Can we use EOG to identify when your attention switches away from the world to focus on your memories?

Anaïs Servais[1,2], Raphaël Poveda[1], Hanna Gerony[1], Emmanuel Barbeau[1], and Christophe Hurter[2]
[1]Centre de Recherche Cerveau et Cognition (CerCo), CHU Purpan, Toulouse, France
[2]Ecole Nationale d'Aviation Civile (ENAC), Toulouse, France
anais.servais@cnrs.fr

INTRODUCTION

Observe what's going on in your mind while answering the following question: "How did you celebrate your last birthday?". Answering this question required the creation of a temporary internal mental space where your attention was focused (Tulving, 2002). Thus, there was an *attentional switch* from the external world to the internal world — a change in mental state commonly known as mind-wandering— a general term popularly used to designate daydreaming and zoning-out (Smallwood & Schooler, 2006). Indeed, since attention is a limited resource, when it is focused on the internal world, the external world vanishes (Fernandes & Moscovitch, 2000), a phenomenon known as perceptual decoupling. Though useful for managing attentional resources, this decoupling has a concerning aspect — of impairing performance and safety in operational tasks (such as driving a car or piloting a plane) where attention must be directed to the external world (Gouraud et al., 2018; Smallwood et al., 2011). Reports show that aviation accidents related to attentional lapses occur (NTSB, 2014), but the origin of these lapses remains unknown. Given perceptual decoupling, mind-wandering could be a potential cause but objective behavioral markers to monitor attention remain elusive.

Here, we propose eye movements as one such potential candidate. Mind-wandering is associated with oculomotor features reducing visual processing: more and longer blinks, fewer and longer fixations, longer saccades durations, and so on (Benedek et al., 2017). However, these eye behaviors cannot be used as markers to detect mind-wandering in real-time because they require posteriori averages. Instead, here we suggest investigating another eye behavior – *gaze aversion* — a very common behavior while answering memory questions. People routinely look away as if they were searching for the answer on the ceiling or "in the sky" (Doherty-Sneddon & Phelps, 2005; Glenberg et al., 1998).

So far, mind-wandering has been seldomly studied in aeronautics, perhaps because it is a spontaneous mental state and therefore difficult to assess. The current methods are based on self-reporting which has several biases including social desirability for pilots (Casner & Schooler, 2014). To overcome this problem, since people tend to retrieve events that occurred in their past during 60% of their zoning out time (Mildner & Tamir, 2019), we propose to trigger attentional switches in the lab using questions like the one you answered – autobiographical memory questions (Conway, 2001) while recording eye movements with electro-oculography (EOG). EOG records the electrical potential between electrodes placed on the muscles around the eyes and allows to quantify vertical and horizontal eye movements. In airplane cockpits, the EOG provides a less invasive alternative to infrared cameras, which generally obstruct part of the visual field. Recent studies have also shown that EOG can be recorded around the ears (Favre-Félix et al., 2017) – opening prospects for integration of the electrodes in the pilot's helmet. In this, currently preliminary, work we aim to estimate the relevance of EOG to study gaze aversion during internal attention.

MATERIALS AND METHODS

Data were collected on 4 participants (2 females, aged between 23 and 28, 1 left-handed) without oculomotor, visual, neurological, or psychiatric disorders.

We designed a task where a participant answers autobiographical memory questions. Each trial starts with a fixation cross (5 sec) followed by a question delivered through loudspeakers (5 sec). After the question, the participant completes a short visual task to keep attention towards the external world: for 8 to 12 letters, the participant presses a key if the letter contains a curve line and another if it does not. When there is no more letter, the participant starts to search for autobiographical memory. This "reflection phase" is divided into an earlier phase of access (max 12 sec) and a later phase of elaboration (5 sec) where the participant respectively selects and explores a personal memory corresponding to a unique and short event (< 24 hours), with a defined spatiotemporal context. An audio "debriefing" indicates the start of the verbalization. Then, the patient presses a key to start the next trial (see Figure 1 for details).

