Original Article

A New Protocol to Study Mind-Wandering for Air Traffic Controllers

A Pilot Study

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Abstract: Although mind-wandering decreases processing of external information, it remains understudied in air traffic controllers (ATCOs), who must constantly attend to external information. Using autobiographical memory retrieval, we propose an innovative protocol to mimic the moment when ATCOs start mind-wandering. A total of 16 participants performed an ATCO simulation task while we triggered attentional switches toward their inner world using memory probes and recorded eye movements with eye-tracking glasses and a camcorder. We successfully induced one to five spontaneous memories for half of the participants and showed the impact on response times (*Mdn* = +0.74 s) to clear flight level. Preliminary results suggest that autobiographical memory could be used to identify a temporal ocular marker – particularly gaze aversion, also positively related to self-reported mind-wandering – to detect the attentional switch.

Keywords: mind-wandering, eye movements, gaze aversion, involuntary memories, air traffic controllers

The current taxonomy of attention (Chun et al., 2011) refers to a distinction between external and internal attention. External attention is directed toward the perceptual world while internal attention is directed to the inner world (i.e., thoughts, memories, etc.). Historically, external attention has received more interest since it is easier to measure and study in the laboratory. In the past decade, however, internal attention became a hot topic as it was found that attention is inherently biased toward internal thoughts (Verschooren & Egner, 2023), which occupy people's minds for about 50% of their daily life (Killingsworth & Gilbert, 2010). *Mind-wandering*, such as daydreaming and zoning-out periods, is the general term broadly used to refer to these internal thoughts (Smallwood & Schooler, 2006).

Since attentional resources are limited, attention switches from the external environment to the internal world multiple times a day. While the attention is focused on the internal world, perceptual decoupling takes place (Schooler et al., 2011), that is, a minimization of external information processing, causing attentional blindness to external information. Useful for managing attentional resources, this is a menace to safety in operational tasks where attention must remain directed to the external world (Gouraud et al., 2018a). Indeed, mind-wandering alters the performance in various tasks (Kam et al., 2012) including safety-sensitive operational systems such as driving a car (Albert et al., 2018; Galéra et al., 2012; Geden et al., 2018; He et al., 2011; Lemercier et al., 2014; Yanko & Spalek, 2014). For example, on the road, the driver's mind-wandering causes a narrowing of the visual attentional focus (He et al., 2011) and is associated with potentially risky behaviors (Albert et al., 2018) such as higher speed, slower reaction times to sudden events, smaller distance with other vehicles (Yanko & Spalek, 2014), and fewer micro-adjustments to speed and trajectory deviations (Lemercier et al., 2014). As a result, mind-wandering increases by 2.12-fold the risk of being responsible for a road accident (Galéra et al., 2012).

Much less is known about the influence of mind-wandering among professionals working in aeronautics. Yet, attentional lapses are reported as the main cause of errors committed by air traffic controllers (ATCOs), when they lead to an incident (Pape & Wiegmann, 2001). Even though the type of these attentional lapses is not specified, mind-wandering should be considered seriously since it is generally classified as one of the *hazardous states of awareness* by NASA (cf. Dickinson et al., 2001) and is part

https://doi.org/10.1027/2192-0923/a000253

of the list of *degraded attentional states* (e.g., Migliorini et al., 2022). A recent survey suggests that mind-wandering is the most prevalent degraded mental state self-reported by ATCOs (Migliorini et al., 2022). Nevertheless, ATCOs estimate that it has a negligible impact on perceived safety (Migliorini et al., 2022). This is surprising given that perceptual decoupling lasts a relatively long time – up to several seconds in the case of autobiographical memory retrieval (Servais, Préa, et al., 2022).

Yet, mind-wandering has been seldomly studied in ATCOs, most likely because it is a spontaneous mental state, therefore difficult to induce and study in the laboratory. Current evaluation methods of mind-wandering rely on self-reports (see Andrews-Hanna et al., 2018, for a general overview of existing methods, and see Casner & Schooler, 2015, and Gouraud et al., 2018b, for use examples in the field of aeronautics). Self-reported measures have inherent limitations in aeronautics since social desirability might prevent workers from reporting that their minds wandered and put the system at risk (Casner & Schooler, 2014).

