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Task-unrelated thought depends on the phonological short-term memory system more than the visual short-term memory system

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ABSTRACT

This study examined which type of short-term memory (STM), phonological or visual, is involved in and more important for representing contents of task-unrelated thoughts (TUTs). Three experiments consistently showed that TUTs were less likely to be reported during phonological STM tasks than either visual STM or control tasks. In contrast, the number of TUT responses did not considerably differ between visual STM tasks and control tasks even for TUTs with many visual images. This difference cannot be explained by the differential involvement of executive control processes because task difficulty was controlled for in the multi-level logistic regression analysis. These results, together with the finding that most TUT responses contained verbal images, suggest that phonological STM plays an important role in representing verbal images in TUTs, while visual STM is less or not involved in representing TUTs, even for those with many visual images.

1. Introduction

When engaged in some activity, our minds often drift away from the current task and become filled with task-unrelated thoughts (TUTs), often consisting of verbal and/or visual images of certain experiences (Delamillieure et al., 2010; Heavey & Hurlburt, 2008; Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011). This phenomenon is termed mind wandering, and many studies have examined the characteristics of this phenomenon (Smallwood, 2013; Smallwood & Schooler, 2006). Regarding the underlying mechanisms of mind wandering, the role of executive control processes has been emphasized (Teasdale et al., 1995). In the executive failure hypothesis (McVay & Kane, 2009, 2010), executive control processes are assumed to prevent mind wandering during tasks by proactively maintaining attention to the task and reactively suppressing TUTs that are activated by certain cues. Accordingly, it is inferred that mind wandering occurs because of a failure of such control processes. On the other hand, the decoupling hypothesis (Smallwood & Schooler, 2006) assumes that executive control processes support the persistence of TUTs and that mind wandering occurs when executive control unintentionally shifts away from the ongoing task to internal thoughts. These two hypotheses differ regarding whether executive control is concerned with the persistence of TUTs; however, they share the same view that executive control is important for preventing mind wandering.

While the mechanisms for both preventing and persisting mind wandering have been intensely studied (e.g., Levinson, Smallwood, & Davidson, 2012; McVay & Kane, 2012), the system for representing (i.e., producing and holding) the contents of TUTs as verbal and/or visual images has been less researched. A candidate for the system of representing verbal images in TUTs would be phonological short-term memory (STM). In Baddeley's model of working memory (Baddeley, 1986, 2007), the phonological STM system (phonological loop) is assumed to compose two subcomponents: a phonological store that maintains phonological information for several seconds and a subvocal rehearsal system that serves the function of refreshing stored phonological information by producing an inner voice. Thus, phonological STM enables us to perform inner speech that is manifested in TUTs (Alderson-Day & Fernyhough, 2015). Similarly, visual STM (the visuospatial sketchpad) is assumed to have the function of holding onto the visual quality of vivid images (Baddeley & Andrade, 2000). It is therefore likely that visual STM is responsible for representing the visual aspect of internal thoughts during mind wandering. These views are consistent with prior findings that the brain areas related to each of the phonological and visual STM systems are active during deliberate thinking about verbal and visual materials, respectively (Albers, Kok, Toni, Dijkerman, & de Lange, 2013; Amit, Hoeflin, Hamzah, & Fedorenko, 2017; Shergill et al., 2001).

However, there is reason to suspect that TUTs might have no relationship with these STM systems, even if they comprise many verbal and/or visual images. Functional brain imaging studies have shown that mind wandering is associated with a brain network termed the default-mode network (DMN; Christoff, Gordon, Smallwood, Smith, &

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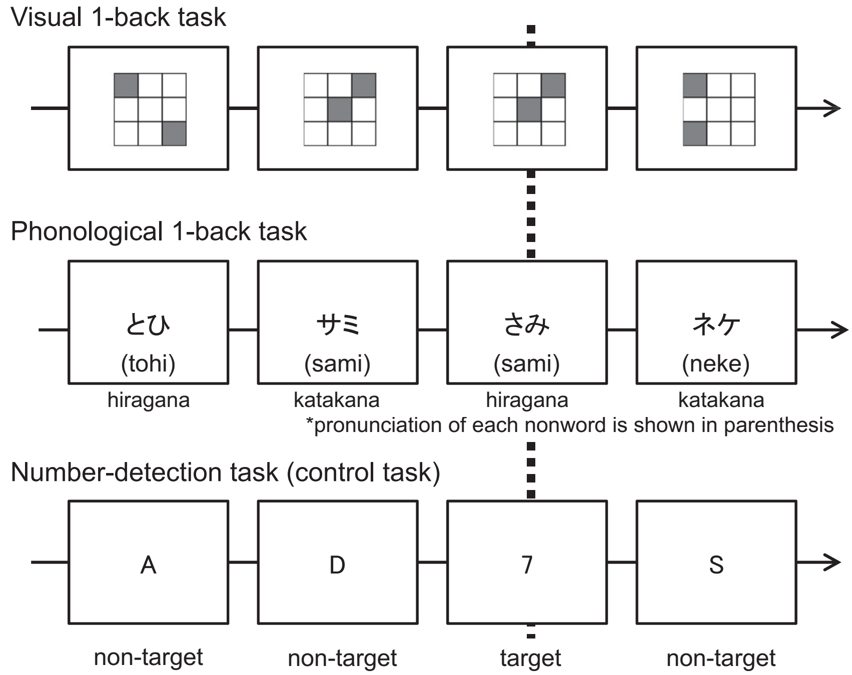

Fig. 1. Schematic illustrations of the tasks used in Experiments 1, 2, and 3.

