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Eye movement during retrieval of emotional autobiographical memories

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A B S T R A C T

This study assessed whether specific eye movement patterns are observed during emotional autobiographical retrieval. Participants were asked to retrieve positive, negative and neutral memories while their scan path was recorded by an eye-tracker. Results showed that positive and negative emotional memories triggered more fixations and saccades but shorter fixation duration than neutral memories. No significant differences were observed between emotional and neutral memories for duration and amplitude of saccades. Positive and negative retrieval triggered similar eye movement (i.e., similar number of fixations and saccades, fixation duration, duration of saccades, and amplitude of saccades). Interestingly, the participants reported higher visual imagery for emotional memories than for neutral memories. The findings demonstrate similarities and differences in eye movement during retrieval of neutral and emotional memories. Eye movement during autobiographical retrieval seems to be triggered by the creation of visual mental images as the latter are indexed by autobiographical reconstruction.

1. Introduction

Autobiographical memories or memories for personal experiences allow individuals to define themselves and make sense and meaning of their life history (Conway & Pleydell-Pearce, 2000). These memories are reconstructed and regulated by control processes that seek to maintain consistency between one's beliefs, goals, emotional state, and the reality of the remembered event itself (Conway, 2005). For instance, individuals may retrieve memories about past victories in order to support their current positive emotion, or selectively retrieve negative memories to prepare themselves for a potential failure. Therefore, it appears that emotion may play a pivotal role in the reconstruction and regulation of autobiographical memories (Holland & Kensinger, 2010). Besides its role in autobiographical regulation, emotion has been found to improve autobiographical memory by enhancing retrieval of sensory and contextual details that were encountered during encoding (Comblain, D'Argembeau, & Van der Linden, 2005; St Jacques & Levine, 2007). Reflecting these outcomes, emotional autobiographical memories have been reported to be experienced with more visual imagery than neutral ones (Schaefer & Philippot, 2005), and rich emotional content has been found to trigger rich subjective experience during autobiographical retrieval (Talarico, LaBar, & Rubin, 2004).

Studies on the involvement of emotion in autobiographical memory have mainly evaluated how emotion influences subjective experience (e.g., vividness) during retrieval of emotional memories (Schaefer & Philippot, 2005). Besides this evaluation, research on cardiovascular and electrophysiological activity during retrieval of emotional autobiographical memories found that significant physiological changes occur (Schaefer & Philippot, 2005). Our paper aimed to further assess the oculomotor behavioral changes that are associated with retrieval of emotional autobiographical memories by testing whether such retrieval may trigger specific eye movement.

In our view, decoding eye movement during retrieval of emotional autobiographical memories may provide a new, ecological and reliable tool to describe the physiological activities that occur simultaneously. This approach might also provide insights into emotional processing in autobiographical memory. A previous study assessed whether autobiographical retrieval is associated with visual exploration or not (El Haj et al., 2014). To this end, participants were asked to retrieve in detail an event in their lives, and in a control condition, they were asked to count aloud. In both conditions, the participants had to look at a blank screen while their gaze location was recorded by an eye-tracker. We found a lower number of fixations but a larger number, duration and amplitude of saccades in the autobiographical condition than in the control one. These findings were attributed to visual imagery as triggered by autobiographical recall (El Haj et al., 2014).

Attributing visual exploration, as assessed by eye movement, to visual imagery fits with the consideration that autobiographical memories come to mind in the form of visual images and that the latter are the main format of autobiographical reliving (Conway, 2009). According to Conway and Pleydell-Pearce (2000), the creation of visual

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mental images facilitates autobiographical recall by increasing the ease and speed of search through the hierarchical structure of autobiographical memory. The contribution of mental imagery to autobiographical memory is also supported by a study showing better autobiographical recall in healthy individuals with high visual imagery than in those with low visual imagery (Vannucci, Pelagatti, Chiorri, & Mazzoni, 2016). Also, Brandt and Stark (1997) assessed visual exploration during imagery. This by comparing the viewing pattern of a diagram of an irregularly checkered grid with the eye movements while subjects imagined that particular grid. The authors found that, for an imagined grid, eye movements were closely correlated with those recorded while viewing the same grid. The authors concluded that eye movements during imagery are not random but reflect the content of the visualized scene. Brandt and Stark (1997) interpreted their findings with the scanpath theory of Noton and Stark (1971), according to which when people are reexposed to a given stimulus, the first visual exploration tends to follow the same scanpath established during the initial viewing of the stimulus, which facilitates stimulus recognition.