Our main objective was therefore to design an innovative experimental protocol that triggers attentional switches toward internal thoughts in the laboratory. Because people spend 60% of mind-wandering episodes retrieving personal past events, that is, autobiographical memories, and because mind-wandering and autobiographical memory retrieval share many similarities and arise from similar neural substrates, some authors consider an overlap between them (Mildner & Tamir, 2019) and view mind-wandering as a by-product of episodic memory (Smallwood & Schooler, 2014). Autobiographical memory retrieval therefore seems appropriate for indirectly studying processes involved in mind-wandering and has the advantage of being inducible in the laboratory. As a second objective, we tried to identify a temporal marker of the switch to the internal world. We focused on eye movements, and more specifically on change in vergence (Huang et al., 2019), looking at nothing (Salvi & Bowden, 2016), and gaze aversions (Glenberg et al., 1998), that is, eye movements participating in perceptual decoupling. More specifically, change in vergence is generally characterized by an increased divergence during internal attention, which blurs visual information as a decoupling strategy (Huang et al., 2019) while normally, during external visual attention, ocular vergence supports accurate binocular vision by simultaneously moving the two eyes in opposite directions to allow for visual focus. Gaze aversion is assumed to act otherwise: It brings the gaze toward a neutral space away from environmental distractions (Glenberg et al., 1998; Salvi & Bowden, 2016). If those eye movements were observed during our task, it would be an argument in favor of using autobiographical memory to discover a physiological temporal marker of internal attention, useful for detecting mind-wandering in real-time during operational tasks. We particularly focus on gaze aversion because it most often occurs in situations requiring a significant cognitive effort (Glenberg et al., 1998) and it is supposed to be linked to the moment when the attentional switch toward the inner world takes place (Servais, Hurter, et al., 2023; Servais, Préa, et al., 2022).

Method

Participants

This pilot study was conducted with 16 healthy French-speaking participants (eight men) aged 21–29 years (M = 24.56 ± 2.68), with 14–19 years of education (corresponding to the numbers of years of education completed from the first year of primary school). As a first pilot study, there was no need to experiment with qualified ATCOs. We only recruited participants who did not wear glasses, to avoid interference with the eye-tracker. None had a history of oculomotor, psychiatric, or neurological disorder. Before their inclusion in the study, participants signed informed consent and image rights consent forms to allow video recordings. This feasibility study took place according to the measures of the research ethics committee number CPP2020-21/2020-A00348-31 issued by the French CPP SUD-EST II.

Stimuli, Task, and Apparatus

We built a protocol that mimics the moment when ATCOs start mind-wandering. To do so, we triggered attentional switches from the external to the internal world using autobiographical memory questions (e.g., "What did you do on your vacation?"). In an experimental condition, we asked autobiographical memory questions to participants while they were performing an air traffic control simulation task, more precisely acknowledging clearances. A limitation of answering those questions is that contrary to mind-wandering, this is not spontaneous. Moreover, in everyday life, memory retrieval is not always voluntary, memories can "pop up" in response to environmental cues (e.g., an aircraft's destination reminding one of the last holidays; Berntsen, 2010). In another experimental condition, we therefore presented cue phrases known to trigger spontaneous memories (Schlagman & Kvavilashvili, 2008). Eye movements were recorded with eye-tracking glasses and a camcorder. Participants were seated comfortably in front of a screen and wore Pupil Core eye-tracking glasses