To isolate the impact of autobiographical memories, we include two control conditions: a semantic memory task (also involving internal attention) concerning famous events or people, and a visual task (external attention) that requires finding the digit "5" hidden in a visual scene. The whole experiment is divided into 5 blocks of 15 questions (5/condition) presented in random order. Each participant completed 25 trials per cognitive condition.

EOG recording

Stimuli presentation was controlled by OpenSesame 3.2.8. BioSemi Active Two amplifier was used to record the EOG with 5 electrodes: a reference on the forehead, one electrode at each extern canthus for horizontal movement, one electrode above the right eyebrow, and one electrode on the top of the right cheek for vertical movements. The frequency rate is 2048 Hz. To guarantee the quality of the EOG data throughout the session, a calibration was performed at the beginning of each block. As ground truth, we recorded a video of the participant's face (with SONY FDR-AX33 Handycam, 1920x1080px resolution).

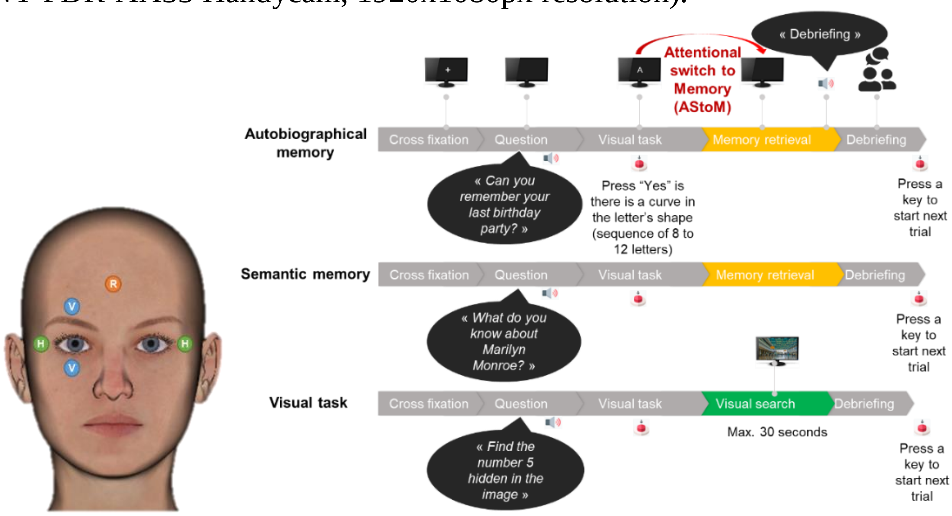

Figure 1: This figure illustrates the method used to collect the data. On the left, is the position of the electrodes. On the right, is the description of the cognitive task.

Data analyses

The signal was preprocessed—resampled to 256Hz, and filtered with a low-pass at 40Hz. All the saccades were labeled manually by two students doing their internship in the lab. While labeling the saccades, they were blind concerning the part of the signal they were processing. Only the saccades labeled by both judges were kept for analysis.

The periods of interest are the moments of visual and memory retrieval (for the 2 memory conditions) trials. The visual trials allow us to get a sample of *visual saccades*, usually done while exploring the environment. During memory retrieval, we focus on the trials where gaze aversion occurs. With the video as ground truth, the saccades initiating gaze aversion were noted as *aversion saccades*. The synchronization between the EOG and the video was performed on BrainStorm (https://neuroimage.usc.edu/brainstorm/).

ERPs were calculated (using BrainStorm) on epochs aligned on the aversion time (settled to zero), a baseline of - 300ms before (because 300ms is the min. time between the start of the memory retrieval and a gaze aversion), and duration of 600ms (the min. duration of a gaze aversion). ERPs allow observing if a similar EOG pattern is repeated between aversions.

