Do we need two separate mechanisms to describe executive failures vs. more adaptive mind-wandering?

(Bachelorproject)

Roald Baas, s1879642, s.h.baas@student.rug.nl,
Marieke van Vugt, m.k.van.vugt@rug.nl*

October 10, 2015

Abstract

Having task-unrelated thoughts is called mind-wandering. Mind-wandering can have both positive and negative effects during certain tasks. We will look at two types of mind-wandering, each corresponding to the negative and positive effects: adaptive mind-wandering (for instance planning the future during a task) and executive failures (failure to attend to a task). Two experiments were set up to examine the differences between these two types of mind-wandering: a Working Memory (WM) task and a Choice Reaction Time (CRT) task. In the CRT task no constant attention was required while in the WM task continuous attention was required in order to minimize errors. Results showed that in the WM task participants reported to be on-task significantly more often than in the CRT task. Two ACT-R models were constructed to examine the differences between executive failures and adaptive mind-wandering, one for each of these tasks.

1 Introduction

People get distracted every day. An often occurring distraction is one through task-unrelated thoughts. This is called mind-wandering. It is something everyone experiences, sometimes without even being aware of it. For example, one is able to plan what they will have for dinner while on the bus. Previous research has shown that about half our time while awake is spent mind-wandering (Killingsworth and Gilbert, 2010). It is suggested that mind-wandering is more frequent in tasks that can be automated, and that mind-wandering has negative effects on nonautomated tasks (Smallwood and Schooler, 2006).

There are different ways to measure mind-wandering, for example by measuring pupil diameter (Smallwood, Brown, Tipper, Giesbrecht, Franklin, Mrazek, Carlson, and Schooler, 2011a), analyzing response time variability (Bastian and Sackur, 2013), or using fMRI scans (see for example (Christoff, Gordon, Smallwood, Smith, and Schooler, 2009)). A more straightforward way of measuring mind-wandering is by using thought probes, which is asking participants whether they were on-task or off-task (Cheyne, Carriere, and Smilek, 2009). The downside to this method however is that it is subjective and may be less accurate than objective measurements.

There are several possible explanations as to why mind-wandering occurs. In this paper we will limit ourselves to two kinds. An executive failure could arise from mind-wandering. An executive failure is a failure to focus one's attention on relevant information (McVay and Kane, 2010). A different explanation is that mind-wandering occurs through more adaptive mind-wandering from the environment (for example thoughts about the future; see (Smallwood, Nind, and OConnor, 2009)).

Mind-wandering can affect the performance of certain tasks both negatively and positively. For instance, research has suggested that mind-wandering has significant negative effects on performance (for a review, see (Mooneyham and Schooler,

*University of Groningen, Department of Artificial Intelligence

2013)). Mind-wandering can have a positive effect during tasks that do not require constant attention in the form of an improvement in for example creativity or problem-solving (Baird, Smallwood, Mrazek, Kam, Franklin, and Schooler, 2012). During mind-wandering, future thoughts are the most common (Smallwood et al., 2009). Planning future events during adaptive mind-wandering has been shown to be of use in day-to-day life (Baird, Smallwood, and Schooler, 2011). Future thoughts about oneself may be linked to being able to mentally simulate future events (Smallwood, Schooler, Turk, Cunningham, Burns, and Macrae, 2011b). In short, the negative effects of mind-wandering are caused by executive failures, while adaptive mind-wandering can have positive effects.

