Can We Use EOG to Identify When Attention Switches Away from the Outside World to Focus on Our Mental Thoughts?

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Abstract: Aviation incidents resulting from attentional failures continue to occur. Attention is a limited resource and perceptual decoupling occurs when the attention switches away from the outside world to focus on the inner mental world. This phenomenon dramatically decreases visual perception, but is common and frequent since human beings spend nearly half of their time immersed in their thoughts, implying numerous switches between the outside and the inner world each day. We believe that detecting these attentional switches in air traffic controllers could improve safety. We suggest gaze aversion as a potential behavioural objective marker and therefore aim to find a method to measure gaze aversion in the lab. Our preliminary study tested EOG and provided encouraging results since movements of gaze aversion differed significantly from visual saccades in terms of amplitude and velocity, two characteristics measurable with the EOG signal. Gaze aversions are faster and related to wider movements. This opens up great perspectives in aviation since the EOG is a non-invasive method.

1 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 can have dramatic consequences—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, behavioural, 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 behaviours cannot be used as markers to detect mind-wandering in real-time because they require posteriori averages. Instead, here we suggest investigating another eye behaviour – *gaze aversion* — a very common behaviour 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).

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So far, mind-wandering has seldomly been studied in aeronautics, perhaps because it is a spontaneous mental state and therefore difficult to assess. 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, i.e., 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 may provide 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 perspectives for integration of the electrodes in the pilot's helmet. In this preliminary work, we aim to estimate the relevance of EOG to study gaze aversion during internal attention.

2 MATERIALS AND METHODS

2.1 Participants

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

2.2 Experimental Task

We designed a task during which participants answered autobiographical memory questions. Each trial started with a fixation cross (5 sec) followed by an oral question delivered through loudspeakers (5 sec). The questions were generated using astread.com. After the question, the participant completed a short visual task to keep attention towards the external world: for 8 to 12 letters, the participant pressed a key if the letter contained a curve line and another if it did not. After the presentation of the letters, the participant started to search in autobiographical memory. This "reflection phase" was divided into an earlier "access" phase (max 12 sec) and a later "elaboration" phase (5 sec) during which the participant respectively selected and explored a personal memory corresponding to a unique and short event (< 24 hours), with a defined

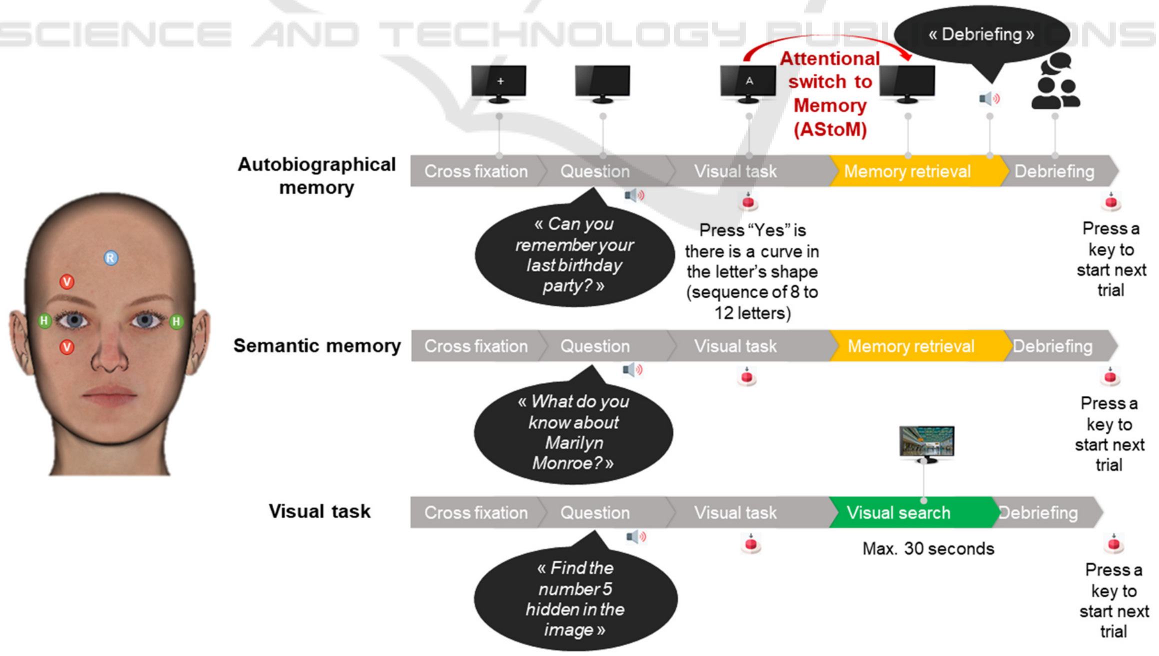

Figure 1: This figure illustrates the method used to collect the data. On the left, is the position of the electrodes. On the right, is the description of the cognitive task.

spatiotemporal context. An audio "debriefing" indicated the start of the verbalization. Stimuli presentation was controlled using OpenSesame 3.2.8 (Mathôt et al., 2012). Then, the patient pressed a key to start the next trial (see Figure 1 for details).