The sensitivity of Eogert (Toivanen, 2015), a probabilistic online method to detect EOG saccades, was compared for visual and aversion saccades. Compared to the saccades labeled manually, false negatives and true positives were counted: sensitivity=*TP/(TP+FN)*. For visual saccades, the sensitivity is 36% against only 9% for the aversions saccades. The algorithm is more accurate on visual saccades than aversion saccades, pleading for different EOG features between these types of eye movements. See Figure 2 for an illustration of the signal during a memory trial with gaze aversion and a visual trial with visual saccades.

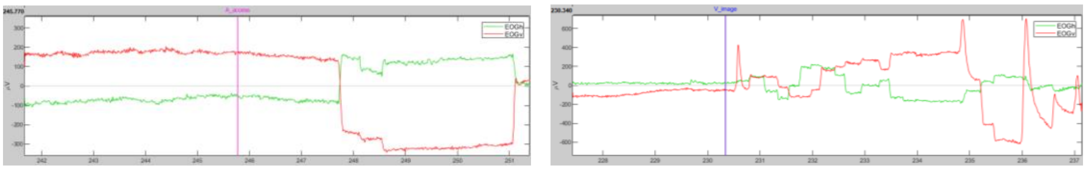

Figure 2: Illustration of the EOG signal during a memory trial (left) and a visual trial (right).

To investigate the differences between the EOG features of visual compared to aversion saccades, we conduct exploratory analyzes comparing the gaze angle and velocity of the two kinds of saccades with the Mann-Whitney U-test (the size effect is the rank-biserial correlation (r), α is corrected with Bonferroni to .016). For each gaze direction, a constant of reference is calculated based on the calibration (in µV/degree). Gaze angle is calculated following a linear relation: $\boldsymbol{Gaze\ angle} = \frac{\text{EOG amplitude } (\mu\text{V})}{\text{Constant } (\mu\text{V/degree})}$ & $\boldsymbol{Velocity} = \frac{\text{Gaze angle (degrees)}}{\text{Duration of the saccade (sec)}}$.

RESULTS

Out of 100, Gaze aversion was observed in 35 trials for autobiographical memory and 26 trials for semantic memory questions. There is inter-individual variability in the occurrence of gaze aversion since the proportion of questions where gaze aversion is observed varies between participants from 4% to 68% for autobiographical questions and from 0% to 56% for semantic questions. During all the visual trials, a total of 1062 visual saccades were counted.

The visualization of the ERPs is possible only for 3 subjects because the fourth one does not do enough gaze aversions. It shows, per individual, a similarity in the vertical EOG pattern of the different aversions (see Figure 3).

The aversion saccades show different gaze angle and velocity than visual saccades (see Figure 4). For the gaze angle, Mann-Whitney U-tests show significant differences between visual and aversion saccades. Gaze angles are much larger for aversions, both in autobiographical (EOGh: U= 7429, p<.001, r=.48; EOGv: U=3669, p<.001, r=.74) and semantic memory trials (EOGh:

U=6961, p=.007, r=.33; EOGv: U = 713, p<.001, r=.93). The angle does not differ significantly between the aversions from the two memory conditions memory (EOGh: U = 263, p=.22, r=.20; EOGv: U =424, p=.08, r=-.28). The velocity of the saccades is also significantly different between visual saccades and aversion saccades, which appear either in autobiographical memory (EOGh: U= 10957, p=.03, r=.23; EOGv: U=5901, p<.001, r=.59) or in semantic memory trials (EOGh: U = 11754, p=.32, r=-.12; EOGv: U= 2486, p=<.001, r=.76). Vertical, but not horizontal, saccades are much faster during gaze aversion than visual saccades. The velocity does not differ significantly between the aversions from the two memory conditions memory (EOGh: U = 218, p=.04, r=.34; EOGv: U =405, p=.17, r=-.23).