Other insights into the contribution of visual imagery to autobiographical memory come from neuroimaging studies showing an association between autobiographical retrieval and increased activation in posterior cortical regions, brain areas that play a major role in the ability to generate visual images (for reviews, see Cabeza & St Jacques, 2007; Svoboda, McKinnon, & Levine, 2006). Taken together, there is substantial behavioral and neurological evidence to suggest the contribution of visual imagery to autobiographical memory.

To summarize, autobiographical recall has been found to trigger visual activity (El Haj et al., 2014). Bearing in mind these consideration, the present paper assessed whether any visual activity is also observed with emotional memories. Participants were asked to retrieve neutral, positive and negative memories. Visual activity (e.g., fixations and saccades) was recorded by an eye-tracker. To further assess whether emotional memories trigger more visual imagery than neutral ones, participants were asked to rate the vividness of each memory. We expected that more visual activity (e.g., more saccades) and more visual imagery would be triggered by emotional memories than by neutral memories. We also expected that more visual activity (e.g., more saccades) would be triggered by positive memories than by negative memories, this in light of research suggesting that the affective intensity of autobiographical memories fade more rapidly for negative than for positive event, providing people with a heightened sense of reliving when remembering positive events (Walker, Skowronski, & Thompson, 2003)

2. Method

2.1. Participants

Seventeen graduate/undergraduate students at the University of Lille participated in the study. They were native French speakers. Exclusion criteria were a history of psychiatric, neurological or learning disorders. Informed consent was also obtained in accordance with the principles laid down by the Helsinki Declaration. Their demographic and cognitive characteristics are summarized in Table 1. In the working memory assessment, they had to repeat a string of numbers in the same order (i.e., forward spans) or in reverse order (i.e., backward spans). Episodic memory was assessed using the test of Grober and Buschke (1987) in which participants had to retain 16 words, each describing an item belonging to a different semantic category; after a 20-s distraction phase, they had to recall as many words as they could, the maximum score being 16 points. On the original sample (n = 37), the eye movement data of 11 participants were corrupted and nine other participants were excluded owing to signal loss during recording. The mean signal loss of eye movement in the final sample was 9.96% (Table 2).

Table 1
Demographic and mnemonic characteristics of participants.

Females/males	10/7
Age in years	23.71 (6.78)
Years of education	14.65 (5.28)
Working memory	
Forward span	7.53 (1.42)
Backward span	5.29 (1.13)
Episodic memory	13.65 (3.53)

Note. Standard deviations are given between brackets; performances on the forward and backward spans refer to number of correctly repeated digits; the maximum score on the episodic memory task was 16 points.

Table 2
Eye movement variations, duration of recording, autobiographical specificity and visual imagery rating for all participants on neutral, positive and negative retrieval.

		Neutral	Positive	Negative
Eye movement	Fixation count per min	67.06 (31.98)**	104.12 (38.24)^{ns}	96.00 (30.67)
	Fixation duration in msec	962.84 (481.33)*	570.78 (373.70)^{ns}	579.99 (320.36)
	Saccade count per min	62.82 (24.84)**	105.88 (41.62)^{ns}	96.71 (33.19)
	Duration of saccades in msec	39.17 (16.37)^{ns}	39.06 (16.38)^{ns}	39.66 (14.60)
	Amplitude of saccades in degrees	743.00 (660.53)^{ns}	978.12 (696.97)^{ns}	907.16 (524.88)
Duration of recording in msec		80,572.53 (27,174.35)^{ns}	77,613.12 (32,990.35)^{ns}	73,786.12 (25,533.62)
Autobiographical specificity		3.67 (0.44)^{ns}	3.82 (0.39)^{ns}	3.47 (0.87)
Visual imagery		2.53 (1.00)*	3.41 (0.79)^{ns}	3.35 (0.93)

Note. Standard deviations are given between brackets; maximum duration of recording was 120,000 msec; maximum score on autobiographical specificity and visual imagery was four points; the difference with the following group was significant at: $^{*}p < 0.05$, $^{**}p < 0.01$; ^{ns} the difference with the following group was not significant.