Schooler, 2009; Hasenkamp, Wilson-Mendenhall, Duncan, & Barsalou, 2012; Mason et al., 2007). This system mainly comprises the medial prefrontal cortex, posterior cingulate cortex/precuneus, and inferior parietal regions (Buckner, Andrews-Hanna, & Schacter, 2008; Buckner & Carroll, 2007; Raichle & Snyder, 2007). The DMN typically shows decreased activity during attention-demanding tasks, whereas the lateral frontal and parietal cortical regions (the task-positive network) show increased activity during such tasks (Fox et al., 2005). Performing STM tasks typically requires attention to memory items, and functional brain imaging studies have shown increased activity in the task-positive regions during both phonological and visual STM tasks (Majerus et al., 2012; Majerus et al., 2010). Hence, there is the possibility that the STM system is specialized in deliberately producing and holding internal images and that verbal and visual images in TUTs are represented by another system that is specific to mind wandering (Alderson-Day & Fernyhough, 2015; Perrone-Bertolotti, Rapin, Lachaux, Baciu, & Loevenbruck, 2014). Therefore, the relationship between TUTs and the phonological and/or visual STM systems remains unclear and requires empirical examination.

In a prior study, to show the involvement of STM systems in representing TUT images, Teasdale et al. (1995) examined the effect of interventions on TUTs through tasks that demand the function of phonological STM (Experiment 1) and visual STM (Experiment 2). The number of TUT reports, which were intermittently sampled during the tasks, was compared with that in the control condition, in which no task was administered. The results showed that the number of TUT reports decreased during both types of STM tasks. This finding suggests that the representation of TUT images depends on the function of both types of STM systems and that TUTs are less likely to occur in such experiments because these systems do not fully represent TUTs owing to the task demands. However, their results can also be interpreted on the basis of the involvement of executive control processes, as the STM conditions likely required executive control to a greater extent than the control condition. The functioning of executive control processes during STM tasks suppresses the occurrence of mind wandering (McVay & Kane, 2009, 2010) or deprives the cognitive resources necessary for the persistence of TUTs (Smallwood & Schooler, 2006). Accordingly, the number of TUT reports would decrease during STM tasks. Indeed, in Experiments 3 and 4 in their study, Teasdale et al. (1995) found that the effect of task interventions on TUTs was reduced by prior practice with the intervening task, and the occurrence of TUTs was impeded by performing tasks that required executive control processes. These results suggest that the production of TUTs depends on executive control processes, although the authors did not deny the possibility of the involvement of STM systems in TUTs.

As just described, because STM tasks are performed more or less with the help of executive control processes, it is difficult to determine whether an STM system is involved in representing TUT images by solely examining the decrease in TUT reports during a task that places demand on that system. The present study approached this question in a somewhat roundabout way. Specifically, the purpose of this study was to elucidate the type of STM system that is involved in and more important for representing TUTs. For this purpose, in Experiment 1, the decrease in the number of TUT reports was compared between phonological and visual STM tasks with equivalent task difficulty. Task difficulty mostly corresponds to the degree of executive control involvement (McVay & Kane, 2010; Smallwood & Schooler, 2006). Thus, if the number of TUT reports is fewer during one type of task than the other, the STM system responsible for performing that task is likely involved in representing TUT images. This is because the difference cannot be explained by variations in the degree of involvement of executive control processes. Furthermore, in Experiments 2 and 3, the degree to which TUTs contained each of the verbal and visual images was also measured. The above discussion is based on the assumption that there is only one type of TUT that comprises both verbal and visual images of some experiences. However, if TUTs have some variation with regard to the degree to which they contain verbal and visual images, the difference in the number of TUT reports between the STM tasks might be attributable to the type of TUT that occurs most frequently. Specifically, if the number of TUT reports decreases to a greater extent during the phonological STM task than during the visual STM task, this result might be explained by the fact that most TUTs comprise verbal images and that they contain only a few visual images. This relationship between the modality of internal images contained in TUTs and the effect of STM load is examined in Experiments 2 and 3.

In the present study, to this end, visual 1-back, phonological 1-back, and number-detection tasks were used for visual STM, phonological STM, and control tasks, respectively (see Fig. 1). For the visual 1-back