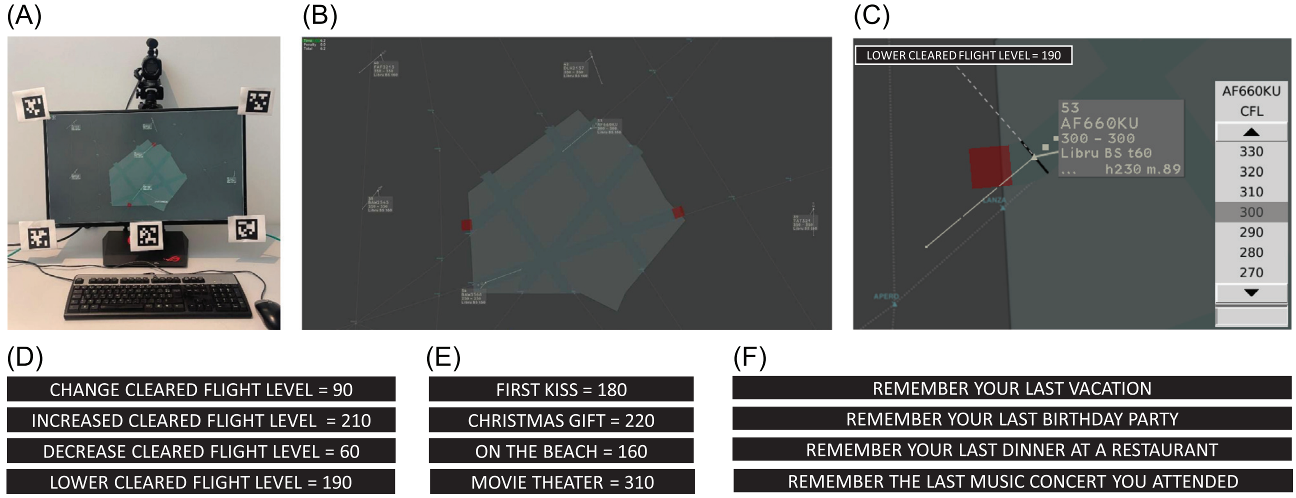

Figure 1. (A) Illustration of the experimental set-up; (B) illustration of the control sector with its five routes and two airplanes; (C) screenshot of an instruction to change cleared flight level (CFL) and the scrolling menu used to respond; (D) examples of messages to request a CFL modification; (E) examples of cue phrases used to trigger spontaneous memories; (F) examples of questions used to induce voluntary memories. Note that instructions have been translated from French to English for this figure.

(Pupil Labs, Berlin, Germany), which recorded binocular eye movements with a sampling frequency of 240 Hz. To guarantee the quality of the eye-tracking data throughout the session, we performed a 5-point calibration at the beginning of the experiment and regularly during inter-trials breaks (after five trials maximum, and less when necessary). The experiment took place in a windowless room. The experiment was presented on a 28″ screen with a resolution of 2,560 × 1,440. Visual fiducial markers (AprilTags by Olson, 2011) were placed on the screen's corners to enable surface detection (i.e., the screen surface). As ground truth, participants' faces were videotaped with a Sony FDR-AX33 Handycam. The camcorder was positioned so that the participant's face was centered in the image. Indirect light projectors ensured that their face was perfectly illuminated (no shadow zone; Figure 1A).

The task was created using the LABY microworld (Imbert et al., 2014). As a background, there was an image of a control sector containing five routes (Figure 1B). Airplanes were moving at a speed of 0.89 Mach. Constraint areas with a duration of 12 s were placed on aircraft trajectories such that participants were required to acknowledge clearances about the cleared flight level (CFL), that is, the altitude at standard air pressure at which the aircraft is currently cleared to (see Figure 1C, instruction and response). To trigger attentional switches to memories (imitating mind-wandering), memory cues were presented during the task (6 s each). Memory cues were inspired by 60 cue phrases chosen from a list known to trigger autobiographical memories (Schlagman & Kvavilashvili, 2008) that were translated into French. Two thirds of the cues (n = 20 per condition) were presented just before a CFL to measure the impact of memory retrieval on the performance for the following request (see section on Procedure for details).

Procedure

Participants were informed that they would act as an ATCO during the experiment and asked to do their best to complete the task without error. The main task consisted of solving the requests by choosing the proper CFL in the scrolling menu, which appeared after clicking on the label of the concerned aircraft (Figure 1C). Participants began by performing a 5-min training to ensure that the instructions were well understood and that they were familiar with the LABY microworld interface.

The task was composed of 20 trials (a trial was a 3–4-min scenario of traffic control). The task was divided into two parts corresponding to two experimental conditions differing by the way memories were induced (10 trials per condition): the condition of interest on the one hand, during which memory cues were cue phrases aimed at triggering *spontaneous memories*, and the control condition on the other hand, during which memory cues were presented as questions that participants were explicitly asked to answer to provoke *voluntary memories*. Each of the two conditions was itself divided into two sub-conditions (including five trials each) depending on the mental load: either *low mental load* when trials contained two airplanes, four CFL requests, and three memory cues; or *high mental load* when trials showed three airplanes, eight CFL requests, and three memory cues.

All participants started with the *spontaneous memories* condition to ensure that they remained naïve to the purpose of the study. Participants were told to solve CFL requests and to continue their task normally if some unrelated message (i.e., memory cue phrase) appeared. Memory cues appeared in the same format as CFL requests (Figures 1C, 1D, 1E). We used different synonyms for CFL instructions to avoid an immediate recognition of CFL instructions versus memory cues. The purpose was to prevent participants from filtering and ignoring memory cues since we needed them to read and process memory cue phrases. For the same reason, cue phrases were followed by the "=" sign and a number, which made it look similar to CFL requests. At the end of the 10 trials, participants completed a cue phrase recognition task: Among 40 phrases (of which 20 were the ones that appeared just before a CFL) randomly presented, participants pressed "y" if they saw it as a cue phrase during the task, and "n" if they did not. If they pressed yes, they were asked whether the cue phrase had triggered a memory or not. If it did, they reported their memory aloud to allow the experimenter to check whether the memory met the criteria for episodic autobiographical memory (Piolino, 2006).