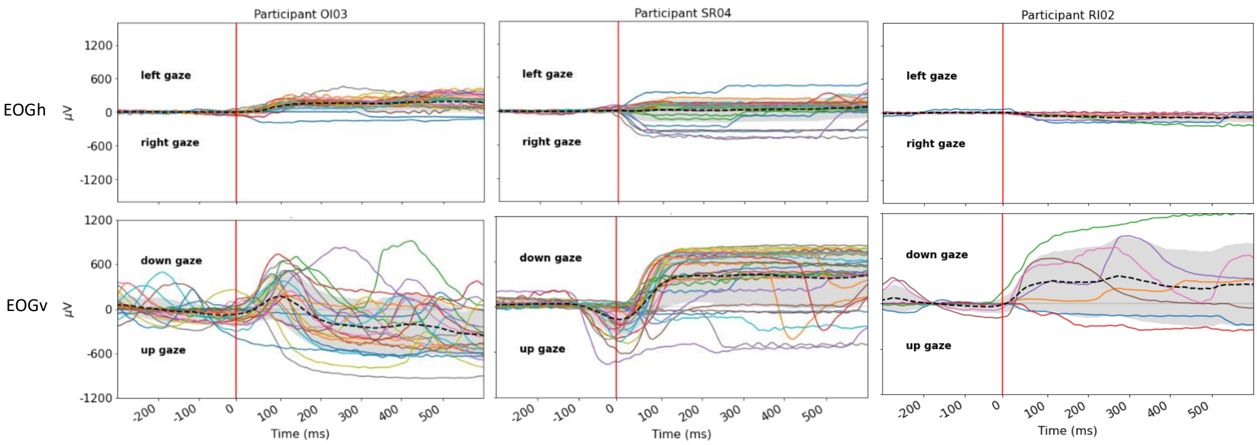

Figure 3. ERPs per participant. Each color represents the epoch of a trial. Aversions from autobiographical and semantic trials have been pooled together. Vertical red lines indicate the start of the aversion separating the baseline from the gaze aversion period.

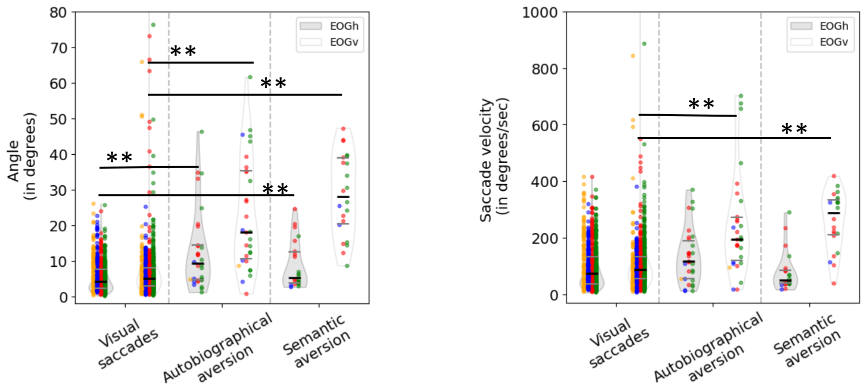

Figure 4. Gaze angle and velocity for visual and aversion saccades. One color stands for all the saccades of a single participant. ** p-value < .001

DISCUSSION

It seems that the EOG signal associated with eye saccades initiating a gaze aversion during attentional switch differs from the EOG signal associated with visual eye saccades that people do when they explore their environment. Saccades initiating gaze aversion are faster and have larger amplitude than visual saccades. As expected, aversions seem to be more distinguishable from the visual saccades on the vertical rather than on the horizontal EOG.

However, the present study is far from real-time detection of attentional switches. We are facing many limits. First, we show that even on a small sample of participants, there is huge individual variability in the gaze aversion behavior. The ERP analysis shows that the pattern of the aversion differs between participants. To be transferred to an application, an individual personal calibration of the system would be necessary. Here, we use a small sample size because we aim to determine the potential interest of the method, but a validation of the method would require a higher sample. Second, to refine the results, future studies should include recordings of head movements and a better calibration to infer gaze angle more accurately. Here, we show that gaze aversions induce a large gaze angle, and the linear relation with EOG is not true for gaze at high eccentricities. Third, it is too early to extrapolate our results to ecological situations because we currently don’t have any proof that gaze aversion happens during spontaneous switches. Fourth, the results for gaze aversion during autobiographical memory do not differ significantly from the one about gaze aversion during semantic memory. It seems therefore linked to internal attention in general, and maybe not specific to autobiographical memory.

