriented, it could also be associated with more "positive thinking".

2.5 Limits

There is also the limit of introspective self-reports. Especially in this case, where intention may be harder to access than the content, people may misinterpret their feeling. One hypothesis is that they perhaps label their mind wandering as intentional when it is self-generated rather than dependent on the environment, as this manipulation didn't make the distinction between stimulus-independent and dependent thoughts. One could also think that participants mistake their mind wandering for intentional if it gradually comes into awareness.

Furthermore, there remain some doubt about the utility of the distinction in other experiments. Usually, participants are primarily asked to focus on the task, and it is implied that they shouldn't deliberately think of something else. Mind wandering experiments are indeed often accompagnied by a cover story declaring that the manipulation is about attentional capacities. In this study, with the probes which participants are presented, they could have been biased to try to voluntarily mind wander.

The distinction seems especially futile in experiments where people are allowed to "self-catch" their mind wandering[15]: it is then even more implied that you should try to avoid it. If they asked about intention in such a set-up, they propably would have gotten close to no instance of deliberate mind wandering. One could also wonder if in these cases, participants voluntarily fail to report intentional or aware mind wandering in order to think about their current concerns undisturbed.

Even if it brings some important distinctions, there are still many imprecisions about the definition of mind wandering, or even self-generated thought. For instance, it is not clear whether the task is done in an automatic manner – without attention or intention – while you mind wander, or whether we maintain actively both our behavior and train of thought – aware or not. Considering the Global Workspace taxonomy[42–44], the task could be done with unconscious working memory manipulating preconsious representations[45] (i.e. perceptions strong enough to be perceived, but not consciously perceived because another representation was already being broadcasted in the global workspace at the time it appeared). However, it feels that we consciously perceive the stimulus in such an experiement, even if we are not "focused" on it. A simple way to test this could be to unexpetedly inquire about the last number seen.

Moreover, it seems that every representation in our stream of consciousness is consciously experienced, so it seems only possible to imagine unawareness about the process and not about the representation currently in our thoughts. Process awareness also seems to behave differently from perceptual awareness: the former is gradual whereas the latter is all or nothing?

3. Proposed experiment

3.1 Introduction

There are still many obscure areas in the field of mind wandering. What we can do is try to better identify to which part of the mind wandering experience the questions we ask in our probes refer. It seems that we can ask about the thoughts themselves: about their **content** (un-/related to the task or the environment, past/future-oriented) and their **features** (modality, vividness). Then when you ask about intention, awareness or agreeability, you inquire about the **feeling** of the phenomenal experience. Finally some questions demand of people to do more introspection on the **process** itself, to retrieve the "route" of the train of thought : that's what happens when you ask " Was your mind moving about freely?" or "Were you aware of your surroundings?"[13,15].

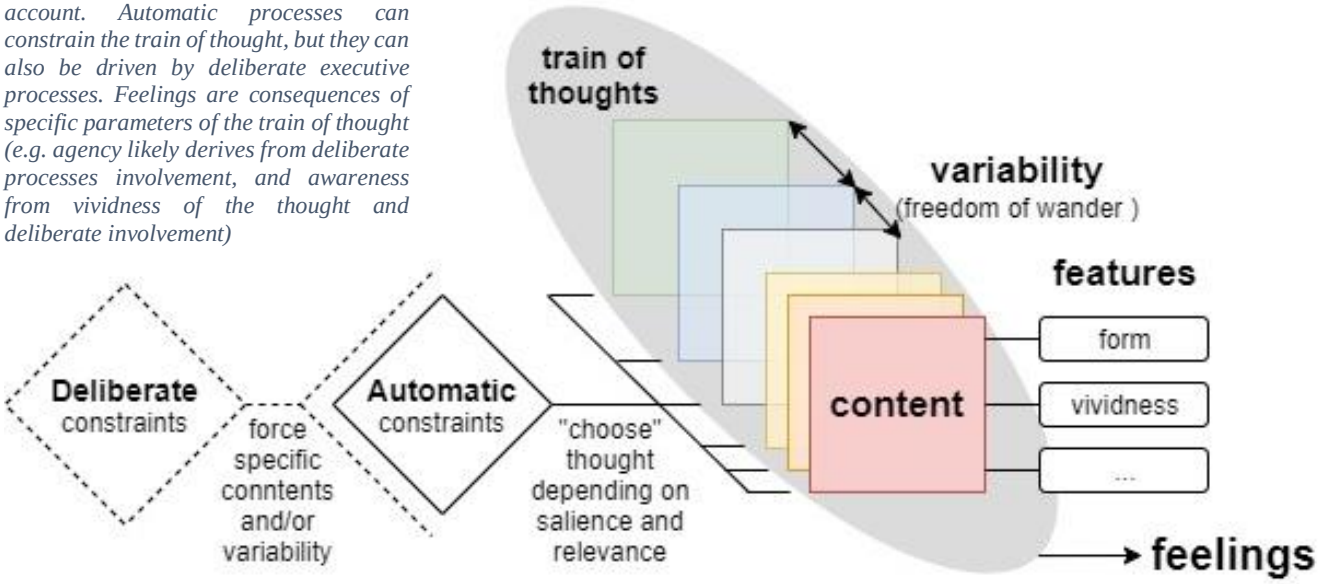
The logic would be that, as you demand more introspection when you go up these dimensions (content, feature, feeling, process), the information gets less accessible, and the results less reliable. Moreover, these

