# Why and When Do You Look Away When Trying to Remember? Gaze Aversion as a Marker of the Attentional Switch to the Internal World

Anaïs Servais[1,2]*, Noémie Préa[1], Christophe Hurter[2], Emmanuel J. Barbeau[1]

[1]Centre de recherche Cerveau et Cognition (CerCo), UMR5549 (CNRS-UPS), Pavillon Baudot, 31052 Toulouse, France

Emails: anais.servais@cnrs.fr; emmanuel.barbeau@cnrs.fr

[2]National Civil Aviation School (ENAC), 7 avenue Edouard Belin, 31055 Toulouse, France

Email: christophe.hurter@enac.fr

* Corresponding author: Anaïs Servais, CerCo, CNRS UMR5549, CHU Purpan, Pavillon Baudot, 31052 Toulouse, France; Telephone: +33 562746159; Email: anais.servais@cnrs.fr

**Abstract**

It is common to look away while trying to remember specific information, for example during autobiographical memory retrieval, a behavior referred to as gaze aversion. Given the competition between internal and external attention, gaze aversion is assumed to play a role in visual decoupling, i.e., allowing suppressing environmental distractors during internal tasks. This suggests a link between gaze aversion and the attentional switch from the outside world to a temporary internal mental space that takes place during the initial stage of memory retrieval, but this assumption has never been verified so far. We designed a protocol where 33 participants answered 48 autobiographical questions while their eye movements were recorded with an eye-tracker and a camcorder. Results indicated that gaze aversion occurred more often, in more people and at an earlier phase of memory retrieval than changes of eye vergence, another possible strategy related to visual decoupling. Gaze aversion lasted a relatively long time (on average 6 seconds), pointed to different directions depending on the subjects, and was notably decoupled from concurrent head movements. Because this significantly reduces visual processing, this is in favor of the role of gaze aversion in perceptual decoupling. Moreover, gaze aversion occurred early (<1s) and predominantly during the access phase of memory retrieval—i.e., the moment when the attentional switch is assumed to take place. Gaze aversion was related to higher retrieval effort and was rare during memories which came spontaneously to mind. This suggests that gaze aversion might be required only when cognitive effort is required to switch the attention towards the internal world to help retrieving hard-to-access memories. Our results provide for the first time several arguments supporting the hypothesis that gaze aversion is related to the attentional switch from the outside world to memory.

**Keywords**: Attention; Autobiographical memory; Eye movements; Gaze aversion; Memory retrieval; Internal attention

## 1. Introduction

Sincerely try to remember your last birthday party. Were you able to do that without moving your eyes? Preventing eye movements hinders autobiographical memory retrieval (Lenoble et al., 2019), defined as the ability to remember personal past events with a unique subjective experience of reliving the episode (Tulving, 2002). It is common to see people look away when answering memory questions as if the answer were *on the ceiling* or *in the sky* (Doherty-Sneddon & Phelps, 2005). It was already reported fifty years ago that humans tend to look away while trying to remember (Kinsbourne, 1972). Those "*lateral eye movements*" were then understood as the reflection of the brain hemispheric asymmetry: rightward gazes were thought to be associated with verbal processes while leftward gazes were thought to be linked to visual imagery processes. Later, Glenberg et al. (1998) suggested that *gaze aversion* could be interpreted in the light of the competition between external and internal attention (Chun et al., 2011): gaze aversion was assumed to bring the gaze away from environmental distractors to optimize internal cognition (e.g. memory retrieval) (Abeles & Yuval-greenberg, 2017; Doherty-Sneddon & Phelps, 2005; Doherty-Sneddon et al., 2002). This phenomenon has also been referred to as *looking at nothing*, i.e. staring at neutral parts of the environment with few distractors when attentional resources are required for internal processes (Salvi & Bowden, 2016).

People also do a lot of eye movements when they try to retrieve memories in the dark or with closed eyes however (Ehrlichman & Micic, 2012; Micic et al., 2010). The role of those nonvisual eye movements is therefore not only to avoid distractors, (Ehrlichman & Micic, 2012). Currently, an influential theory about the relation between autobiographical memory retrieval and eye movements is *gaze reinstatement* or *scan path theory*, which states that during memory retrieval, the gaze reenacts the visual pattern observed during the encoding of the event (for recent studies, see Johansson et al., 2021; Wynn et al., 2019). Gaze aversion and gaze reinstatement are not mutually exclusive and may both play a role in autobiographical memory retrieval, albeit at different timepoints. Gaze reinstatement is closely linked to mental imagery, allowing the scene to be mentally explored (Bone et al., 2019). It therefore possibly occurs more likely during the elaboration phase–the point at which mental imagery occurs (Daselaar et al., 2008; Inman et al., 2018). As for gaze aversion, we hypothesize that it could occur early during the access phase of memory retrieval to disengage the gaze from the environment. Given the competition between internal and external attention (Chun et al., 2011), the *cognitive load hypothesis of gaze aversion* (Abeles & Yuval-Greenberg, 2017) suggests that averting the gaze from distractors in the surrounding environment optimizes internal cognition (e.g. memory retrieval). Gaze aversion could therefore support *perceptual decoupling*—i.e. the decreased processing of external visual information during internal attention. It could occur through two different mechanisms. The first, posited by Glenberg et al. (1998), consists in directing the gaze toward the floor, ceiling, or sky-in other words, a neutral uniform surface containing fewer distractors than the rest of the surrounding environment (Markson & Paterson, 2009). The second is based on the properties of the oculomotor system. Physically, the eyes can move about 50° from the central primary position, but at far eccentricity, the eye position is less stable causing less accurate fixations (Nakashima & Shioiri, 2014). To visually explore the environment, the head therefore also rotates to help maintain the eyes within a comfortable oculomotor range (Land & Tatler, 2009). It can thus be suggested that, despite the significant eye rotation caused by gaze aversion, the head does not follow the eyes when attention is oriented toward memories. This mismatch between the direction of the eyes and the head could presumably lead to less accurate processing of visual information, thereby favoring perceptual decoupling.

Studies linking gaze aversion to perceptual decoupling implicitly suggest that it happens early during memory retrieval—the moment where the attentional switch from the external world towards the inner world takes place. But this has never been verified so far. In this study, our aim was therefore to test this hypothesis. Strangely enough, even if gaze aversion is a common and natural behavior easily observable, there have been almost no scientific studies about its characteristics. As a consequence, little is known about its duration, direction, the proportion of the population prone to it or related cognitive processes. This is a surprising situation since the identification of an objective and measurable marker of the attentional switch toward the inner world could have a major impact on a variety of domains including neuropsychology (diagnosis of memory impairment), experimental neuroscience for EEG and fMRI studies (aligning trials on a trial-by-trial basis on the timing of gaze aversion), comparative psychology (investigation of autobiographical memory in other species), and social cognition (monitoring of gaze aversion during social interactions).

Although gaze aversion has been observed in a few studies during different internal tasks such as mental calculation, semantic memory retrieval, autobiographical retrieval, creativity and problem solving (Doherty-Sneddon & Phelps, 2005; Glenberg et al., 1998; Salvi & Bowden, 2016), it appears more prevalent during autobiographical memory retrieval (Doherty-Sneddon & Phelps, 2005). We will therefore use a protocol where we ask autobiographical memory questions to participants to induce gaze aversions, while eye movements are recorded with both an eye-tracker and a camcorder as a ground truth. Autobiographical memory retrieval is a complex cognitive experience where individuals embark on mental time travel (Tulving, 2002) in a temporary internal mental space (Cheng et al., 2016), considered as a theater stage on which individuals can mentally re-instantiate memories of personal past events (Breeden et al., 2016; Cheng et al., 2016; Suddendorf & Redshaw, 2013). The attention to memory (AtoM) model has emphasized the involvement of internal attention in memory retrieval (Ciaramelli et al., 2008) since the attention must be oriented toward the inner world. To initiate memory retrieval, attention therefore needs to switch early from the external world toward the inner world. Our main hypothesis is that gaze aversion is related to this early attentional switch.

As a novel approach to investigate this relation between gaze aversion and the attentional switch between the external and internal worlds, we investigated the timing of its occurrence and at what stage of memory retrieval it occurred. Importantly, its participation in perceptual decoupling would plead in favor of its involvement in disengaging the attention from the external world. We, therefore, investigated whether it is decoupled from head movement. We also explored the direction in which the gaze is averted. While pseudo-sciences theories such as neuro-linguistic programming postulated that people look up to the left during memory retrieval (Wiseman et al., 2012), those claims have not been scientifically replicated (Diamantopoulos et al., 2009; Rochat et al., 2018). Here, we expected the gaze to be averted in any direction with fewer visual distractors (Salvi & Bowden, 2016). To increase our knowledge of the characteristics of gaze aversion, we looked at its relationship with cognitive factors such as vividness of memory, quality of retrieval, and cognitive effort. Since gaze aversion is generally linked to cognitive difficulty (Doherty-Sneddon & Phelps, 2005; Glenberg et al., 1998), we expected it to be more prevalent when a higher effort was required. Last, because perceptual decoupling is assumed to optimize memory retrieval performance (Abeles & Yuval-greenberg, 2017; Glenberg et al., 1998), we expected gaze aversion to be associated with higher memories vivacity and quality. As a control condition, we compared the prevalence and the time of apparition of gaze aversion with eye vergence, another eye behavior known for its role in perceptual decoupling during internal attention (Walcher et al., 2017).