Previous research has shown a difference in future thoughts between two tasks: the Choice Reaction Time (CRT) task and the Working Memory (WM) task (Smallwood et al., 2009). In both tasks participants are presented with a series of numbers. In the CRT task participants wait for a target number (coloured green) to appear, at which point they have to answer whether that number is odd or even. In the meantime, there is no need for constant attention because once a green number appears it is automatically detected and participants will be able to return to the task. In the WM task, when a target (red question mark) appears, participants have to determine whether the number that appeared before the target was odd or even. This means that in this task recent stimuli need to be remembered to be able to correctly perform the task. This means that in the CRT task, there is room for adaptive mind-wandering. In the WM task however, mind-wandering is necessarily caused by executive failures, because in this task it is not adaptive to let your mind wander due to the risk of missing stimuli needed to perform well. The experiment by Smallwood et al. showed that more time was spent thinking about the future in the CRT task than in the WM task. Therefore, we predict that people tend to pay more attention in the WM task than in the CRT task.

An ACT-R 6.0 (Anderson, 2007) model of mind-wandering in the Sustained Attention to Response Task (SART) (Peebles and Bothell, 2004) was developed by van Vugt. In this task, participants were presented with a constant stream of digits, and had to press a button as fast as possible every time a target appeared, except for when a rare non-target appeared. The model made use of a "distracted" and an "attentive" model, where the two would compete with each other, thus being able to alternate between attentive and distracted (mind-wandering) (van Vugt, Taatgen, Sackur, Bastian, Borst, and Mehlhorn, 2015). The model showed that both task performance and responses to thought probes could be predicted.

By modifying the ACT-R model of mind-wandering by van Vugt to include the CRT and WM tasks, we can examine the two types of distraction described earlier: executive failures and more adaptive mind-wandering. By comparing the model with collected data, we can try to find and answer to the question on whether or not we need two separate mechanisms to describe executive failures vs. more adaptive mind-wandering. Based on earlier research suggesting a higher degree of mind-wandering in less intensive tasks (such as the CRT task) and that mind-wandering has little to no negative side-effects during adaptive mind-wandering, we believe there to be a difference between adaptive mind-wandering and the executive failures that can occur in more intensive tasks.

Thought probe
1. Were you thinking about the task or something else? 2. How much were you thinking about other people? 3. How much were you thinking about the past? 4. How positive were your thoughts? 5. How aware were you of whether you were on task?
Answer
1. -50: Not at all about task +50: Excusively about task 2. -50: Exclusively about others +50: Exclusively about self 3. -50: Exclusively about the past +50: Exclusively about the future 4. -50: Purely negative +50: Purely positive 5. -50: Not at all aware +50: Completely aware

Table 1: The thought probes presented to the participants in order. The questions are answered using a scale system ranging from -50 to +50. Both the thought probe questions and explanations of what the numbers on the scale mean were presented to the participants.

2 Methods

2.1 The experiment

Twenty four participants agreed to partake in the experiment, and received monetary compensation for their time. Twenty three of the participants succesfully completed the experiment.

The experiment is based on the experiment by Smallwood (Smallwood et al., 2009). The experiment consists of two tasks: the CRT task and the WM task. In both the CRT and WM task there are six blocks of twenty trials for a total of twelve blocks. Each trial is made up of a series of two to five random numbers ranging from one to nine, followed by either a target or a thought probe. The non-target numbers appear in black for 1000ms. The stimuli were seperated by a fixation cross presented on screen for a randomized duration of 900 to 2100ms. Each block of twenty trials contains sixteen targets and four thought probes. Participants alternated between the two tasks, where the order of the tasks was determined by their subject number (odd numbers performed the experiment in reverse order). Participants were familiarized with the experiment by doing eight practice trials.

In the CRT task, the target is a green number ranging from one to nine. When the target appears, participants were asked to indicate if this number is odd or even by pressing "o" or "e" on the keyboard respectively. In the WM task, the target is a red question mark. When this target appears, a decision has to be made about whether the number that appeared before the question mark was odd or even.

Both the CRT and WM task contain thought probes, which take the form of a series of five questions. Participants were asked to answer these questions using the mouse via a scale system ranging from -50 to +50. On the scale system, text explaining how much these numbers mean appeared at both ends of the scale. The questions and the explanations of the numbers ranging from -50 to +50 are depicted in table 1. The thought probes were designed to not only serve as an indication for mind-wandering, but also to give more insight on the contents of task-unrelated thoughts and to be able to compare our results to those of Smallwood.