dimensions are of course related to each other, as results link for instance content and features: visual and auditory thoughts are less vivid in on-task then off-task, but it is not the case for verbal thoughts[15].

Christoff's model provides a good account of the observations we have on spontaneous thoughts[7]. The main idea is that you have both automatic and deliberate constraints. For instance, ruminations or obsessive thoughts are highly constrained, but not deliberately. Moreover, the same deliberate involvement can be accompanied by different levels of constraints on variability and content: imagining a story would be little constrained, whereas problem solving a lot more. The deliberate component only modulates the automatic component that regulates the train of thought. Here, we believe that the only real determiners of the spontaneous thought experience are those two types of executive constraints; and that the perceptual decoupling and self-generation components classically proposed[1,34] refer more to feelings than to the process itself (Figure 2).

One can already explain a range of results and intuitions with this distinction. In the obsessive example before, you could predict that one would feel particularly aware and find their thoughts rather vivid and clear – without being deliberate. And vividness has indeed been shown to increase awareness[15]. Furthermore, in this framework, the involvement of deliberate constraints at the onset of the mind wandering episode would be what brings the feeling of intention in Seli's manipulations, and that would bring a feeling of awareness. So, it seems that both automatic and deliberate constraints bring awareness.

***Figure 2**: Proposed spontaneous thought account. Automatic processes can constrain the train of thought, but they can also be driven by deliberate executive processes. Feelings are consequences of specific parameters of the train of thought (e.g. agency likely derives from deliberate processes involvement, and awareness from vividness of the thought and deliberate involvement)*



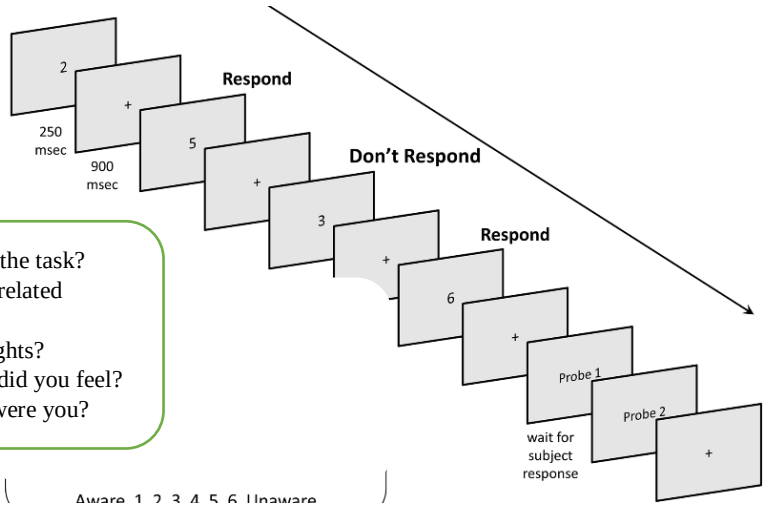
One feeling that hasn't really been discussed in the mind-wandering and spontaneous thought literature is **agency**. Here we propose that it is similar to the deliberateness feeling, but refer to intention at the time of the current thought (or just before probe) rather than at the onset of mind wandering episode. If Smallwood described this as awareness[32], we rather believe that the feeling of awareness derives from deliberate involvement, i.e. from the feeling of agency. As vividness is also correlated with awareness, we could have a case of collinearity with agency. However, we predict those two are independent, as compulsive thought are vivid and aware without being deliberate. We could hypothesize that if you inquire about these three aspects on Likert scales, agency and vividness are going to predict awareness. This can be tested with a paradigm similar to Seli's above described, with different probes (Figure 3).