## 2. Methods

### 2.1 Participants

The sample size was based on a priori power analyses using G*Power (Version 3.1.9.2; Faul et al., 2009). Based on preliminary pilot studies, we expected different profiles of participants (most likely three: subjects who would favor gaze aversion, those favoring changes of vergence and those and those not moving their eyes). If clustering analyses allowed us to distinguish three subgroups of participants in our sample, we had planned running a statistical model with repeated measures (within and between interactions). To do so, the power analysis determined that 33 participants would be necessary to achieve a statistical power of .80 with an alpha of .05, and a Cohen's d effect size of .30. This sample size is appropriate as it provides sufficient statistical power (> .80) for the correlations and Friedman tests which were planned.

We recruited 33 healthy French-speaking participants. One participant was excluded because of visual problems reported during the experiment. The analyses were therefore conducted on 32 participants (20 women; 28 right-handed) aged 19-44 years ($M$ = 24.06 ± 5.20), with 12-20 years of education ($M$ = 15.94 ± 2.02). 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 underwent two basic neuropsychological tests to verify that the cognitive functions required during the task were not impaired: the D2 selective attention test (Brickenkamp et al., 2015) and a short 5-item version (Clément et al., 2008, CRIUGM) of the Memory Self-Assessment Questionnaire (Van der Linden et al., 1989). A table of the scores is available online https://osf.io/pbvmq/.

The experiment was approved by the Lyon Ethics Committee, France (CPP2020-21/2020-A00348-31). Participants signed an informed consent form. At the end of the experiment, all participants received financial compensation of 20 euros.

### 2.2 Stimuli and Display

We created 48 autobiographical memory questions from a list of words and expressions known to trigger autobiographical memories (Schlagman & Kvavilashvili, 2008). To ensure that participants remained motivated, the questions were inspired solely by words with a positive emotional valence. The questions were in French and lasted approximately 5 seconds. The audio files were created on an open-source text-to-audio converter (astread.com). All the questions started with the following words: "Can you remember an event when…?"

OpenSesame 3.2.8 software (Mathôt et al., 2012) was used to control stimulus presentation and record response times. The experiment was presented on a gray screen (hex color # 808080) 33.7 cm (width) by 27 cm (height) with a resolution of 1024 x 768 px.

Participants began by performing two training trials. These were followed by a debriefing to ensure that the instructions were well understood. The experimental phase consisted of 48 questions divided into four blocks of 12 questions each. The order in which the four blocks were administered was counterbalanced between participants, and within each block, the questions were presented in random order. Participants were free to take a break between blocks if needed. The experimenter remained present throughout the experiment, to provide feedback during the verbal recall part of each trial. The experimenter was seated behind the participant. To help participants identify episodic 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 hours), and unique event, associated with a specific spatiotemporal context. They were also invited to retrieve the emotions, thoughts, and perceptions present during encoding. The difference between knowing and remembering was explained, and participants were explicitly asked to retrieve memories that they *remembered* (i.e., with a feeling of pastness and reliving, personal but not related to a photograph or somebody else's report, and not an often-repeated anecdote).

**2.3 Task**

We designed a protocol (illustrated in Fig. 1A) where participants were asked to answer autobiographical memory questions while their eye movements were recorded with an eye-tracker and a camcorder (see subsection 2.4 for details).

Each trial started with the display of a black fixation cross in the center of the screen for 5 seconds. This ensured that the gaze was captured by the eye-tracker at the beginning of the trial. An autobiographical question was then presented orally through the computer's loudspeakers. This was followed by the access phase, during which participants embarked on a mental search for a relevant autobiographical event. Once they had selected an event, they pressed a key to end the access phase and start the elaboration phase, during which they were invited to mentally relive and visualize the selected event in order to retrieve as many details as possible. If no autobiographical event was found, the access phase automatically ended after 12 seconds (depending on studies, the average access time varies from 2.9 seconds (McCormick et al., 2015) to 6.28 seconds (Inman et al., 2018), we chose a longer maximal time to be sure we let a sufficient period of time to the participant to retrieve memories). An audio message indicated the end of the elaboration phase after 10 seconds (this period of time seems sufficient given the literature (Addis et al., 2007; McCormick et al., 2015) while being short enough to keep the duration of the experimental session inferior to two hours and a half), and participants were then asked to verbalize the event, with no time limit. This procedure allowed the experimenter to check that participants had performed the task properly and that their memory met all the criteria for autobiographical memory. At the end of the verbal recall, the experimenter asked three questions: (i) "Can you mentally relive the event?" (1- *Not at all*; 2- *Yes, but it is blurry*; 3- *Yes, it is as clear as if I were there*); (ii) "How much effort did it take to access the event?" (1- *It came spontaneously*; 2- *It required a moderate effort*; 3- *It required a high effort*); (iii) "Did you remember it or did you know it?" The first question probed the subjective impression of vividness, the second served to estimate the level of attentional effort, and the third checked the presence of an autonoetic state of consciousness, a necessary characteristic of autobiographical memory retrieval. All the material needed to reproduce the experiment is available at https://osf.io/6w5yq/download.

**2.4 Apparatus**

Participants were seated comfortably in front of a screen. The eye-tracker was positioned below the screen. The eye-lens distance was 500-700 mm. The precise distance was continuously monitored using an Eyelink target sticker placed on the forehead. Participants were asked to behave naturally, forgetting the devices around them. Indirect light projectors ensured that their face was perfectly illuminated (no shadow zone) for the eye-tracking and video analyses.

We used the EyeLink 1000 Plus (SR Research, Ontario, Canada) to record eye movements. As we were interested in ecological behavior, we decided to use the head-free tracking mode, so as not to constrain the participants' natural movements. We recorded binocular eye movements with a sampling frequency of 500 Hz. To guarantee the quality of the eye-tracking data throughout the session, we performed a 13-point calibration at the beginning of each block.

Participants' faces were videotaped with a Sony FDR-AX33 Handycam, with 1920 x 1080 px resolution. The camcorder was positioned so that the participant's face was centered in the image. Two loudspeakers on either side of the screen delivered the questions and messages.

### 2.5 Measures & Statistical Analysis

#### 2.5.1 Autobiographical memory analysis.

Based on the video recordings, the first author (A. Servais), a trained neuropsychologist, checked whether the memories met the criteria for autobiographical memories (Piolino, 2006) and assessed their richness (i.e., number of details). Responses that did not meet one or more criteria were discarded.

#### 2.5.2 Gaze aversion measurements.

The eye-tracking data were used to identify the point at which a gaze aversion occurred. As individuals obviously look away during gaze aversion, their gaze left the screen, leading to a loss of signal, as the eye-tracker was calibrated to record only eye positions in the screen area. Gaze aversions were therefore defined as periods when the eye-tracker signal was absent and/or located outside the screen for more than 500 ms, to exclude signal losses due to blinks (Huette et al., 2016). Trials were excluded from the analysis if there was a loss of signal > 500 ms during the display of the fixation point or the question, as this could not be interpreted as gaze aversion.

For each detected gaze aversion, we calculated the interval between the end of the question and the start of the gaze aversion (*delay*), and the total time during which the gaze remained averted (*duration*). We ran Hartigan's dip test on the distribution of the percentages of trials where gaze aversion was observed for each participant, to test the unimodality of the data. A bimodal distribution would force us to divide participants into subgroups. We ran separate dip tests on the percentages of gaze aversions for the access and elaboration phases.

#### 2.5.3 Head movement analysis.

Head movements were analyzed on the basis of screenshots extracted from the video. For each trial where a gaze aversion occurred, two frames were extracted from the video as screenshots: the last frame of the question (where the individual was still looking at the center of the screen), which served as the baseline, and a frame where the gaze aversion was visible. We first carried out a subjective analysis. A student who was naive about our hypotheses evaluated head movements during each gaze aversion ($N$ = 790) and compared the head positions in the two pictures and assessed whether the head had moved: not at all (scored 0), almost not (scored 1), moderately (scored 2), or strongly (scored 3). A second student performed the same assessment on 10% of the trials, chosen randomly, and interrater agreement was measured using Kendall's tau coefficient.