2.2 The Model

The ACT-R model of the SART task constructed by van Vugt starts by retrieving the "paying attention" goal. This goal then gradually decays until the "distraction" goal becomes stronger, at which point the mind-wandering model begins (van Vugt et al., 2015). Distraction in the models is done using a thought pump, where subsequent memories are retrieved. If a remembered item is the attention object, the model returns to paying attention with a certain probability. See also figure 1. While the model is paying attention, the current goal is constantly retrieved. On a scene change a stimulus can be attended to.

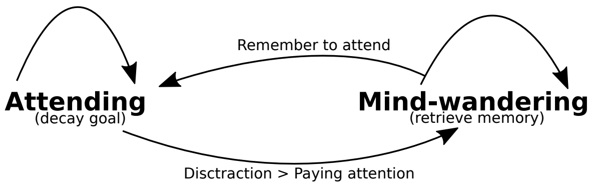

Figure 1: The model starts by paying attention (left). This goal decays over time, and when the goal to become distracted is stronger than the attending goal, the process of mind-wandering starts (right), which is simulated by the model continuously retrieving memories. At some point in this process the model will retrieve the memory which says to pay attention, at which point the model goes back to attending and entire process starts over.

In the SART model by van Vugt, the model has to press a key every time a target appears, except for when an infrequent non-target number "3" appears. When the model is distracted, a default response is given (which means the model presses the key). This means that when the model is distracted, errors occur. The SART model doesn't make a distinction between executive failures and adaptive mind-wandering, since there is no room for adaptive mind-wandering in this task. To make this distinction, we modify the model to perform the CRT and WM tasks, where adaptive mind-wandering is possible in the CRT task, and executive failures have an effect on the performance in the WM task. In the CRT task, we should not notice negative effects on performance when the model is engaged in mind-wandering, meaning that there is a possibility for adaptive mind-wandering during this task.

In the WM task, a negative effect on performance should occur when the model is mind-wandering, which take the form of an increase in the amount of errors (which are executive failures).

In both the CRT and WM task the model starts by paying attention to the screen. When a stimulus appears it is processed and a response is given (or no response when the stimulus is a non-target). Responses to thought probes are in the form of stating whether the model was on-task or off-task. A target (either a green number or a red questionmark) will cause the model to pay attention again if it is currently mind-wandering.

In the CRT task the target is a green number. When this target appears, the model will decide whether it is odd or even by retrieving the current number's corresponding chunk (which states if it is odd or even) from declarative memory, and then respond by pressing "o" or "e" respectively. Mind-wandering in the CRT should not affect accuracy much, as the model is always able to decide the correct answer. Mind-wandering could however, affect the reaction times, since re-focusing when a green target appears takes some time.

In the WM task the model has to be able to remember the number before the target red questionmark. While the model is attending, each latest black number is stored in the imaginal buffer used by ACT-R to store task relevant information. Upon seeing a red questionmark, the model is able to retrieve the last number and respond if it has been attending. While the model is distracted, the current black numbers are not stored in the imaginal buffer. Therefore, a default response is given when presented with a red questionmark when the model has been mind-wandering.

3 Results

3.1 The experiment

We first looked at whether the task performance differed between the CRT and WM tasks. Previous research has shown that performance was significantly worse under load (Smallwood et al., 2009).

The results from the experiments showed that participants did not have any problems correctly assessing whether the targets were odd or even in both the CRT and WM task (see figure 2). A paired t-test showed that there was no significant difference in accuracy between the CRT and WM tasks ($t(22) = 0.99667$, $p > 0.05$).