2.2. Apparatus

Eye movements were recorded by a remote pupil-tracking system (RED-m, Senso-Motoric Instruments, Berlin, Germany) based on a pupil eye-tracking system that uses infrared illumination. The system (iViewX) records the position of the eye at a sampling rate of 120 Hz and compensates for slight head movements. Images of the eye are analyzed in real time by detecting the pupil, calculating the center and eliminating artefacts. The manufacturers report a gaze position accuracy of $< 0.1°$ for this system. The stimuli were displayed with Experiment Center software (Senso-Motoric Instruments) and the eye movement data were analyzed with the BeGaze software (Senso-Motoric Instruments).

2.3. Procedures

Participants were tested individually in a quiet office at the University of Lille. They were asked to verbally generate three autobiographical events, each of which was cued by one of the following: “happy”, “sad”, and “city”, as the latter cue may be considered a neutral cue (Maki, Janssen, Uemiya, & Naka, 2013). Cues were randomly counterbalanced across participants. Prior to each autobiographical recall, participants were instructed to retrieve in detail an event related to the cue. They were also told that the event had to be personally experienced in the past, and that the description had to be precise and specific (e.g., where and when the event occurred, what they were doing during it, who was present, what their feelings were). Two minutes were allocated to generate each autobiographical memory, and the duration was made clear so that participants could structure their memories accordingly (for studies adopting the same autobiographical instructions, see El Haj, Antoine, & Kapogiannis, 2015a, 2015b; El Haj, Kapogiannis, & Antoine, 2016). Following each memory, participants were asked to rate its visual imagery according to the following statement "I can see it in my mind" on a five-point scale (0 = not at all, 1 = slightly, 2 = moderately, 3 = quite a bit, and 4 = extremely). The latter rating replicated the visual imagery scale of the Autobiographical Memory Questionnaire (Rubin, Schrauf, & Greenberg, 2003).

Autobiographical cuing and retrieval occurred while gaze was recorded. Recording was stopped directly after memory retrieval. Prior to recording, in order not to influence their performance, the participants were not informed about autobiographical retrieval. During autobiographical retrieval, participants were seated in front of a 21-inch flat blank-displayed screen, under which the eye tracker was positioned. Participants were free to explore all parts of the screen and were asked not to look outside its borders, their gaze location being recorded throughout by the eye-tracker. The distance between the participants and the screen was approximately 45 to 60 cm. Prior to each autobiographical retrieval, calibration was checked by displaying five successive test positions (center, top-left, top-right, bottom-left, bottom-right). Participants had to fixate the test positions and calibration was accepted only if the average error was $< 0.5°$.

The mean of all "eye movement" variables (number of fixations, fixation duration, number of saccades, duration of saccades, and amplitude of saccades) was calculated for each autobiographical condition. Fixation/saccade count refers to the number of fixation/saccades per minute; a ratio was applied since the autobiographical retrieval of some participants ended before the two min delay. Average fixation/saccade duration was the mean duration of fixation/saccades (in ms). Amplitude of saccades refers to the total angle covered by the saccades. Blinks were identified by the typical loss of corneal reflection and were automatically excluded from the data. Gazes were automatically eliminated when the horizontal deviation of gaze exceeded 2° (5% of our dataset). Besides the eye movement variables, we measured the total duration of recording in order to determine whether neutral and emotional memories had triggered a similar reconstruction time. Rating of visual imagery was also compared as well as autobiographical specificity. The latter variable was determined on the basis of specificity scales that are widely applied in autobiographical research (Kopelman, 1994). More precisely, zero was attributed if there was no memory or only general information about a theme (e.g., "in my childhood"). One point was attributed for repeated or extended events (e.g., "I'm studying in X university"); two points for an event situated in time and/or space; three points for a specific event lasting < 24 h and situated in time and space; and four points for a specific event situated in time and space with the presence of phenomenological details (e.g., feelings, perceptions or thoughts). Thus, the maximum specificity score for each participant was four points. An inter-rater agreement coefficient of 0.85 and higher was obtained for the specificity assessment, as evaluated by the intra-class correlation coefficient, two-way, random effects model (Shrout & Fleiss, 1979).