Then, participants performed the *voluntary memories* control condition. Participants performed the same ATCO simulation task while they were explicitly asked to mentally retrieve memories related to questions (Figure 1F), which appeared in the same format as CFL requests for 6 s (two thirds of them just before a CFL request and the last third when no action was required to avoid anticipation of clearances by participants). To help participants identify autobiographical memories, the instructions mentioned criteria defined by Piolino (2006): Participants were asked to select a personal memory corresponding to a short (lasting less than 24 hr), and a unique event, associated with a specific spatiotemporal context. They were invited to retrieve the emotions, thoughts, and perceptions. In the end, participants reported the memories they retrieved for each question.

At the end of each condition, participants were asked to rate the frequency at which they experienced mind-wandering – described as task-unrelated thoughts – during the task (1 = *no intrusive thoughts at all*; 5 = *many intrusive thoughts*). Which cues were used for spontaneous and voluntary memories was counterbalanced between two groups. The total duration of the experiment was approximately 2 hr.

Measures and Analysis

The main goal of the present study was to test the efficacy of our protocol. We therefore calculated the proportion of memory cues that successfully triggered spontaneous or voluntary memories.

To estimate the impact of attentional switches on the performance, we compared the success rate and response time median between CFL instructions that were preceded by a memory cue (cue phrases or question) and those that were not, for spontaneous and voluntary memories separately. For instructions preceded by a memory cue, we considered only those for which participants reported memories. Given the well-known impact of the mental load on performance and eye movements, analyses were performed for trials with high and low mental load separately.

Pupil Player (Version 3.5.1) was used to detect fixations and blinks and to detect the position of the screen surface in the world video. To guarantee data quality, only gaze points with a confidence higher than 80% were kept for analyses. Participants with a large number of data below that confidence threshold were excluded from eye movement analyses.

To compare eye movements between periods with and without memories, we focused on *periods of interest* defined as the 5 s following the appearance of a CFL request. First, we considered changes in vergence angle – often associated with internal attention (Huang et al., 2019). Vergence angle was estimated by calculating the angle between the two vectors going from the estimated 3D position of the gaze to the position of, respectively, the left or the right pupil in world coordinates. Second, we considered the dwell time out of the control sector, that is, the area of interest (AOI) where participants were supposed to maintain their visual scan path to complete the task efficiently. We hypothesized that periods with memories may be linked with a higher dwell time outside of the sector since gaze aversion (Servais, Préa, et al., 2022) or looking at nothing (Salvi & Bowden, 2016) are commonly observed behaviors in situations requiring internal attention. Looking away from areas rich in visual information (here the sector) is assumed to help in retrieving memories. Because gaze aversion is difficult to measure with eye-tracking data, the video was used as ground truth. When the gaze left the sector during a period of interest, an evaluator looked at the video and decided whether there was gaze aversion or not. From previous pilot studies, judgments from different evaluators generally have a high concordance (e.g., Servais, Poveda et al., 2023). To compare dwell time out of sector and vergence angle between CFL requests preceded by memories and those that were not, we ran a Wilcoxon signed-rank test, when sample size allowed it. Bonferroni correction was applied to correct the α value for the number of comparisons (α = .025). Point-biserial correlation coefficient was reported as size effect.

Finally, we were interested in the relations between memories induced by the memory cues from the protocol

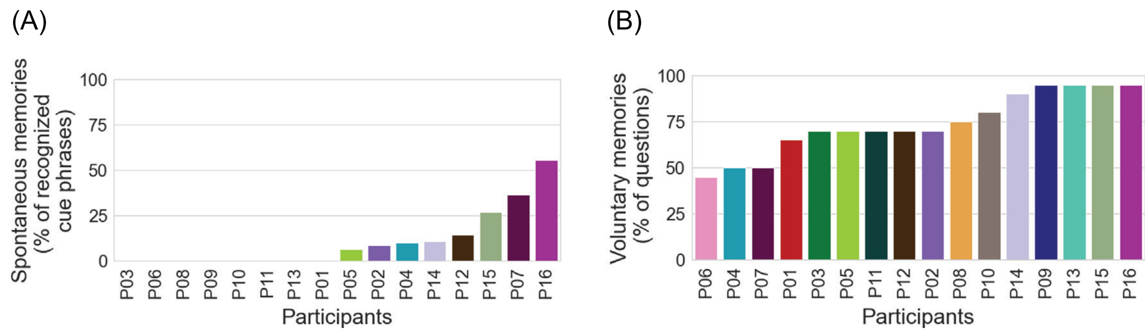

Figure 2. (A) Percentage of voluntary memories per participant in response to questions followed by cleared flight level (n = 20). (B) Percentage of spontaneous memories per participant in response to cue phrases. The percentages were calculated for every participant on the number of cue phrases they recognized. Each participant is associated with a specific color for all the figures so that it is possible to follow individual performance. Pxx = anonymized code assigned to the participant.

and self-reported mind-wandering. The sample size was too small and did not provide enough statistical power to calculate correlations. Tendencies were therefore analyzed visually on regression lines and scatter plots.