3.2 Methods

We would first need to test the validity of our probes by seeing if we reproduce previous results. Studies didn't contrast awareness with similar conditions before, but we can look for an increase in RTs before unaware episodes (1-4) in the hard condition[14] with a t-test. Vividness is similar to what certain papers refer to as "intensity of focus"[12], and those found that RTV was modulated by an interaction of relatedness and intensity (more RTV for more intense unrelated thoughts, less for more intense related ones). An ANOVA would tell us if we reproduced those results. Agency is a newly proposed probe, but we can expect it behaves

similarly to intentionality in Seli's paper: we think a mixed ANOVA will yield a similar interaction of difficulty and type (agency 1-4 vs 6-9) of unrelated thoughts. However we believe the means of these results differ in both experiments – as agency and intention don't refer to the same feeling. That can be verified with t-tests as our set-ups are almost identical. We should also control that vividness and agency are indeed independent by looking for a linear relationship between them.

***Figure 3**: Sustained-attention-to-response task (SART), adapted from Jha, et al.[46]. The probes inquire respectively: relatedness, vividness, agency and awareness. We need the first probe to compare our results to studies that only inquired about unrelated thoughts (restrictive definition of mind wandering).*



Probe 0: How were your thoughts related to the task?
Totally unrelated 1 2 3 4 5 6 7 8 9 Totally related

Probe 1: How vivid were your last thoughts?
Probe 2: How in control of you train of thought did you feel?
Probe 3: How aware were of your thoughts were you?

Aware 1 2 3 4 5 6 Unaware

Our main hypothesis is that agency and awareness are both positively correlated to awareness, because they respectively reflect the allocation of deliberate and automatic resources. And the more resources are involved, the more the feeling of awareness is going to grow. We expect that to be true, independently of relatedness (i.e. for both mind wandering and on task-thought), and we can explore all this with linear regressions.

Another hypothesis would be an interaction of difficulty and relatedness to predict vividness: the less the thoughts are related to the task, the more vivid they are going to be in the easy condition, and vice versa in the hard one. As you don't need resources to complete the easy task successfully, on task thoughts reflect an unfocused state – maybe similar to day dreaming or mind-blanking. On the other hand, on tasks thoughts in the hard condition would reflect a focus on the task, and consequently more vividness. The same parameters could also predict agency and awareness in linear regressions. Consequently, (less) awareness and (more) relatedness could predict (greater) RTV in the easy condition, and the opposite in the hard one.

3.3 Perspectives

We could test the relationship between different components defining our train of thought, without a restrictive definition that can make us loose some effects. Here we investigate thought generally, but could still compare our data to previous results by binning it into several categories. We hope this can test the proposed distinction of thought components, and validate this methodology, allowing more reproducibility.

A way to account for greater RTV in mind-wandering has been the perceptual decoupling. But one can go farther by looking at working memory and consciousness models. Research on executive functions tells us that the only way we can do two things at the same time (here the task and mind wandering), is to switch between those things[47]. As little resources are needed in those tasks, one can think of something else and switch without "loosing" its train of thought. But the difference might be, do you switch when a stimulus appears (low RTV), or when you "finish" your thought? Recent research (notably on retro-perception[42,48–50]) has shown us that the conscious access to an external stimulus' representation isn't necessarily time-locked to the stimulus apparition, but that the process is rather flexible. We can explain the results this way: if we dedicate more attentional resources to our inner processes, we won't be more variable in our response time, and maybe accuracy.

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