3. Results

For neutral, positive and negative autobiographical retrieval, we compared: I- the five eye movement variables (number of fixations and saccades, fixation duration, duration of saccades, and amplitude of saccades), II- duration of recording/120,000 ms, III- autobiographical specificity/4 points, and IV- visual imagery rating/4 points. Since data were not distributed normally as observed by Kolmogorov-Smirnov tests, non-parametric tests were used. When reporting significant Wilcoxon test values, we also provided effect sizes by using Cohen's d criterion (Cohen, 1992) (0.20 = small, 0.50 = medium, 0.80 = large). For all tests, the level of significance was set as $p \leq 0.05$, p values between 0.051 and 0.10, if any, were considered as trends.

3.1. More fixations and saccades but shorter fixation duration in emotional than in neutral memories

The Friedman test showed significant differences between the three autobiographical conditions (i.e., neutral, positive and negative retrieval) for fixation count, χ^2 (2, $N = 17$) = 10.71, $p < 0.01$, fixation duration, χ^2 (2, $N = 17$) = 12.82, $p < 0.01$, and saccade count, χ^2 (2, $N = 17$) = 12.83, $p < 0.01$, but not for duration of saccades, χ^2 (2, $N = 17$) = 12, $p > 0.1$, or amplitude of saccades, χ^2 (2, $N = 17$) = 0.82, $p > 0.1$.

The post hoc Wilcoxon rank sums test carried out to compare eye movements between neutral and positive retrieval showed significant differences for fixation count, $Z = -3.06$ $p < 0.01$ (Cohen's $d = 1.05$), fixation duration, $Z = -2.48$ $p < 0.05$ (Cohen's $d = 0.91$), and saccade count, $Z = -3.25$ $p < 0.01$ (Cohen's $d = 1.26$), but not for duration of saccades, $Z = -0.16$ $p > 0.1$, or amplitude of saccades $Z = -1.06$ $p > 0.1$. As for comparisons between neutral and negative retrieval, analysis showed significant differences for fixation count, $Z = -2.18$ $p < 0.05$ (Cohen's $d = 0.92$), fixation duration, $Z = -2.82$ $p < 0.01$ (Cohen's $d = 0.94$), and saccade count, $Z = -2.98$ $p < 0.01$ (Cohen's $d = 1.16$), but not for duration of saccades, $Z = -0.17$ $p > 0.1$, or amplitude of saccades $Z = -0.64$ $p > 0.1$. As for comparisons between positive and negative retrieval, analysis showed no significant differences for fixation count, $Z = -0.45$ $p > 0.1$, fixation duration, $Z = -0.35$ $p > 0.1$, saccade count, $Z = -0.65$ $p > 0.1$, duration of saccades, $Z = -0.07$ $p > 0.1$, or amplitude of saccades $Z = -0.17$ $p > 0.1$. Thus, similar eye movements were observed during positive and negative retrieval, whereas positive and negative retrieval triggered a higher fixation count, less fixation duration, and a higher saccade count than neutral retrieval.

3.2. Similar reconstruction time and autobiographical specificity for neutral and emotional retrieval

The Friedman test showed no significant differences between the three autobiographical conditions (i.e., neutral, positive and negative retrieval) for duration of recording, χ^2 (2, $N = 17$) = 0.47, $p > 0.1$, and autobiographical specificity, χ^2 (2, $N = 17$) = 2.21, $p > 0.1$.

3.3. More visual imagery for emotional than for neutral retrieval

The Friedman test showed significant differences between the three autobiographical conditions (i.e., neutral, positive and negative retrieval) for visual imagery, χ^2 (2, $N = 17$) = 9.68, $p < 0.01$. The post hoc Wilcoxon rank sums test showed more visual imagery in positive than in neutral retrieval, $Z = -2.17$ $p < 0.05$, and in negative than neutral retrieval, $Z = -2.35$ $p < 0.05$, but no significant differences between positive and negative retrieval, $Z = -0.25$ $p > 0.1$.