Results

Induction of Attentional Switches by the Protocol

The cue phrase recognition task showed an average recall rate (i.e., the percentage of hits) of .59 ± .17 while the specificity (i.e., the percentage of correct rejections) was always between .80 and 1 (M = 0.94 ± 0.09). Results revealed that eight of the 16 participants (i.e., 50%) experienced spontaneous memories in response to cue phrases (between 1 and 5 memories, M = 1.25 ± 1.69) of which 40% were autobiographical. To ensure that we calculated the percentage of memories based on cue phrases that had been actually processed, we considered only the phrases that were correctly recognized. Participants experienced spontaneous memories for 6.25–55.56% of the cue phrases they had actually processed during the task. In response to memory questions, all participants reported voluntary memories (between 9 and 19, M = 14.81 ± 3.35) of which 82.97% were autobiographical. See Figure 2 for individual results.

Impact of Attentional Switches on the Performance

Low Mental Load

There was a ceiling effect of the success rate at 100% for both conditions. The sample size was too small to run a statistical comparison for the cue phrases condition, but it seems that the presence of spontaneous memories did not impact response times under low mental load (see Figure 3). Retrieving voluntary memories did not impact significantly on response times according to the Wilcoxon signed-rank test, T = 46, p = .274, r_{pb} = −.32.

High Mental Load

In the spontaneous memories condition, the CFL success rate was on average 87.04% ± 17.62 when no memory cue was presented, but unexpectedly reached 100% during spontaneous memories. Similarly, in the voluntary memories condition, the CFL success rate was on average 88.20% ± 6.74% when no question was asked, but reached 92.05% ± 9.08% during voluntary memories. Nevertheless, recall of spontaneous memories increased response time of Mdn =.74 s and up to 1.69 s (see Figure 3). Voluntary memories increased the response time of Mdn = .70 s and up to 1.90 s, which was significant, T = 2, p < .001, r_{pb} = .97.

Eye Movements During Induced Memories

Eye movements analyses were performed on the data from 12 participants, the four others were excluded because of the low quality of the recordings. For the *cue phrases condition* with spontaneous memories, the sample size was too small to run a statistical comparison, but we observed that the presence of spontaneous memories decreased dwell time out of the sector along with a decreased vergence angle (i.e., increased divergence) both in low and high mental load situations (see Figure 4). For the *questions condition* with voluntary memories, a Wilcoxon signed-rank test showed no significant difference for dwell time out of sector or for vergence angle, for neither the low nor the high mental load situation. However, we observed tendencies (i.e., p value significant before Bonferroni correction or < .10). During voluntary memory retrieval, there was an increased vergence angle (i.e., increased convergence) and a longer proportion of time looking outside of the control sector in the high mental load condition (see Figure 4).

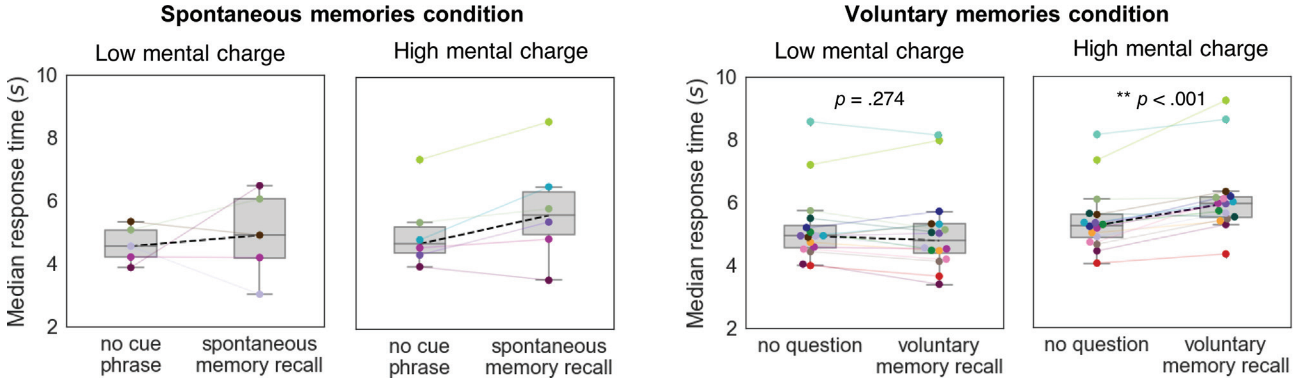

Figure 3. Median responses time of participants for cleared flight level requests preceded by spontaneous or voluntary memories compared with no memory cue for both trials with low or high mental load. **Significant *p* value of Wilcoxon signed-rank tests. Dotted black lines link medians.