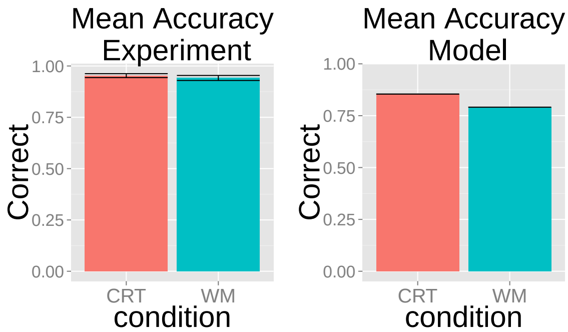

Figure 2: The mean accuracy over all participants for the CRT task (red) and the WM task (blue) for the experiment (left) and the model (right), with error bars showing the standard error.

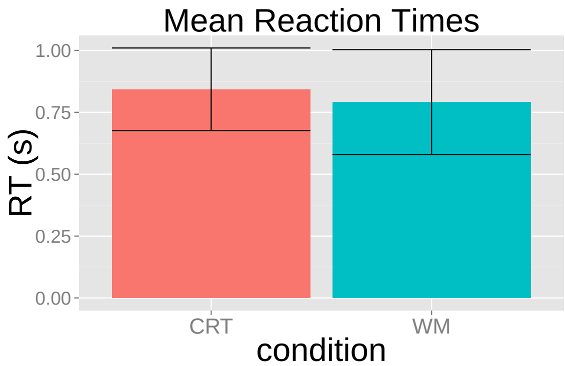

Figure 3: The mean reaction time over all participants for the CRT task (red) and the WM task (blue), with error bars showing the standard error.

Figure 3 shows that the mean reaction time for both tasks was just under one second, where the mean reaction time for the CRT task was higher than that of the WM task. This difference was not significant ($t(22) = 1.4464$, $p > 0.05$).

Figure 4 shows the mean ratings of the thought probes over all participants for both tasks. While ratings for each question can range from -50 to +50, the participants' mean valuations to the thought probes were positive. Paired t-tests were conducted for each of the thought probe questions between CRT and WM. A significant difference between the two tasks was observed in how much participants reported to be on-task ($t(22) = -2.8936$, $p < 0.05$), and how aware they were of being on or off-task ($t(22) = -2.4044$, $p < 0.05$). Participants were on-task more often in the WM task than in the CRT task, and they were more aware of being on or off-task in the WM task. No significant differences between CRT and WM were observed for the other thought probe questions.

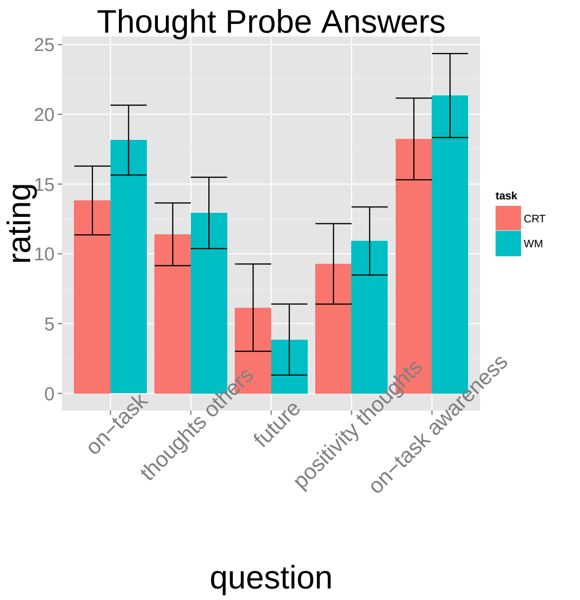

Figure 4: The mean valuation of the thought probes over all participants for the CRT task (red) and the WM task (blue). The answers given by participants can range from a value of -50 to +50.

3.2 The model

The results from the current model show a mean accuracy that is lower than the actual experiment. Figure 2 shows that the difference in accuracy for CRT and WM is greater in the model data than in the empirical data. The accuracy in the CRT task is higher than that of the WM task in both the experiment and the models.