3.4. Complementary analysis

For the reader's convenience, we analyzed the average saccade amplitude. The Friedman test showed no significant differences between the three autobiographical conditions (i.e., neutral, positive and negative retrieval) for the average saccade amplitude, χ^2 (2, $N = 17$) = 2.30, $p > 0.1$ [M neutral = 8.85, SD = 8.48, M positive = 8.89, SD = 6.31, M negative = 9.17, SD = 3.57].

4. Discussion

Since previous research had shown visual exploration during autobiographical retrieval (El Haj et al., 2014), the present paper assessed whether such exploration is also observed for emotional memories. Our findings showed that positive and negative emotional memories resulted in a larger number of fixations and saccades and shorter fixation duration than neutral memories. No significant differences were observed between emotional and neutral memories for duration and amplitude of saccades. Similar eye movement was observed during positive and negative retrieval. As for autobiographical characteristics, similar reconstruction time and specificity were observed for neutral, positive and negative memories. Interestingly, more visual imagery was found for emotional than for neutral memories.

Emotion is regarded as a key element in the reconstruction and regulation of autobiographical memories (Holland & Kensinger, 2010). Besides its role in autobiographical regulation, it has been found to enhance sensory and contextual retrieval (Comblain et al., 2005; Gandolphe & El Haj, 2016; St Jacques & Levine, 2007), subjective experience (Talarico et al., 2004) and visual imagery during autobiographical retrieval (Schaefer & Philippot, 2005). On a neuroanatomical level, the involvement of emotion in autobiographical memory can be attributed mainly to activity in the amygdala (for a review, see Dolcos & Denkova, 2008; Holland & Kensinger, 2010) the hippocampus (Dolcos, LaBar, & Cabeza, 2004; Kensinger & Corkin, 2004), orbitofrontal cortex (LaBar & Cabeza, 2006), temporo-occipital area (Vuilleumier & Driver, 2007), and the visual cortices (Piefke, Weiss, Zilles, Markowitsch, & Fink, 2003). In addition to their psychological and neural implications, emotional autobiographical memories have been found to trigger physiological reactions, as observed by measurements of cardiovascular and electrophysiological activity (Schaefer & Philippot, 2005). Our findings contribute to this body of literature by revealing specific eye movement during retrieval of emotional autobiographical memories.

As shown by our data, emotional memories triggered more fixations and saccades and less fixation duration than neutral memories, regardless of their valence. In other words, participants demonstrated more alternation between fixations and saccades, or more visual activity, during emotional than during neutral autobiographical retrieval. Generally speaking, eye movement during autobiographical retrieval can be attributed to visual imagery (El Haj et al., 2014). This assumption fits with the consideration that autobiographical memories come to mind in the form of visual images and that visual images are the main format of autobiographical reliving (Conway, 2009). The contribution of mental imagery to autobiographical memory is supported by research showing better autobiographical recall in healthy individuals with high than in those with low visual imagery (Vannucci et al., 2016), as well as neuropsychological studies showing autobiographical amnesia in patients with damage in the right occipital lobe at the temporo-occipital junction (Greenberg, Eacott, Brechin, & Rubin, 2005).

The fixations and saccades observed in our participants during autobiographical retrieval can be interpreted in the light of an assumption by Ferreira, Apel, and Henderson (2008). In their opinion, fixations, or looking at nothing, reflect the attempt of the visual system to find and activate stored memory representations. In this view, fixations reflect the attempt to activate a representation of a memory as derived from visual and linguistic cues (i.e., verbal instructions in our study). When part of the memory representation is reactivated, the eyes move to the location in which the item originally appeared, and this fixation enhances subsequent memory recall. Hence, the intense fixation observed in emotional autobiographical retrieval can be interpreted as an index of memory activation, serving to facilitate retrieval of further information. The theory of Ferreira et al. (2008) is based on important empirical research suggesting that looking at a "now-empty" location facilitates retrieval of information that was previously exposed in that location (Henderson & Hollingworth, 1999; Hollingworth, 2006). However, this research attributes fixations to the presence of items that were reliably displayed in the same location as that point of fixation (Ferreira et al., 2008; Henderson & Hollingworth, 1999; Hollingworth, 2006), which was not the case in the present study. When retrieving memories, our participants looked at a blank screen that did not display any previously studied items, so their fixations could not be reliably interpreted in terms of retrieving a particular item. Although relevant, the theory of Ferreira et al. (2008) attributing fixations to previously displayed items should be interpreted with caution since the autobiographical retrieval of our participants concerned uncontrolled encoding events.