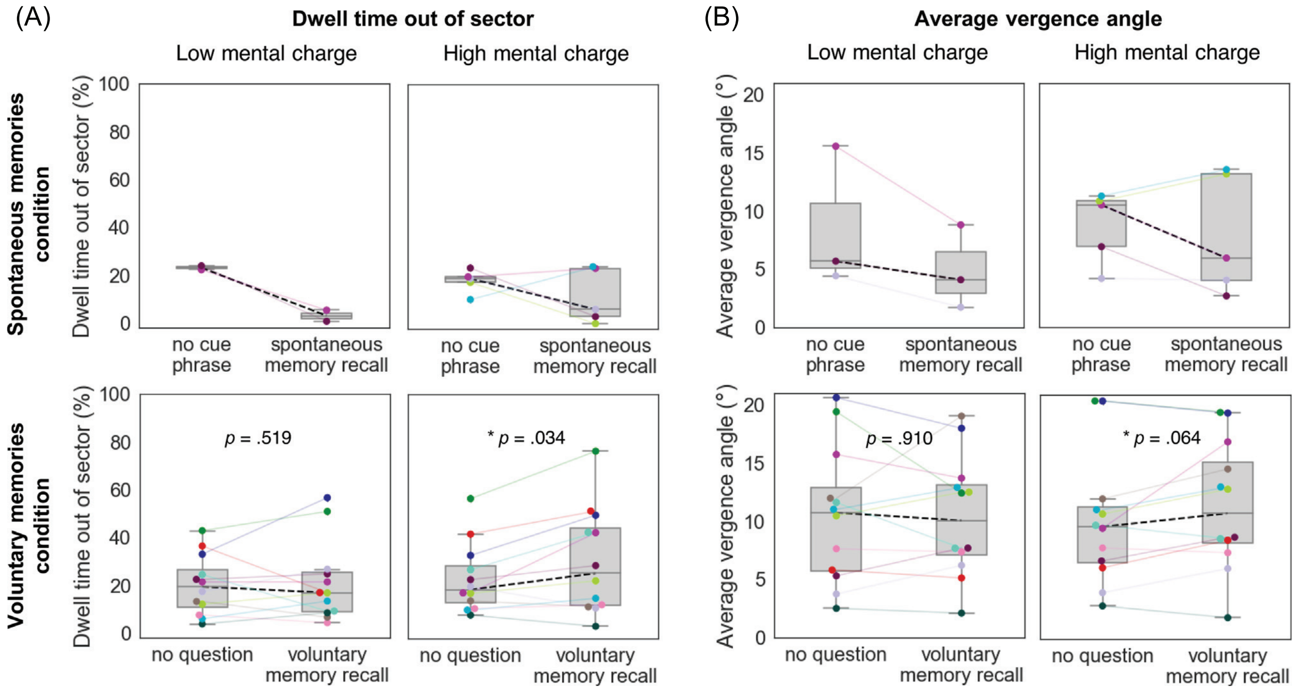

Figure 4. (A) Dwell time (%) spent looking outside of the sector area of interest and (B) average vergence angle after cleared flight level requests preceded by a cue phrase or a question compared with no memory cue for both trials with low or high mental load. The *p* values result from Wilcoxon signed-rank tests. Wilcoxon tests were performed only for trials with questions because of the insufficient number of trials for the cue phrases condition. *Tendency (significant before Bonferroni correction or < .10). Dotted black lines link medians.

Interestingly, visual analyses of the video recording showed that, when the gaze exits the control sector, it sometimes corresponds to the gaze aversion behavior. For trials from the cue phrases condition, none of the gaze exits was considered as gaze aversion for the few trials where spontaneous memories were reported, but surprisingly there were 14.86% ± 23.90% of gaze aversions for trials where no memory was reported in response to the cue phrase (observed in five participants, between 20% and 80%). For trials from the questions condition, when voluntary memories were reported, 16.58% ± 19.57% of sector exits were classified as gaze aversion (observed in nine participants, between 5.88% and 69.23%) versus 19.99% ± 27.74% for trials where no memory was reported (observed in five participants, between 16.67% and 66.67%).