Second, we sought to quantify the amplitude of both eye and head movements during gaze aversion, to determine how much the head contributed to the gaze. During a visual task involving external attention, the head is known to contribute to approximately 35% of the gaze direction (Franchak et al., 2021). To quantify eye and head movements, we used OpenFace 2.0 (Baltrusaitis et al., 2018). Each screenshot was submitted to OpenFace to calculate gaze angles and head orientations. As our experiment was conducted during the COVID-19 pandemic, participants wore a mask, which affected the accuracy of OpenFace. Accordingly, all the pictures where OpenFace had automatically drawn the facial landmarks were examined manually, and only images with correct landmark detection were retained for this analysis (Fig. 1B). OpenFace correctly detected the face in 234 of the 790 trials (29.6%). No face was detected in 209 trials, and detection was not sufficiently accurate for the remaining 347 trials. Of the 234 trials, 186 were eligible for further analysis, as all the criteria for autobiographical memory were met. For the head, OpenFace yielded pitch and yaw values. For the eyes, OpenFace provided the gaze direction relative to the camcorder. We therefore multiplied the coordinates of this gaze direction vector by the head rotation matrix to transfer it to the head referential. Using the resulting vector and standard Euler angles, we then calculated the pitch and yaw rotations of the eyes. To work out the movement that took place during gaze aversion, we subtracted the baseline angles from the gaze aversion angles. The head's contribution to overall gaze direction was calculated with the following partial fraction, where the angle was either pitch (vertical up-down direction) or yaw (horizontal left-right direction):

$$Contribution\ of\ the\ head\ (\%)\ = \frac{Head\ angle}{Head\ angle +\ Eye\ angle} * 100$$

**2.5.4 Direction of gaze aversion.**

The direction of gaze aversion in the access phase was inferred from the last position of the gaze recorded on the screen prior to the aversion. The screen was divided into eight equal areas, allowing us to classify the gaze aversion according to eight different directions: up, down, left, right, upleft, upright, downleft, and downright. For directions deduced from the eye-tracking data, 10% were manually verified with the help of the video. This method proved highly accurate (i.e. > 80%) for all the directions (downleft: 87%; downright: 100%; left: 83%; right: 100%; up: 90%; upleft: 100%; upright: 83%) except for the down direction (71%). Therefore, all gaze aversions given the latter classification were manually corrected and the appropriate area assigned. The proportions of gaze aversions in each direction were calculated both for the group and for each participant.

We ran a cluster analysis to identify different subgroups of participants according to the direction of their gaze aversions. We used the NbClust package in R (Charrad et al., 2014) to determine the optimum number of clusters, and ran a *k*-means cluster analysis.

**2.5.5 Eye vergence analysis.**

For trials where there was no gaze aversion, we calculated changes in eye vergence behavior. We based our estimations of vergence on the positions of both eyes on the screen (i.e., based on fixation disparity, a measure of eye vergence that is easy to interpret; Ceh et al., 2021, Huang et al., 2019). More specifically, the change in vergence was calculated for each trial, relative to the fixation cross preceding the trial. Vergence was calculated from the position of each eye on the screen during the fixations detected by the Eyelink 1000 eye-tracking software. To detect saccades and fixations, we used the following recommended parameters: saccade velocity threshold of 30°/s, and saccade acceleration threshold of 8000°/$s^2$. Within each fixation, the distance on the screen between the left and right eyes was calculated for every timestep. We then calculated the centroid (normalized on the sum of the radii of the minimal bounding circles; i.e., most eccentric position of the eye during the fixation) of all the positions calculated during the same fixation for each eye, and the eye's mean position during this fixation. To calculate the distance between the two eyes, we therefore subtracted one centroid position from the other. When the result of this subtraction was negative, it meant that the eyes converged. By the same token, when the result was positive, it meant that the eyes diverged. When participants fixated on the cross during the baseline period, the positions of the two eyes were close to each other. If vergence changed during memory access, the distance between the two eye positions on the screen would presumably increase. For each trial, the distance between the two eyes during the access phase was compared with the distance between the eyes during the fixation cross period. First, we calculated the mean distance and standard deviation for all the fixations that occurred during the fixation cross period. Then, for every fixation that occurred during the access phase, we calculated a $z$ score for the distance between the two eyes. If this score was above 1, the fixation was deemed to show significant divergence. On the contrary, if it was below -1, the fixation was deemed to show significant convergence. If more than 70% of fixations during the access phase were characterized by significant divergence, the trial was deemed to be a significant divergence trial. Similarly, if more than 70% of fixations were characterized by significant convergence, the trial was deemed to be a significant convergence trial. We set the threshold at 70%, in order to be above 50% without being too strict. The same method was used to calculate the change in vergence during the elaboration phase.

### 2.5.6 Relations between vergence change and gaze aversion.

To explore whether the gaze aversion and vergence strategies depended on the individual, we calculated the Spearman correlation between the percentage of trials with gaze aversion and the percentage of trials with either significant divergence or convergence for each participant. To ascertain whether different patterns of strategies were preferred by different subgroups of participants, we then ran an ascendant hierarchical cluster analysis using the NbClust package in R (Charrad et al., 2014) to determine the optimum number of clusters.

#### 2.5.7 Relations between gaze aversion and memory retrieval.

To understand the impact of cognitive effort on the occurrence of gaze aversion, we calculated the Friedman test for repeated measurements on the proportion of questions where gaze aversion was observed, with the three levels of effort as the within-participants factor. Separate analyses were performed for the access and elaboration phases. The Bonferroni correction was applied to correct $\alpha$ for the number of comparisons ($\alpha = .025$). The size effect reported for the Friedman tests was Kendall's $W$ statistic. To investigate whether there were only differences between certain levels of cognitive effort, we calculated pairwise comparisons with the Nemenyi post hoc test. To understand the impact of the vividness of the memory on the occurrence of gaze aversion, the same tests were calculated with the three levels of vividness (not at all, blurry, clear) as the within-participants factor. To test whether the quality of reported memories was higher (i.e., more details) during trials with gaze aversion than trials without gaze aversion, we ran the Wilcoxon signed-rank test, where the dependent variable was mean memory quality per participant and the repeated-measures variable was the presence or absence of gaze aversion. The size effects reported for Wilcoxon signed-rand tests was point-biserial correlation coefficient.

**2.5.8 Relations between vergence change and memory retrieval.**

To understand the impact of cognitive effort on the occurrence of divergence behavior, we calculated the Friedman test for repeated measurements on the proportion of questions where a significant divergence was observed, with the three levels of effort (spontaneous, moderate, high) as the within-participants factor. Separate analyses were performed for the access and elaboration phases. We then ran the same test for convergence behavior. The Bonferroni correction was applied to correct α for the number of comparisons (α = .0125). To understand the impact of the vividness of memories on the occurrence of divergence and convergence behaviors, we ran the same tests as those performed for cognitive effort. To test whether the quality of the reported memories was higher (i.e., more details) during trials with a change in vergence than during trials with no divergence or convergence, we ran the Wilcoxon signed-rank test, where the dependent variable was mean memory quality per participant and the repeated-measures variable was the presence or absence of either divergence or convergence.

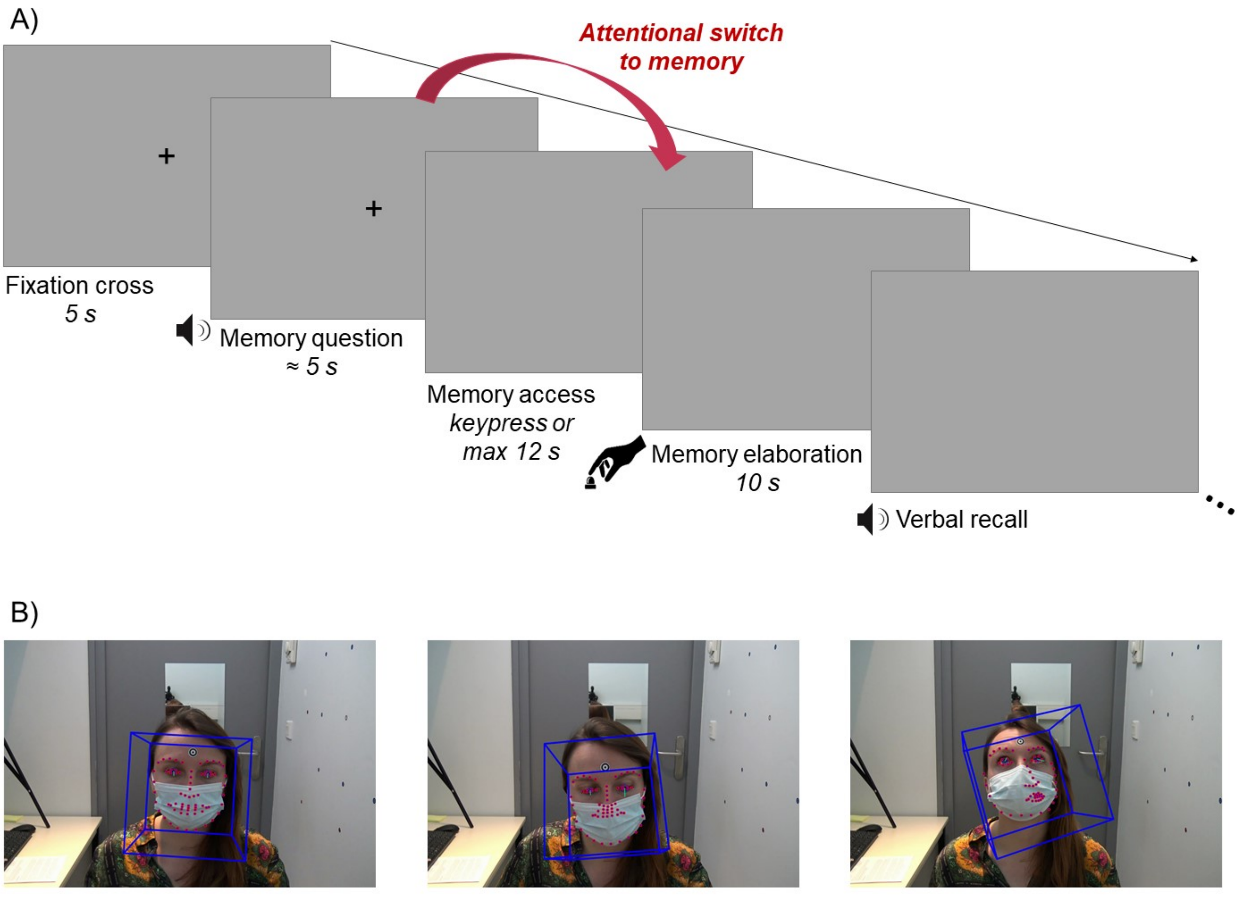



*Figure 1.* A) Trial time course. B) The image on the left shows good detection of the landmarks by OpenFace. The two images on the right are examples of erroneous detection (i.e., images that were excluded from the analyses). It should be noted that, in accordance with data protection regulations, the images represent a co-worker, not a participant.