To isolate the impact of autobiographical memories, we included two control conditions: a semantic memory task (also involving internal attention) concerning famous events or people, and a visual task (external attention) that required finding the digit "5" hidden in a visual scene. The whole experiment was divided into 5 blocks of 15 questions (5/condition) presented in random order. Each participant completed 25 trials per cognitive condition. Explanations about the task were first provided and then participants had 2 practice trials per condition (not further analysed).

2.3 EOG Recording

A BioSemi Active Two amplifier was used to record the EOG with 5 electrodes: a reference on the forehead, one electrode at each external 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 of acquisition was 2048 Hz. To guarantee the quality of the EOG data throughout the session, a calibration was performed at the beginning of each block. In order to have a ground truth, we recorded a video of the participant's face using a SONY FDR-AX33 Handycam, with 1920x1080px resolution, positioned above the screen.

2.4 Data Analyses

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

The periods of interest were the visual task and the 2 memory conditions. The visual trials allowed us to get a sample of natural *visual saccades*, of the type usually done while exploring the environment. During memory retrieval, we focus on the trials where gaze aversion occurred. 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 using BrainStorm (https://neuroimage.usc.edu/brainstorm/).

Event related potentials (ERPs) were calculated 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 labelled manually, false negatives and true positives were counted: sensitivity=*TP/(TP+FN)*. For visual saccades, the sensitivity was 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).

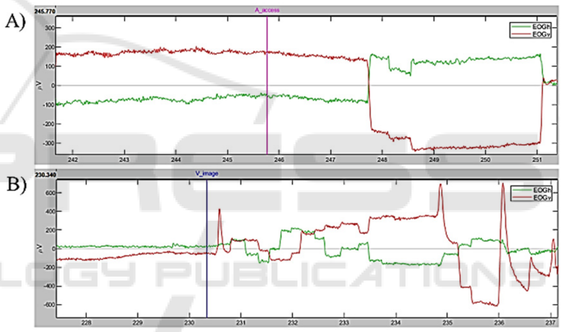

Figure 2: Illustration of the EOG signal during A) a memory trial; B) a visual trial for the same subject.

To investigate the differences between the EOG features of visual compared to aversion saccades, we conducted exploratory analyses comparing the gaze angle and velocity of the two kinds of saccades with Mann-Whitney U-tests (the size effect is the rank-biserial correlation (r), α was corrected with Bonferroni to .016). For each gaze direction, a constant of reference was calculated based on the calibration (in µV/degree). Gaze angle was calculated following a linear relation.

$$\text{Gaze angle} = \frac{\text{EOG amplitude } (\mu V)}{\text{Constant } (\mu V/\text{degree})} \quad (1)$$

$$\text{Velocity} = \frac{\text{Gaze angle (degrees)}}{\text{Duration of the saccade (sec)}} \quad (2)$$

3 RESULTS

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

The visualization of the ERPs was possible only for 3 subjects because the fourth one did not do enough gaze aversions. It revealed individual similarity of the vertical EOG pattern (Figure 3).

The aversion saccades showed different gaze angle and velocity than visual saccades (Figure 4). For the gaze angle, Mann-Whitney U-tests showed significant differences between visual and aversion saccades. Gaze angles were 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 did 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 was also significantly different between visual saccades and aversion saccades, which appeared either in autobiographical memory (EOGh: U= 10957, p=.03, r=.23; EOGv: U=5901, p<.001, r=.59) or in semantic memory trials