The emotional memories in our study triggered shorter fixation duration than neutral memories, a finding that is consistent with a study showing that fixation times on emotion words (positive or negative) were significantly shorter than those on neutral words (Scott, O'Donnell, & Sereno, 2012). According to the latter authors, emotional words have higher arousal values and trigger higher vigilance than neutral words. Hence, eye movement, at least the shorter fixation durations as observed in emotional autobiographical memories, can be attributed to a high level of arousal.

To our knowledge, there is a lack of research on eye movement during emotional autobiographical retrieval. However, there is a substantial body of research on eye movement for semantic memory (Althoff & Cohen, 1999; Loftus & Mackworth, 1978; Ryan, Althoff, Whitlow, & Cohen, 2000) and on temporal memory. For instance, in a study by Ryan and Villate (2009), participants were successively exposed to items that were later presented simultaneously. Recordings of eye movement showed that participants had inspected the items in the order that matched the original order of display. Eye movement was also considered a reliable index of spatial memory. Another study reported that, when asked to retrieve the image, participants were likely to fixate the same regions of space as those fixated during the perceptual scrutiny of the image (Laeng, Bloem, D'Ascenzo, & Tommasi, 2014). In a similar vein, other studies found a greater number of fixations and saccades for scenes where items had been removed than for intact scenes, suggesting that participants moved their eyes in an attempt to retrieve previously processed information (Ryan et al., 2000; Scholz, von Helversen, & Rieskamp, 2015).

One interesting finding in our study was the striking similarity in eye movements for positive and negative autobiographical retrieval. Unlike our expectation, both types of retrieval triggered a similar fixation count, fixation duration, saccade count, duration of saccades, and amplitude of saccades. Both types also triggered a similar reconstruction time and autobiographical similarity. These outcomes could be considered at odds with other studies showing differences between positive and negative autobiographical memories. For instance, the affective intensity of autobiographical memories was found to fade more rapidly for negative than for positive events, providing people with a heightened sense of reliving when remembering positive events (for review, see Walker et al., 2003). This assumption fits with the consideration that individuals are motivated to maintain a positive sense of self so that they can re-experience past events in a manner that allows them to achieve that goal (Conway, 2005). Hence, although functional differences may be observed between positive and negative memories, both types of memory seem to activate similar eye movement patterns. Visual images during generation of both positive and negative autobiographical memories seem to be constructed in the same pathway.

A limitation of our study is the absence of a control condition involving no autobiographical retrieval. Previous research on eye movement during autobiographical retrieval (El Haj et al., 2014) has implemented a control condition in which participants were required to count aloud. Findings showed more saccadic activity and less fixation activity during autobiographical recall than during the control condition. The decrease in fixations, as observed in the study of El Haj et al. (2014), can be attributed to the fact that participants were asked to "recount in details an event in their lives", regardless of its emotional valence; thus, their recall might trigger a variety of emotional experiences and affective processes that influenced their visual fixations. It is also likely that the control condition of the study El Haj et al. (2014) implied a bias in eye movement activity. This assumption can be supported by a study demonstrating bias in eye movement activity during arithmetic operations (Hartmann, Mast, & Fischer, 2015). Together, future studies should implement a control condition implying neither autobiographical knowledge, nor arithmetic operations.

Another suggestion for future studies would be to analyze pupil dilation during autobiographical retrieval. Studies suggest that pupil size changes following visual imagery and emotion (D'Ascenzo, Tommasi, & Laeng, 2014; Laeng, Sirois, & Gredeback, 2012).

By revealing differences in eye movement during neutral and emotional autobiographical retrieval, the present findings contribute to the literature that suggests that there are psychological, physiological and neuroanatomical differences between neutral and emotional memories. The present findings also throw new light on eye movements that occur during the processing of semantic, temporal and spatial information. The decoding of eye movements during the retrieval of emotional autobiographical memories could be a new, ecological and reliable tool to describe the physiological activities that occur at the same time.

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