The response time coefficient of variation (RTCV) can be used to look at distraction. When a person is engaged in mind-wandering, an increase in the RTCV should be observed (Bastian and Sackur, 2013).

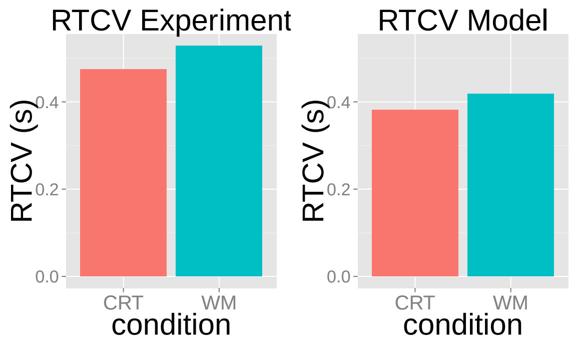

Figure 5: The reaction time coefficient of variation for the CRT model (red) and the WM model (blue) for the empirical data (left) and the model (right).

Figure 5 shows the reaction time coefficient of variation for both the empirical data and for the model data. The RTCV for the WM task was higher than that of the CRT task in both the experimental data and the model data. Overall, the RTCV was slightly lower in the model data.

4 Discussion

This paper sought to examine the difference between adaptive mind-wandering and executive failures in the Choice Reaction Time task and the Working Memory task proposed by Smallwood et al. Using the explicit mind-wandering model of the Sustained Attention to Response task by van Vugt as a base, we proposed a model for the CRT task, and a model for the WM task.

We hypothesised that there is a difference between the degree of mind-wandering that occurs in the CRT and WM tasks, where we believed there to be less room for mind-wandering in the more intensive WM task.

In the empirical data we observed that participants showed a stronger tendency for mind-wandering during the CRT task. Participants reported being off-task more often in the CRT task, which is consistent with our prediction. Previous research by Smallwood et al. suggested that future thoughts occur more often in the CRT task. Although we have found a significantly higher degree of mind-wandering in the CRT task, no evidence was found to support a significantly higher degree of future thoughts in this task compared to the WM task. The mean reaction time in the CRT task was higher than that of the WM task, where there is less room for mind-wandering. This difference however was not significant. The RTCV of the WM task was higher than that of the CRT task. A higher RTCV should predict mind-wandering, meaning that this conflicts with our earlier finding that there is a stronger tendency for mind-wandering in the CRT task. This difference in RTCV values could be caused by the two tasks being slightly different from each other, and thus may not be a reliable method of predicting mind-wandering in this case. For instance, in the CRT task if the target appears participants are able to respond correctly even if they were mind-wandering at the time. In the WM task, after having missed a target participants might think about what the target might have been, causing a much higher overall RTCV (which is then partly due to mind-wandering, and partly due to participants wanting to get it right). The RTCV values of the model data resembles the empirical data, albeit with slightly lower values. This means that the models are qualitatively consistent with the empirical data, although it is too early to make a definitive statement on whether the model is an accurate representation of reality.

The accuracy of the empirical data was very high for both the CRT and WM tasks. Participants reported being off-task more often in the CRT task. Participants were less aware of being on-task or not in the CRT task than in the WM task. This supports earlier claims that mind-wandering occurs more often in less intensive tasks. In the slightly harder WM task, participants were more focused on the task. The model's accuracy and reaction times were lower than that of the experiment. This means that while the developed models were able to perform the CRT and WM task, they currently are too fast compared to our gathered data. The current model does not handle thought probes as it should, and since we have not changed the values of the model in the Sustained Attention to Response task as was modelled originally by van Vugt, future research could potentially improve our models to the point of being a good representation of reality by tweaking values to increase for instance reaction times so that they are closer to the reaction times of our empirical data.