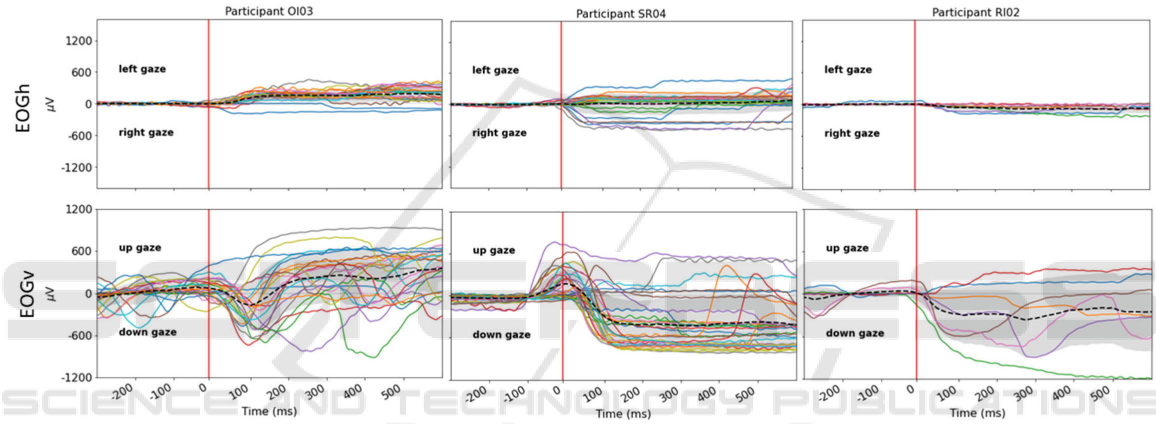

Figure 3: ERPs per participant. Each colour represents the epoch of a trial. Aversions from autobiographical and semantic trials have been pooled together. Vertical red lines indicate the start of the aversion separating the baseline from the gaze aversion period. EOGh: EOG signal for horizontal movements; EOGv: EOG signal for vertical movements.

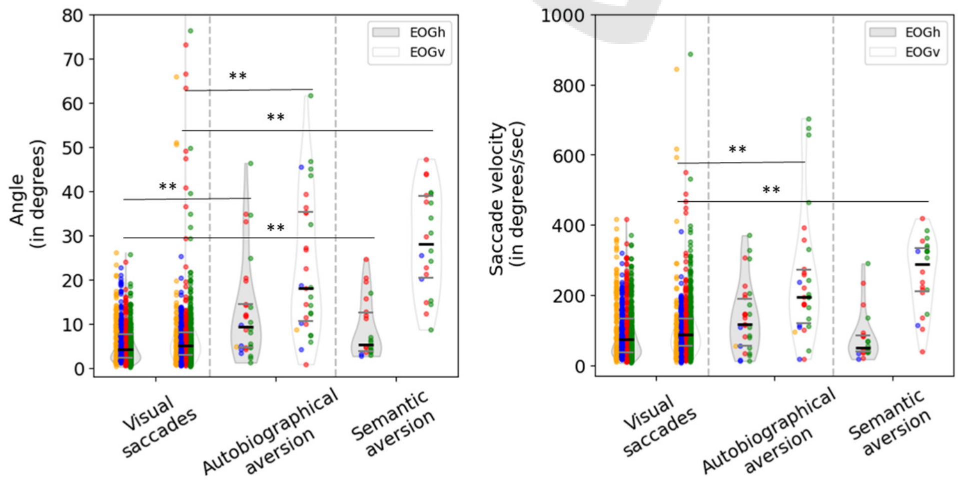

Figure 4: Gaze angle and velocity for visual and aversion saccades. One colour stands for all the saccades of a single participant. ** p-value < .001.

(EOGh: *U* = 11754, *p*=.32, *r*=-.12; EOGv: *U*= 2486, *p*=<.001, *r*=.76). Vertical, but not horizontal, saccades were much faster during gaze aversion than visual saccades. The velocity did not differ significantly between the two memory conditions (EOGh: *U* = 218, *p*=.04, *r*=.34; EOGv: *U* =405, *p*=.17, *r*=-.23).

4 DISCUSSION

From these preliminary results, 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 were faster and had larger amplitude than visual saccades. As expected, aversions seemed 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 behaviour. The ERP analysis shows that the pattern of the aversion differs between participants. To be applicable, an individual personal calibration of the system would be necessary. Here, we used a small sample size because we aimed 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. However, the linear relation with EOG is not true for gaze at high eccentricities (e.g., Hládek et al., 2018). Interestingly however, the results for gaze aversion during autobiographical memory do not differ significantly from the one during semantic memory. It seems therefore linked to internal attention in general, and maybe not specific to autobiographical memory.

Despite these limits, we want to emphasize the importance of studying such behaviour 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 behaviour is similar to what occurs during mind-wandering and in fact any behaviour 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.

5 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 using EOG only.

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