## 3. Results

Analyses were performed on 1274 of the 1536 questions (48 trials * 32 participants) (76 were excluded because the participants talked during retrieval, 57 because responses did not meet the episodic autobiographical memory criteria, and 129 because of signal loss). Assessment of the memories' richness revealed that participants reported on average 6.68 details per memory event ($SD = .96$).

### 3.1 Presence and Timing of Gaze Aversion

Results revealed that 30/32 participants averted their gaze during the access phase, which had a median duration of 3.90 s (Q1 = 1.65 s; Q3 = 7.86 s). Gaze aversion was observed in 492 trials (38.62%). It started after a median delay of 1.09 s (Q1 = 0.47 s; Q3 = 2.02 s) and had a median duration of 6.12 s (Q1 = 2.17 s; Q3 = 12.46 s) (Fig. 2), representing 65.59% on average of the access phase. It should be noted that 52.84% of the gaze aversions that started during the access phase continued during the elaboration phase. The proportion of trials where gaze aversion was observed during the access phase varied considerably (5-91%, *Mdn* = 35%) between participants (see Fig. 3A). Hartigan's dip test of unimodality was not significant ($D_{32} = .05$, $p = .74$).

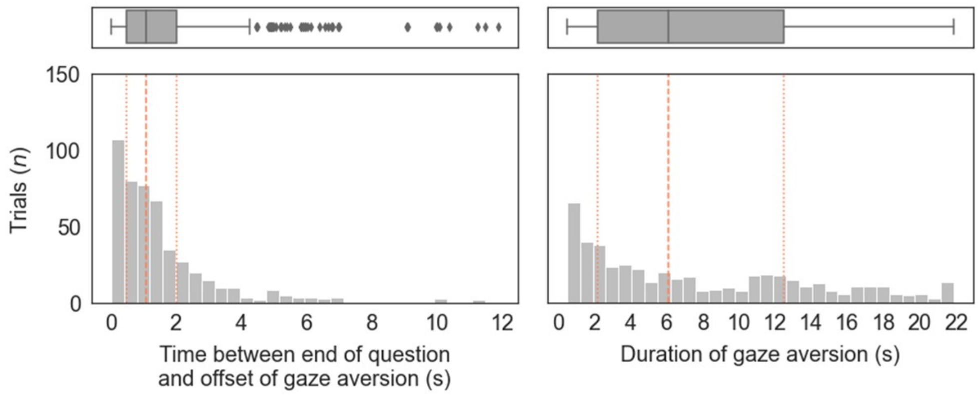



*Figure 2.* Boxplots and histograms of the distribution of gaze aversions during the access phase according to 1) delay and 2) duration. The dashed lines represent the median, and the dotted lines the first and third quartiles.

The elaboration phase had a fixed duration of 10 s for all the questions. Nearly all (30/32) participants averted their gaze during this phase. The proportion of trials where gaze aversion was observed during the elaboration phase varied from 2% to 54% (*Mdn* = 22%) (see Fig. 3A). The distribution resembled that of the access phase, and here too Hartigan's dip test of unimodality was not significant ($D_{32} = .07$, $p = .26$). Gaze aversion was observed during the elaboration phase for 595 questions (46.70% of all the questions), but in 316 cases, it had started during the access phase. Therefore, only 279 questions resulted in an aversion that started during the elaboration phase itself (21.90%).

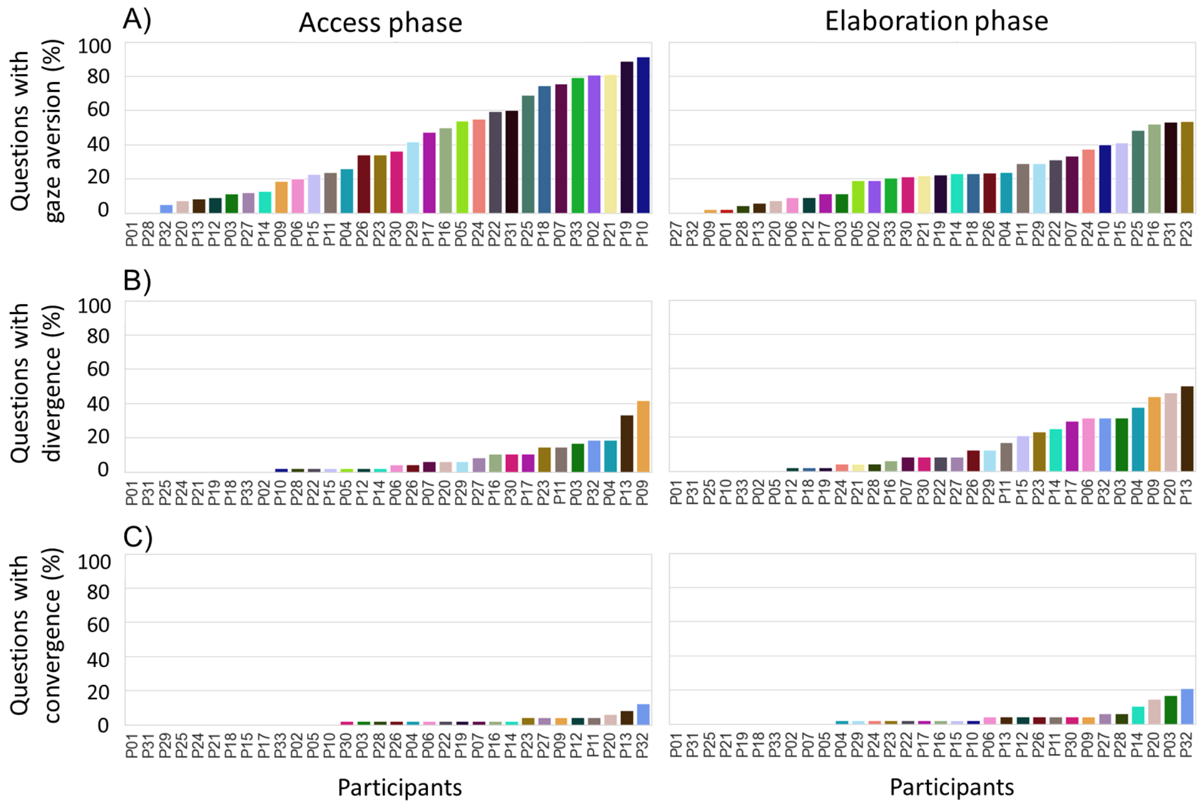



*Figure 3*. Bar graphs showing for each participant: A) the percentages of trials that elicited gaze aversion during the access (left) and elaboration (right) phases, B) the percentages of trials featuring divergence, and C) the percentages of trials featuring convergence. Pxx: code of the participant, xx being the anonymization number assigned to the participant.

### 3.2 Eye-Head Coordination

The subjective assessment of eye-head coordination suggested that the head did not move at all for 72.85% of gaze aversions in the access phase (interrater agreement, $r_t = .37$, $p < .001$) (Fig. 4A). The objective, quantitative assessment (in degrees) revealed a higher frequency of small head angles for both yaw (horizontal) and pitch (vertical), with a high concentration of trials where head movement was close to 0°. We observed a higher angle values for the eyes by contrast (Fig. 4C). The head contributed to less than 35% of the total horizontal movement (eye + head yaw, Franchak et al., 2021) in a large majority (74.59%) of gaze aversions, highly suggestive of a decoupling between gaze aversion and head movement.