Relations Between Induced Memories and Self-Report Mind-Wandering

On a Likert-scale from 1 to 5, participants self-reported on average 2.62 for mind-wandering frequency during the cue

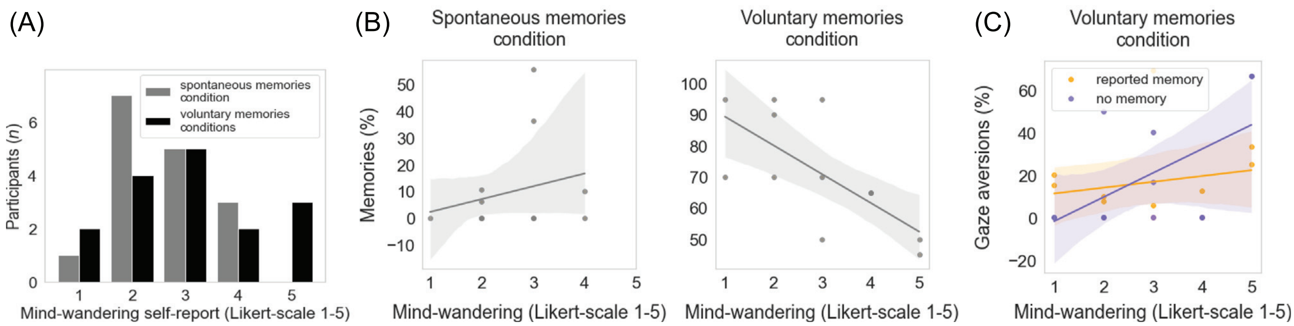

Figure 5. (A) Distribution of mind-wandering self-report scores for both tasks; (B) relations between self-reported mind-wandering and frequency of induced memories for both spontaneous and voluntary memories; (C) relations between gaze aversions and self-reported mind-wandering for trials with or without memories for voluntary memory condition (not enough data for the spontaneous memories condition).

phrases condition, and 3 for the questions condition (Figure 5A). The frequency of self-reported mind-wandering was weakly positively linked to the number of spontaneous memories while it was negatively associated with the number of voluntary memories (Figure 5B). Interestingly, Figure 5C suggested a positive relation between gaze aversions and self-reported mind-wandering while considering only the questions that did not induce memory recall. This relation was not observed for questions that successfully induced voluntary memories.

Discussion

Despite its threatening aspect for safety, mind-wandering has been very rarely studied in ATCOs. This might be partially due to the lack of adapted methods to study mind-wandering in that context. Indeed, self-reports methods are suboptimal given the high sensitivity of aeronautics professionals to social desirability that may prevent them from admitting high levels of mind-wandering, which is considered a failure. In support of this interpretation, participants of our study reported a lower frequency of mind-wandering during the cue phrase condition (during which participants were naïve) compared to the question condition (where participants were explicitly asked to remember memories and therefore more prone to report them). This highlights the limitations of self-reports, and the need for new evaluation methods such as the one we propose here – using autobiographical memory to induce a “mind-wandering-like” mental state in the laboratory.

In that regard, our protocol successfully induced spontaneous memories for 50% of the participants by showing some cue phrases (e.g., “birthday party” or “Valentine’s Day”) while doing an ATCO simulation task, revealing that people are sensitive to memory cues in this situation. Moreover, participants showed between 6% and 55% of spontaneous memories in response to the cue phrases that they actually processed during the task. This represents an initial success showing the protocol worked as expected. However, we would like to stress that it is preliminary, and the efficacy of the protocol needs to be improved further (we discuss below the possibilities of improvement for authors who would like to redesign a protocol for future studies).

Transposed to ATCOs, our results suggest that controllers could undergo attentional switches when memory cues pop up, for example, an aircraft’s destination reminding them of their last vacation, a coworker on the phone having a light conversation, or a conflict reminiscent of a previous experience. This is not trivial since our results show an impact of spontaneous memories on the performance in terms of time required to acknowledge a clearance – the response time was significantly longer (on average 0.74 s) during periods where memories were reported. The impact on the performance in our simulation task was predominant in situations of high mental load, which is the case when ATCOs solve conflicts in high traffic situations, increasingly frequent given the predicted rise in the number of flights for the upcoming years. Because our task was oversimplified, we observed a ceiling effect in the success rate regardless of the presence of memories or not. We even observed a counterintuitive result since the success rate looked slightly higher when a memory event was recalled. The alteration of performance in terms of success rate might have been underestimated due to the implicit learning of the probabilistic rule existing between the appearance of memory cues and CFL requests (two thirds of the clearances), which might have implicitly allowed the participants to anticipate the appearance of a clearance and thus increased arousal, explaining higher success rates after a memory cue.