We want to emphasize the importance of studying such behavior in aeronautics. Although here we have focused on gaze aversion occurring during memory retrieval for the sake of developing an experimental paradigm, in our view such behavior is similar to what occurs during mind-wandering and in fact any behavior requiring access to internal thoughts including when one is speaking to an interlocutor. Monotonous tasks generate higher rates of mind-wandering, which is a problem given the increasing automation in the cockpits (Gouraud et al., 2018). Therefore, we urgently need an objective marker allowing real-time detection of internal thoughts switching to monitor attention in critical situations. In this context, our work aims to open discussions and perspectives.

CONCLUSION

Although our results are preliminary, they are encouraging. First, we propose a protocol to trigger attentional switches in the lab. Second, we show that these switches are associated with gaze aversions. Third, since we observe that gaze aversion have different EOG features compared to visual saccades, we think that EOG could be a potential method to study and detect attentional switch. In an early laboratory phase, EOG could be coupled with augmented reality helmets to characterize gaze aversion better before reaching a reliable detection in EOG only.

REFERENCES

Benedek, M., Stoiser, R., Walcher, S., & Körner, C. (2017). Eye behavior associated with internally versus externally directed cognition. *Frontiers in Psychology*, *8*(JUN), 1–9.

Casner, S. M., & Schooler, J. W. (2014). Thoughts in flight: Automation use and pilots ’task-related and task-unrelated thought. *Human Factors*, *56*(3), 433–442.

Conway, M. a. (2001). Sensory-perceptual episodic memory and its context: autobiographical memory. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *356*(1413), 1375–1384.

Doherty-Sneddon, G., & Phelps, F. G. (2005). Gaze aversion: A response to cognitive or social difficulty? *Memory and Cognition*, *33*(4), 727–733.

Favre-Félix, A., Graversen, C., Dau, T., & Lunner, T. (2017). *Real-time estimation of eye gaze by in-ear electrodes*. 4086–4089.

Fernandes, M. A., & Moscovitch, M. (2000). Divided attention and memory: Evidence of substantial interference effects at retrieval and encoding. *Journal of Experimental Psychology: General*, *129*(2), 155–176.

Glenberg, a M., Schroeder, J. L., & Robertson, D. a. (1998). Averting the gaze disengages the environment and facilitates remembering. *Memory & Cognition*, *26*(4), 651–658.

Gouraud, J., Delorme, A., & Berberian, B. (2018). Out of the Loop, in Your Bubble: Mind Wandering Is Independent From Automation Reliability, but Influences Task

Engagement. *Frontiers in Human Neuroscience*, *12*(September), 1–13.
Mildner, J. N., & Tamir, D. I. (2019). Spontaneous Thought as an Unconstrained Memory Process. *Trends in Neurosciences*, *42*(11), 763–777.
Smallwood, J., Brown, K. S., Tipper, C., Giesbrecht, B., Franklin, M. S., Mrazek, M. D., Carlson, J. M., & Schooler, J. W. (2011). Pupillometric evidence for the decoupling of attention from perceptual input during offline thought. *PLoS ONE*, *6*(3).
Smallwood, J., & Schooler, J. W. (2006). *The Restless Mind*. *December*.
Tulving, E. (2002). Episodic memory: From mind to brain. *Annual Reviews*, *53*, 1–25.
Yanko, M. R., & Spalek, T. M. (2014). Driving with the wandering mind: The effect that mind-wandering has on driving performance. *Human Factors, 56*(2), 260–269.