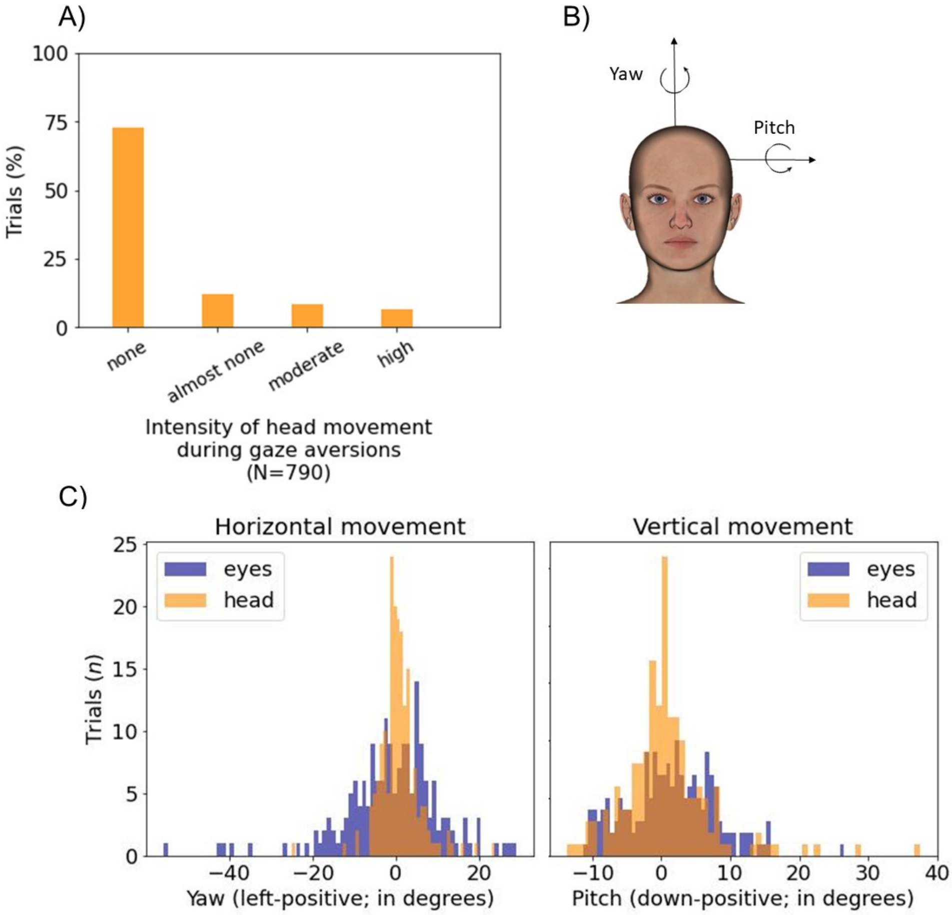
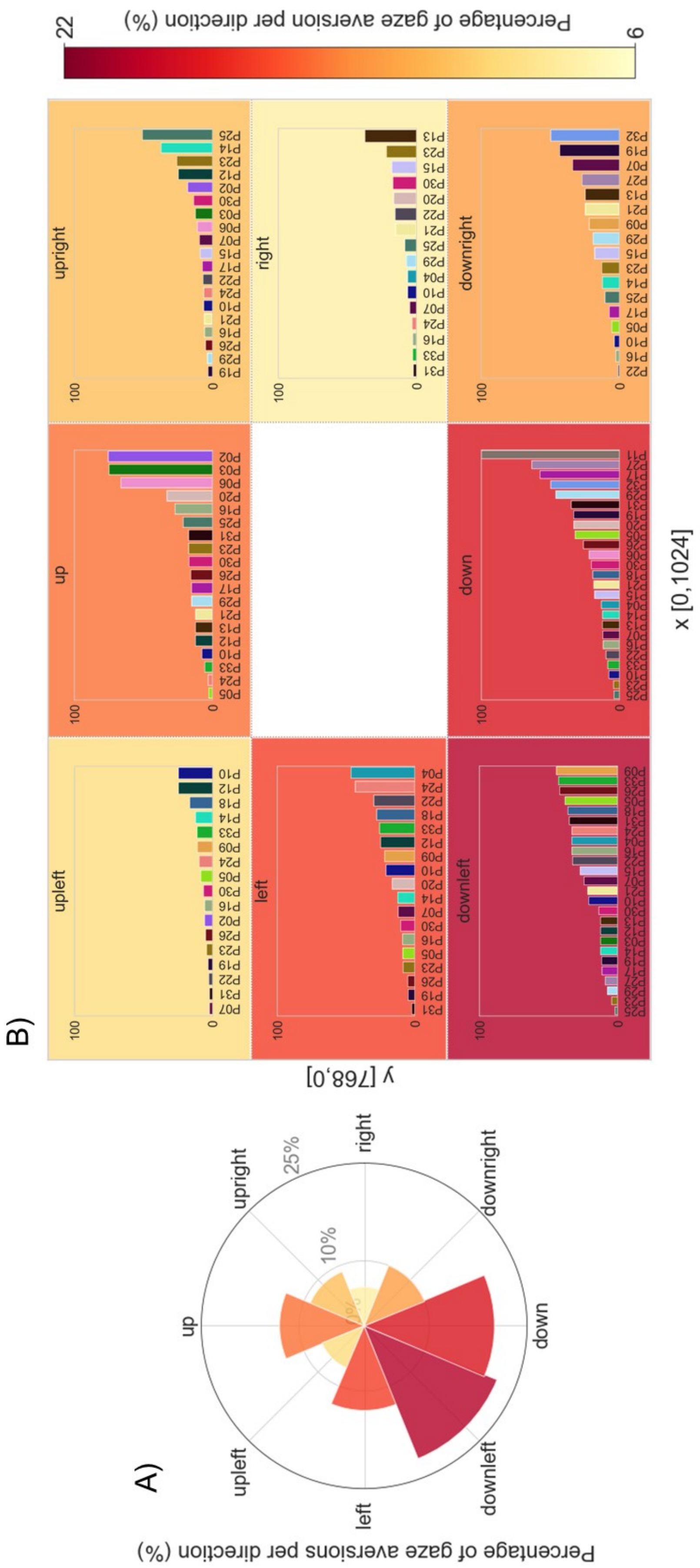



*Figure 4*. A) Subjective assessment: Bar graph of percentages of responses (*none*, *almost none*, *moderate*, *high*) concerning head movement during gaze aversion. B) Illustration of rotation axes. C) Quantitative measures: Histograms of rotational angles of the head and eyes between baseline and gaze aversion. Pitch is a vertical angle where positive values correspond to a downward movement. Yaw is a horizontal angle where positive values correspond to a leftward movement.

### 3.3 Direction of Gaze Aversion

Data from the 30 participants who exhibited gaze aversions during the access phase were included in the analysis. We observed a higher frequency of down- and down-leftward gaze aversions (see Fig. 5A). However, there was considerable interindividual variability (see Fig. 5B). This variability was confirmed by a cluster analysis (see Fig. 6). The NbClust R package determined that the optimum number of clusters was three based on 30 indices. The first cluster (C1) contained three participants who mostly produced upward gaze aversions, the second cluster (C2) included six participants who mostly produced downward gaze aversions, and the third cluster (C3) contained 21 participants with heterogeneous profiles. Recursive clustering on C3 revealed that the optimum number of subclusters was again three. C3.1 included four participants who showed a preference for up-rightward gaze aversions, C3.2 included 7 seven participants with down-/down-leftward gaze aversions, and C3.3 showed high heterogeneity. In total, 20/30 participants exhibited a preferential gaze direction.



A)
B)
Percentage of gaze aversions per direction (%)
up
upright
right
downright
down
downleft
left
upleft
10%
25%
y [768,0]
x [0,1024]
Percentage of gaze aversion per direction (%)
22
6

*Figure 5.* A) Polar plot of the percentages of gaze aversions in each of the eight directions for all participants. B) Representation of the eight screen zones with the heatmap representing the percentage of gaze aversions occurring in the direction corresponding to the zone for all the participants. Inside each zone is a histogram representing the percentage of gaze aversions in the given direction for each individual.