Interestingly, eye movements generally associated with internal attention were also present during memory recall under high mental load. This is compatible with perceptual decoupling due to the competition between external and internal attention in high-demand situations (Dixon et al., 2014). Because they compete for limited resources, internal and external attention can only coexist when both require few resources so that resources can be shared. As soon as one of the processes becomes too demanding, it cancels the other one (Dixon et al., 2014) – in this case, under high external demand, internal attention can take place only if external demand is reduced thanks to perceptual decoupling. As expected, voluntary memory recall, which is more demanding, was related to higher eye convergence and longer time spent looking outside of the control sector, which is congruent with *looking at nothing* (Salvi & Bowden, 2016). Although the sample size was too small to calculate inferential statistics for the spontaneous memories condition, these latter seemed related to an increased divergence, known as *staring into space* in the context of mind-wandering (Huang et al., 2019). The differences in eye movements associated with spontaneous and voluntary memories confirm that developing protocols to induce spontaneous memories is advantageous. Mainly because spontaneous memories induced similar eye behaviors to what is known to be associated with mind-wandering, this appears to be a handy model for the indirect study of mind-wandering in the laboratory and finding other ocular signatures, which would not be based on a posteriori average and would therefore allow for real-time detection of mind-wandering to monitor attention in critical situations.

In that sense, we found it interesting to observe gaze aversion during the task, and to detect it using our set-up. Nevertheless, the underlying cognitive factors remain to be investigated because we observed it during voluntary memories (16.58%), but also during periods where no memory was recalled (19.99%). The negative relation between the number of voluntary memories and the frequency of self-reported mind-wandering suggests that participants in fact had their own moments of spontaneous mind-wandering that were not triggered by our memory cues. Interestingly, gaze aversion also appears during spontaneous mind-wandering since the higher rate of mind-wandering people reported, the higher frequency of gaze aversions was observed during trials where no triggered memories was reported. To our knowledge, this is the first time that gaze aversions are observed and documented while performing a task simulating the job of ATCOs. It would be necessary to replicate these results in a more realistic simulation task with qualified ATCOs. But the existence of gaze aversions deserves to be investigated since such eye movements could potentially disturb visual scanning strategies used by ATCOs to do their job efficiently. Eventually, a fine description of their pattern would be extremely interesting, especially given their potential variable forms (Servais, Hurter, et al., 2022), but this still requires finding a recording method that makes continuous monitoring of gaze aversions possible. In this sense, electrooculography seems promising (Servais, Poveda, et al., 2023).

Limitations and Conclusion

Besides these promising results, the protocol is currently at a preliminary stage and therefore has limitations. The protocol should be tested with qualified ATCOs as differences are expected depending on expertise, but also with more ecological tasks. Finally, it is also necessary to optimize the efficiency of the protocol – boost the number of induced memories – in order to make it worthwhile. For research to continue with this momentum, we propose here avenues of improvement. A first upgrade would be to increase the processing rate of cue phrases (currently at 59% only): the more cue phrases are processed, the higher their likelihood of triggering a memory. One possibility could be to enhance their saliency (e.g., by increasing the font size, using colors, or extending the duration of presentation). A second upgrade concerns the power of a specific cue phrase to trigger memory – some work better than others, and for a larger number of people. In the current experiment, we chose to preserve the motivation of the participants by not making the experience emotionally unpleasant – we therefore presented only cue phrase with a positive valence. However, using negative cues might generate more involuntary memories (Plimpton et al., 2015; Schlagman & Kvavilashvili, 2008). Another possibility is to use more specific cue phrases, that is, cue phrases that are linked to fewer events stored in memory (Berntsen, 2021). For example, "first kiss," which corresponds to a single memory event in memory, is more likely to induce the appearance of a memory than "new year," which is associated with one evening per year, therefore several evenings.

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History
Received January 9, 2023
Revision received May 16, 2023
Accepted August 18, 2023
Published online January 5, 2024

Acknowledgments
This paper received the Best Conference Paper Award at the 34th conference of the European Association for Aviation Psychology (EAAP, Gibraltar, September 2022).

Conflict of Interest
The authors declare that there were no conflicts of interest.

Publication Ethics
This feasibility study took place according to the measures of the research ethics committee number CPP2020-21/2020-A00348-31 issued by the French CPP SUD-EST II. The experiment was conducted in conformity with the Declaration of Helsinki and GDPR.

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Funding
Supported by a grant from the Aeronautics–Astronautics Doctoral School and Paul Sabatier University of Toulouse.

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