In short, while the models show promise in finding out whether two seperate mechanisms are required to describe adaptive mind-wandering and executive failures, more work is needed to refine the models. The empirical data suggests that there is a difference in mind-wandering between our two tasks, one where adaptive mind-wandering is possible (CRT) and one where executive failures harm performance (WM). The data from the models resembles reality in the way that there is a difference between the two tasks, but the values are currently lower than that of the reality. Improving upon our models in future research by adapting the way distraction works should bring us closer to the empirical data.

5 Acknowledgments

Marieke van Vugt developed the ACT-R model, which was modified by Roald Baas & Joram Koiter to perform the CRT and WM tasks. The experiment was constructed in Psychopy (Peirce (2007)), using code provided by van Vugt as a base. The experiment was performed by Roald Baas & Joram Koiter at the University of Groningen.

References

John R Anderson. *How can the human mind occur in the physical universe?* Oxford University Press, 2007.

Benjamin Baird, Jonathan Smallwood, and Jonathan W Schooler. Back to the future: autobiographical planning and the functionality of mind-wandering. *Consciousness and cognition*, 20(4):1604–1611, 2011.

Benjamin Baird, Jonathan Smallwood, Michael D Mrazek, Julia WY Kam, Michael S Franklin, and Jonathan W Schooler. Inspired by distraction mind wandering facilitates creative incubation. *Psychological Science*, page 0956797612446024, 2012.

Mikaël Bastian and Jérôme Sackur. Mind wandering at the fingertips: automatic parsing of subjective states based on response time variability. *Frontiers in psychology*, 4, 2013.

James Allan Cheyne, Jonathan SA Carriere, and Daniel Smilek. Absent minds and absent agents: Attention-lapse induced alienation of agency. *Consciousness and cognition*, 18(2):481–493, 2009.

Kalina Christoff, Alan M Gordon, Jonathan Smallwood, Rachelle Smith, and Jonathan W Schooler. Experience sampling during fmri reveals default network and executive system contributions to mind wandering. *Proceedings of the National Academy of Sciences*, 106(21):8719–8724, 2009.

Matthew A Killingsworth and Daniel T Gilbert. A wandering mind is an unhappy mind. *Science*, 330(6006):932–932, 2010.

Jennifer C McVay and Michael J Kane. Does mind wandering reflect executive function or executive failure? comment on smallwood and schooler (2006) and watkins (2008). 2010.

Benjamin W Mooneyham and Jonathan W Schooler. The costs and benefits of mind-wandering: a review. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, 67(1):11, 2013.

David Peebles and Daniel Bothell. Modelling performance in the sustained attention to response task. In *ICCM*, pages 231–236, 2004.

Jonathan W Peirce. Psychopypsychophysics software in python. *Journal of neuroscience methods*, 162(1):8–13, 2007.

Jonathan Smallwood and Jonathan W Schooler. The restless mind. *Psychological bulletin*, 132(6): 946, 2006.

Jonathan Smallwood, Louise Nind, and Rory C OConnor. When is your head at? an exploration of the factors associated with the temporal focus of the wandering mind. *Consciousness and cognition*, 18(1):118–125, 2009.

Jonathan Smallwood, Kevin S Brown, Christine Tipper, Barry Giesbrecht, Michael S Franklin, Michael D Mrazek, Jean M Carlson, and Jonathan W Schooler. Pupillometric evidence for the decoupling of attention from perceptual input during offline thought. *PloS one*, 6(3): e18298, 2011a.

Jonathan Smallwood, Jonathan W Schooler, David J Turk, Sheila J Cunningham, Phebe Burns, and C Neil Macrae. Self-reflection and the temporal focus of the wandering mind. *Consciousness and Cognition*, 20(4):1120–1126, 2011b.

Marieke K van Vugt, Niels A Taatgen, Jérôme Sackur, Mikaël Bastian, Jelmer Borst, and Katja Mehlhorn. Modeling mind-wandering: a tool to better understand distraction. 2015.