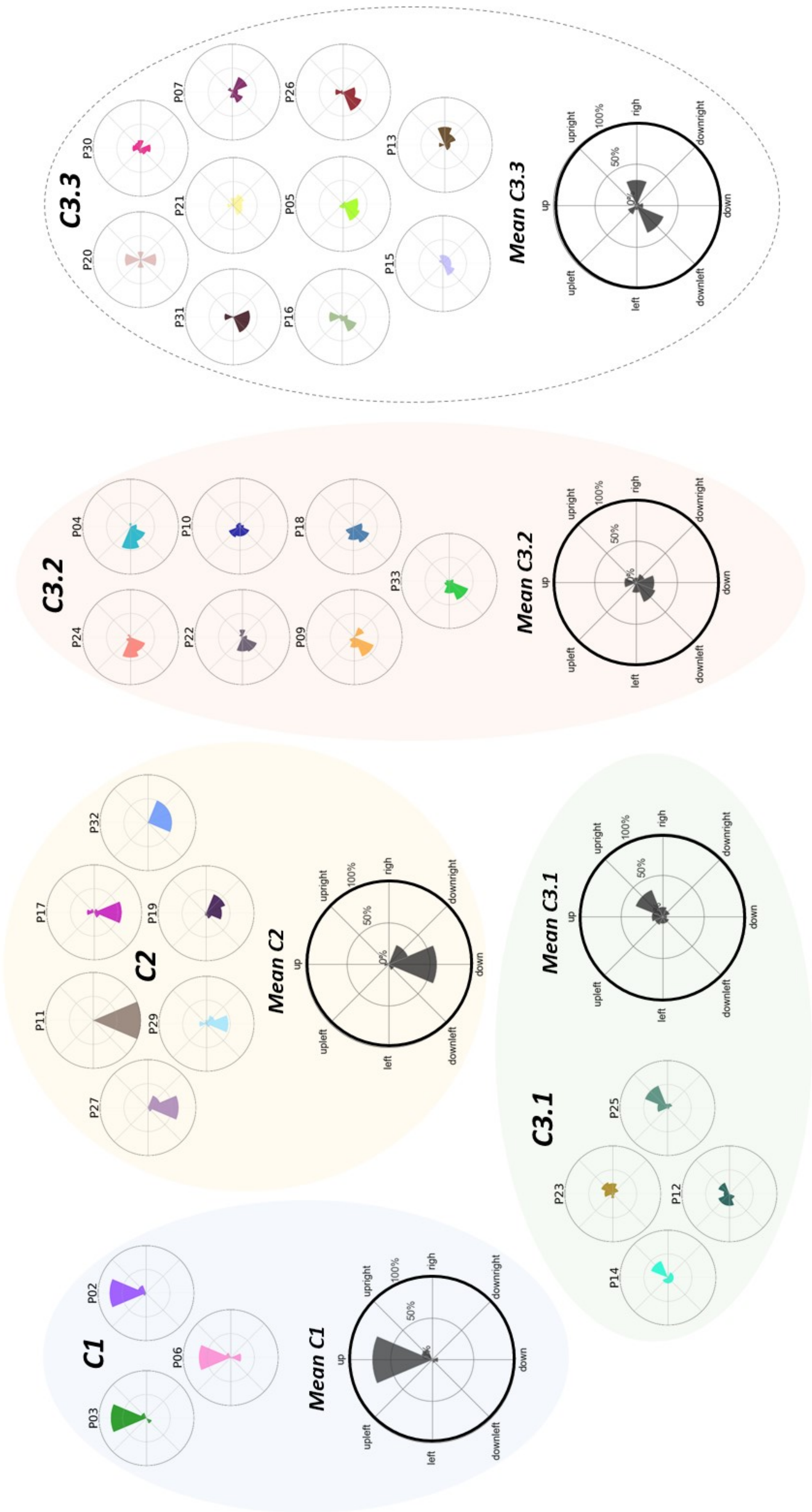

C1
P03
P02
P06
Mean C1
C2
P27
P11
P17
P29
P19
P32
Mean C2
C3.1
P14
P23
P25
P12
Mean C3.1
C3.2
P24
P04
P22
P10
P09
P18
P33
Mean C3.2
C3.3
P20
P30
P31
P21
P07
P16
P05
P26
P15
P13
Mean C3.3
up
upright
righ
downright
down
downleft
left
upleft
0%
50%
100%

*Figure 6.* Gaze aversion direction clusters and subclusters revealed by the cluster analyses. Each cluster or subcluster contains the profiles of individual participants showing the distribution (in %) of gaze aversions according to direction. The cluster with the greatest heterogeneity is surrounded by a dotted line. The mean pattern of each cluster is shown in the circles in bold.

### 3.4 Change in Vergence

As we found high variability in the propensity of participants to exhibit gaze aversions, we analyzed vergence as an alternative way of disengaging from the outside world. The analyses were run on the 392 trials where there was no gaze aversion. During the access phase, there was significant (i.e., $z > 1$) divergence in 115 trials, and convergence in 34 trials. During the elaboration phase, there was significant divergence in 225 trials, and convergence in 59 trials. Figures 3B and 3C show the numbers of trials with convergence or divergence across participants. To compare the proportion of the two different eye movements, Figures 3B and 3C can also directly be compared with Figure 3A.

### 3.5 Relation Between Change in Vergence and Gaze Aversion

During the access phase, there were significant negative correlations between the percentages of trials with gaze aversion and either divergence, $r(30) = -.51$, $p = .003$, or convergence, $r(30) = -.61$, $p < .001$. During the elaboration phase, there was a significant negative correlation between the percentages of trials with gaze aversion and convergence, $r(30) = -.45$, $p = .009$, but the correlation between divergence and gaze aversion was not significant, $r(30) = -.26$, $p = .147$ (see Fig. 7).

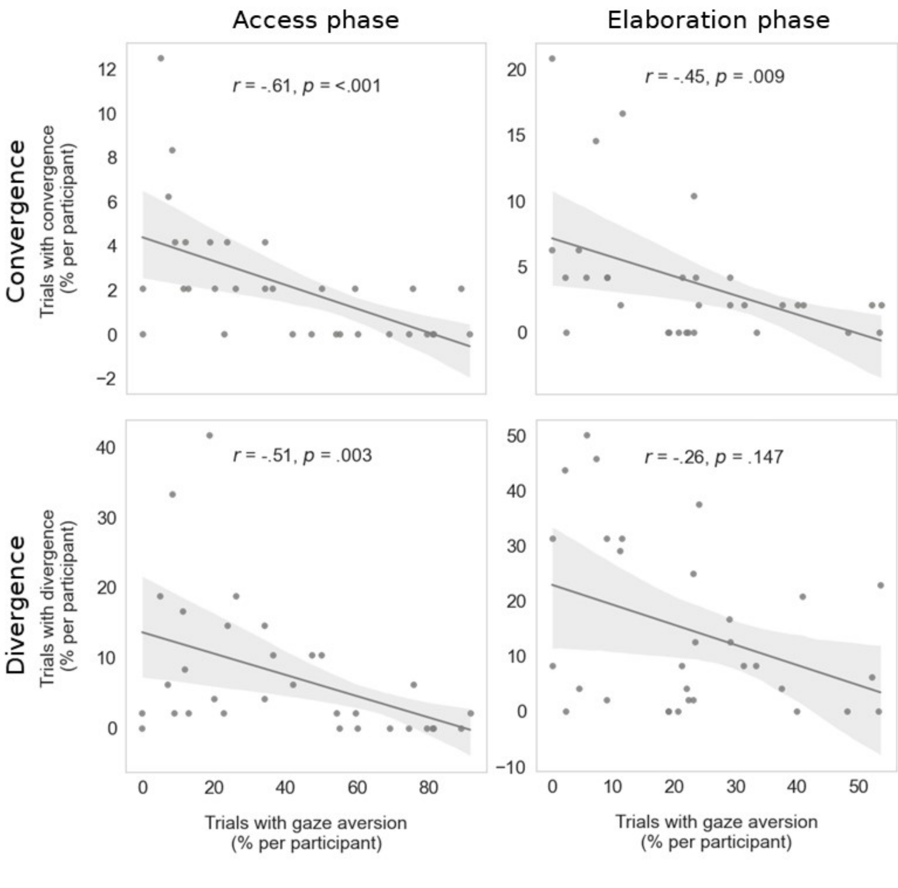


*Figure 7.* Correlations between frequency of gaze aversion and frequency of convergence or divergence behavior, during access or elaboration phase. Each dot represents the percentage of trials showing the given behavior for one participant.

We then ran an ascendant hierarchical clustering analysis to determine whether participants could be classified according to their preferential oculomotor strategy during memory retrieval: gaze aversion, divergence, or convergence during the access or elaboration phase. The optimum number of clusters was three (see dendrogram in Fig. 8). C1 contained 13 participants who predominantly used gaze aversion during both the access and elaboration phases. These participants seldom used vergence strategies. C2 included nine participants who mostly engaged in gaze aversion during both the access and elaboration phases, but who also used divergence in some trials during the elaboration phase. C3 seemed to be composed of two subclusters: four participants who did not use any of these strategies, and six participants who mostly used divergence.

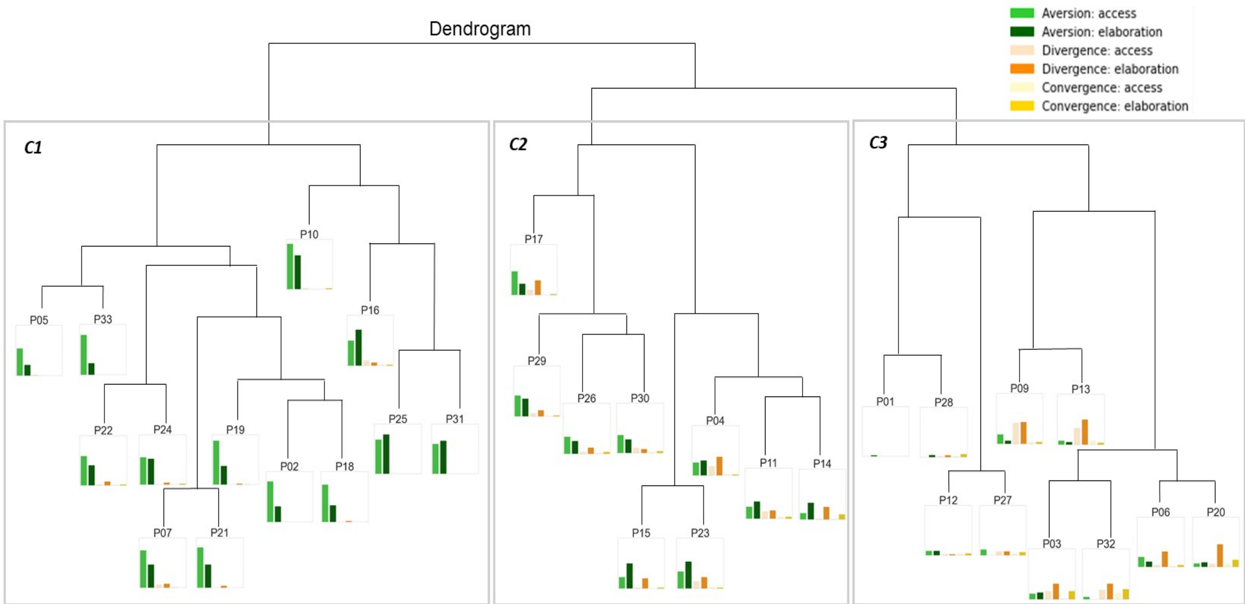



*Figure 8.* Dendrogram showing hierarchical cluster analysis. Each gray box represents one cluster. The profile of each participant is represented as a bar on a scale of 100% of the trials.

### 3.6 Links Between Gaze Aversion and Memory Retrieval

Friedman tests revealed a significant difference in the proportion of gaze aversion according to the level of cognitive effort during the access phase, $F_{(2, 60)} = 26.16$, $p < .001$, $W = .46$, indicating a higher frequency of gaze aversion for questions requiring greater cognitive effort, but not during the elaboration phase, $F_{(2, 60)} = 1.38$, $p = .26$, $W = .05$ (Fig. 9).

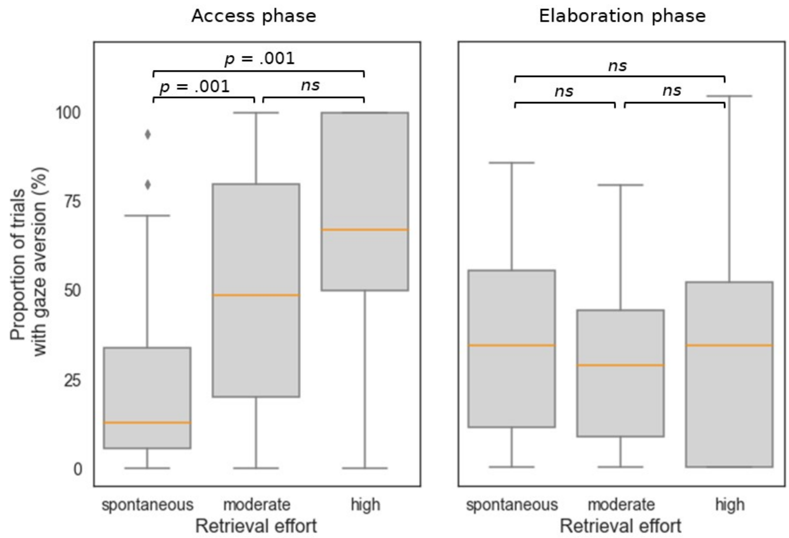



*Figure 9.* Box plots showing percentages of trials with gaze aversion according to level of cognitive effort for the access and elaboration phases. The *p* values of the Nemenyi post hoc tests are reported where significant. *ns* = nonsignificant.

Friedman tests revealed a significant difference in the proportion of gaze aversions according to the vividness of memories for both the access, $F_{(2, 60)} = 8.48$, $p < .001$, $W = .21$, and elaboration, $F_{(2, 60)} = 5.83$, $p = .005$, $W = .16$, phases (Fig. 10), indicating that a higher frequency of gaze aversion was associated with greater vividness.

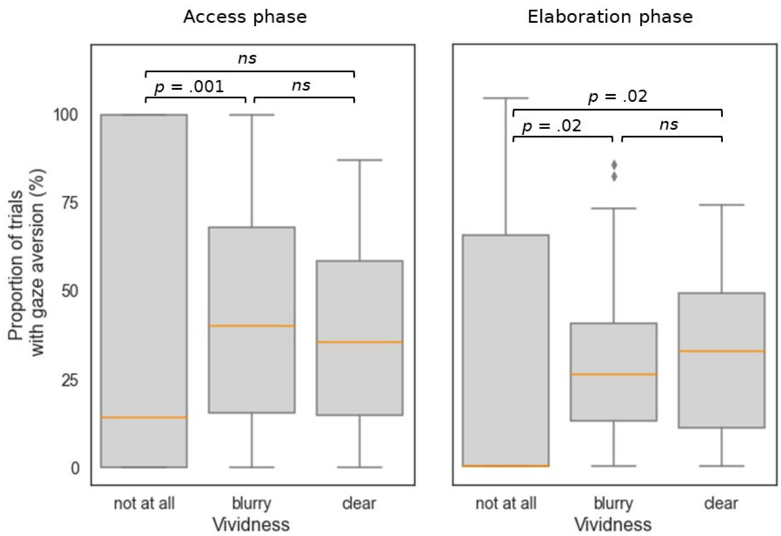



*Figure 10.* Box plots of the percentages of trials with gaze aversion for every level of vividness for access and elaboration phases. The p values of the Nemenyi post hoc tests are reported where significant. *ns* = nonsignificant.

The mean number of details was 6.42 ± 1.17 for trials with gaze aversion versus 6.38 ± 1.08 for trials without aversion. This difference was not significant (Wilcoxon signed-rank test, $T = 211$, $p = .66$, $r_{pb} = .09$).

### 3.7 Links Between Changes in Vergence and Memory Retrieval

Friedman tests revealed significant differences in the proportions of trials where there was significant convergence, $F_{(2, 60)} = 6.53$, $p = .003$, $W = .17$, or divergence, $F_{(2, 60)} = 9.30$, $p < .001$, $W = .23$, according to the level of cognitive effort, but solely for the elaboration phase, indicating that convergence and divergence occurred more often when memories were recalled spontaneously, rather than effortfully. Cognitive effort did not have a significant effect on the frequency of change in vergence during the access phase. Regarding the vividness of memories, Friedman tests revealed a significant difference in the proportion of trials with significant convergence, depending on the vividness of memories in both the access, $F_{(2, 60)} = 9.37$, $p < .001$, $W = .23$, and elaboration, $F_{(2, 60)} = 11.32$, $p < .001$, $W = .27$, phases, indicating that convergence occurred more often when memories were highly vivid, in both the access and elaboration phases. The vividness of memories did not have a significant effect on the frequency of divergence. These figures are available online as supplementary material (https://osf.io/pbvmq/) and can be reproduced using the code (https://github.com/AnaisServais/Gaze-aversion-Memory-retrieval). The average number of details did not differ significantly either between trials with and without divergence, $T = 98$, $p = .23$, $r_{pb} = -.29$, or between trials with and without convergence, $T = 76$, $p = .47$, $r_{pb} = -.20$ (Wilcoxon signed-rank test). The mean number of details during trials with divergence was 6.49 ± 1.72 versus 6.83 ± .88 for trials without divergence. The mean number of details during trials with convergence was 6.34 ± 2.21 versus 6.81 ± .90 for trials without convergence.

## 4. Discussion

This study is particularly novel since it is, to the best of our knowledge, the first one to provide specific characteristics of gaze aversion such as time of occurrence, duration, and direction. Gaze aversion was also compared for the first time with vergence in order to assess how specific were our findings.

Gaze aversion is a commonly observed behavior during memory retrieval that has been documented long ago (Glenberg et al., 1998; Kinsbourne, 1972), but has received surprisingly little scientific interest so far. In line with the *cognitive load theory of gaze aversion* (Abeles & Yuval-Greenberg, 2017) and the *looking at nothing* phenomenon (Salvi & Bowden, 2016), we tested the hypothesis that gaze aversion could be related to the attentional switch from the external world toward the internal mental world. Results of the present study confirm that gaze aversion frequently occurs during autobiographical memory retrieval, but to varying degrees across individuals. More specifically, compared with divergence, another eye behavior related to internal attention (Benedek et al., 2017; Huang et al., 2019), gaze aversion is more frequent: it was observed in a greater number of participants (all but 2) and in response to a greater number of questions. We never saw participants spontaneously close their eyes during memory retrieval (Perfect et al., 2008; Vredeveldt et al., 2011). Gaze aversion therefore seems to naturally prevail over other eyes disengagement behaviors.

Large interindividual differences were observed however. We found a negative correlation between the individual propensity to avert the gaze and change in vergence. In addition, cluster analyses revealed three subgroups of participants: those who preferentially exhibited gaze aversion (41%), those who exhibited either gaze aversion or divergence (28%), depending on the question, and those who preferentially exhibited divergence (19%). It should be noted that a minority of individuals did not engage in any of these ocular strategies (12%). Although gaze aversion is the eye movement most often used, this interindividual variability means that individuals may favor different perceptual decoupling strategies during autobiographical memory retrieval, possibly linked to individual factors such as personality traits, mental imagery, attention, or memory capacities. However, the choice of one strategy or another may not depend solely on the individual's cognitive profile, and may also be influenced by the characteristics of the memory retrieval.

Divergence and gaze aversion may also occur at different stages of memory retrieval and for different cognitive purposes. For example, our results showed that eye vergence occurred more often during the elaboration phase of memory retrieval, and was more frequently observed for spontaneous memories than for those requiring cognitive effort. Conversely, gaze aversion was more likely to occur when memories required a high cognitive effort, and was predominantly observed during the access phase. Indeed, gaze aversion occurred early during memory retrieval—generally within the first second. It was also more frequent during the initial access phase than during the later elaboration phase. This is a first argument in agreement with our hypothesis according to which gaze aversion is related to the switch between the external and internal world during the initiation of memory retrieval since this corresponds to the moment where the attentional switch takes place.

Our results provide several other arguments supporting this idea. First, as expected, gaze aversion lasted several seconds (6 s on average), a relatively long duration that is believed to facilitate perceptual decoupling during memory retrieval. This is congruent with the idea that people can remain immersed in their internal thoughts without awareness of the external world for multiple seconds—on average between 1 and 3 seconds, sometimes up to 10 seconds (Huang et al., 2019). Second, we showed that the head did not follow the eyes during gaze aversion, or to a smaller extent than during visual exploration of the environment. This may further support perceptual decoupling, as visual processing at far eccentricities is less accurate because of unstable fixations (Nakashima & Shiori, 2014). Third, our clustering analyses revealed that there is no typical and unique direction of gaze aversion. Instead, a majority of individuals seem to have their own preferential direction, with one-third of the participants showing no specific preference. In our experimental room, participants were facing the computer screen and a neutral grey wall right behind. This seems compatible with the "looking at nothing" phenomenon reported by Salvi & Bowden (2016), and also in favor of the perceptual decoupling assumption. The individual preferences in gaze direction are difficult to explain at this stage and require more investigation, but we hypothesized, that once participants found a neutral location, they tend to orient their gaze in that direction again. Fourth, the fact that gaze aversion occurred more likely during the access phase for questions requiring high cognitive effort is consistent with studies reporting that gaze aversion occurs while answering difficult memory questions (Doherty-Sneddon & Phelps, 2005; Glenberg et al., 1998). It has been suggested that external and internal attention compete when cognitive processes are voluntary and effortful, not when they are spontaneous (Dixon et al., 2014). Gaze aversion may therefore help individuals to deal with this competition by disengaging from the environment when a high retrieval effort is required. On the contrary, gaze aversion would not be necessary for spontaneous memories since internal and external worlds can be attended simultaneously in that case (Dixon et al., 2014).

Given that the attentional switch is closely related to perceptual decoupling, we also examined the relationship between gaze aversion and the vividness and quality of the memories. Our results showed that gaze aversion occurred more often for vivid memories rather than for unclear ones. We don't have evidence about any causal direction, but because the perceptual decoupling induced by gaze aversion induce better mental imagery (Markson & Paterson, 2009), this might explain the higher subjective feelings of vividness. However, gaze aversion did not significantly increase the objective quality of retrieval in terms of the number of details. Gaze aversion therefore seems to be related to effortful retrieval, rather than to successful memory retrieval, perhaps because the context of the requested memory event is difficult to retrieve. Nevertheless, even though gaze aversion occurred more frequently for hard-to-access memories, the quality of these memories was no less good than that of easily accessible memories. In future studies, it would be interesting to investigate whether there is an interaction effect between cognitive effort, vividness, and the presence of gaze aversion on memory quality. Not all participants provided memories for all categories, which prevented us to run such statistical analyses and test these interactions. The hypothesis would be that gaze aversion, thanks to the perceptual decoupling it causes, helps retrieval for an equivalent cognitive effort. Another question also remains open. If gaze aversion is related to the attentional switch, we are unsure why we also observed a certain number of gaze aversions during the elaboration phase of memory retrieval. An hypothesis is that individuals may sometimes simply relaunch research processes to look for new elements (Henson et al., 1999).

As perspectives, because our behavioral results support our hypothesis, it would be interesting to use other approaches to test further the link between gaze aversion and attentional switch away from the external world. Neuropsychological studies could help corroborate this or not. For example, it would be interesting to observe whether amnesic patients, who have difficulties accessing memories, do even more gaze aversion since it requires potentially more effort to switch their attention towards their inner world to initiate memory retrieval. Aphantasic patients, who have an incapacity to generate mental images (Dawes et al., 2020; Zeman et al., 2015), could also improve our understanding of those mechanisms. If aphantasic individuals do gaze aversion while trying to remember, it would support that gaze aversion, as a perceptual decoupling strategy, is not directly linked with mental imagery, but rather to more early cognitive processes such as the attentional switch. Neuroimaging studies could also help investigating this relation. Internal and external attention activate anti-correlated brain networks (Fox et al., 2005). Switching to the inner world therefore require the brain to switch from one network to the other (Tang et al., 2012). We showed that gaze aversion is related to higher cognitive effort and is quite rare during memories which come spontaneously to mind. This is most likely because spontaneous memories don't compete with external tasks and can be retrieved in parallel (Dixon et al., 2014). When memory retrieval requires cognitive effort in contrast, external and internal information compete for attentional resources, which may involve specific brain regions such as the lateral prefrontal cortex (Burgess et al., 2007; Dixon et al., 2014) and modify their connectivity with other brain networks (Dixon et al., 2014). Investigating if gaze aversion occurs while this functional brain reorganization takes place would be a quintessential argument in favor of our hypothesis.

It is worth highlighting how challenging recording and measuring gaze aversion is. This is perhaps one of the reasons why it has been rarely studied so far. Indeed, identifying gaze aversion using a remote eye-tracker is difficult since, by definition, it brings the gaze outside of the trackable range of the eye-tracker. Here, we designed a novel methodology where we identified gaze aversion as the period where the gaze was outside of the screen for some time—indicated by a loss of signal and we validated this analysis by verifying the videos of the participant's eyes as ground truth. Although imperfect, this is a substantial step towards a more automatized analysis of gaze aversion. Future studies might want to use alternative solutions, such as eye-tracking glasses or electro-oculography. However, those also have their own limits in our experience.

Our study helped characterizing gaze aversion but faces limitations. First, we used only autobiographical memory questions to induce gaze aversion, but given that it occurs during other cognitive processes such as arithmetic or semantic memory retrieval (Doherty-Sneddon & Phelps, 2005), future studies should determine whether the characteristics of gaze aversion are common or different depending on the underlying cognitive demand. Second, given the high inter-individual variability, it seems necessary to investigate the factors influencing gaze aversion in more details. Potential factors could be related to individual traits such as personality or cognitive abilities. Culture, for example, has an impact on the direction in which the gaze is averted (McCarthy et al., 2008). Individual characteristics could explain the inter-individual variability reported in this study. Experimental conditions such as the specificities of the memory event or the experimental protocol could also influence the occurrence of gaze aversion. We would, for example, expect a higher rate of gaze aversion if the experimenter was seated face-to-face with the participant (Doherty-Sneddon & Phelps, 2005) and not behind as we did here.

To conclude, our results provide arguments that gaze aversion is a perceptual decoupling strategy that is implemented during the attentional switch from the outer to the inner world, here during autobiographical memory retrieval. We can therefore assume that gaze aversion supports a critical early cognitive step that allows for the initiation of effortful memory retrieval. This raises the question of a clear definition of what gaze aversion is. It was initially used to refer to the behavior consisting in avoiding looking at the interlocutor during social interactions (Glenberg et al., 1998). It has since also been observed in the absence of an interlocutor (Doherty-Sneddon & Phelps, 2005). More recently, it has been referred to as *looking at nothing* (Salvi & Bowden, 2016). Based on the cognitive load hypothesis of gaze aversion (Abeles & Yuval-Greenberg, 2017) and on our results showing the close relation with the attentional switch to memory, we propose to revise this terminology and to define it more exactly as a *visual disengagement* from external information.

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**Open Practices**

All the anonymized data and the material needed to reproduce the experiment are publicly available via OSF and can be accessed at https://osf.io/pbvmq/. The code to reproduce the analyses is publicly available at https://github.com/AnaisServais/Gaze-aversion-Memory-retrieval. Note that the links have been made anonymous for the reviewing process, but will be replaced. As the General Data Protection Regulation prohibits the divulgation of data that would allow participants to be identified, we cannot share any of the video recordings. The design and analysis plan for the study were not preregistered.

**Declaration of Competing Interests**

The authors declare that there were no conflicts of interest.

**Author Contributions**

All the authors engaged in conceptual and methodological discussions. A. Servais and N. Préa designed the study, tested the participants, and analyzed the data. A. Servais wrote the draft manuscript, and E. Barbeau and C. Hurter provided critical feedback and revisions. All the authors approved the final version of the manuscript before submission.

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