



HAL
open science

Impact of emotionally negative information on attentional processes in normal aging and Alzheimer's disease

Jessica Bourgin, Laetitia Silvert, Céline Borg, Alexandrine Morand, Mathilde Sauvée, Olivier Moreaud, Pascal Hot

► To cite this version:

Jessica Bourgin, Laetitia Silvert, Céline Borg, Alexandrine Morand, Mathilde Sauvée, et al.. Impact of emotionally negative information on attentional processes in normal aging and Alzheimer's disease. *Brain and Cognition*, 2020, 145, pp.105624. 10.1016/j.bandc.2020.105624 . hal-02977992

HAL Id: hal-02977992

<https://hal.science/hal-02977992>

Submitted on 4 Nov 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Impact of emotionally negative information on attentional processes in normal aging and Alzheimer's disease

Jessica Bourgin^a, Laetitia Silvert^b, Céline Borg^c, Alexandrine Morand^d, Mathilde Sauvée^e, Olivier Moreaud^{a,e}, Pascal Hot^{a,f**}

^a Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS UMR 5105, Laboratoire de Psychologie et Neurocognition (LPNC), 38000 Grenoble, France

^b Université Clermont Auvergne, UCA-CNRS UMR 6024, Laboratoire de Psychologie Sociale et Cognitive (LAPSCO), 63100 Clermont-Ferrand, France

^c Département de Neurologie, CHU Saint-Etienne, 42270 Saint-Priest-en-Jarez, France

^d Université de Caen, UMR-S 1077, Neuropsychologie et Imagerie de la Mémoire Humaine (NIMH), 14000 Caen, France

^e Centre Mémoire de Ressources et de Recherche, Pôle de Psychiatrie et Neurologie, CHU Grenoble, 38000 Grenoble, France

^f Institut Universitaire de France

** Correspondence concerning this article should be addressed to Pascal Hot, Laboratoire de Psychologie et Neurocognition (LPNC, CNRS UMR 5105), UFR LLSH, Université de Savoie, Domaine Universitaire de Jacob-Bellecombette, BP 1104, F-73011 Chambéry cedex, France. E-mail: pascal.hot@univ-savoie.fr; Tel: +33-479-758-566; Fax: +33-476-827-834

Abstract

Impairments of emotional processing have been reported in Alzheimer's disease (AD), consistently with the existence of early amygdala atrophy in the pathology. In this study, we hypothesized that patients with AD might show a deficit of orientation toward emotional information under conditions of visual search. Eighteen patients with AD, 24 age-matched controls, and 35 young controls were eye-tracked while they performed a visual search task on a computer screen. The target was a vehicle with implicit (negative or neutral) emotional content, presented concurrently with one, three, or five non-vehicle neutral distractors. The task was to find the target and to report whether a break in the target frame was on the left or on the right side. Both control groups detected negative targets more efficiently than they detected neutral targets, showing facilitated engagement toward negative information. In contrast, patients with AD showed no influence of emotional information on engagement delays. However, all groups reported the frame break location more slowly for negative than for neutral targets (after accounting for the last fixation delay), showing a more difficult disengagement from negative information. These findings are the first to highlight a selective lack of emotional influence on engagement processes in patients with AD. The involvement of amygdala alterations in this behavioral impairment remains to be investigated.

Keywords: emotion; Alzheimer's disease; aging; attention; eye movements

Running title: Impact of emotion on visual search in aging and AD

1. Introduction

People mostly encounter complex and rich situations in which they cannot attend to all available stimuli. Attention allows them to deal with the overwhelming amount of information that they encounter by focusing on specific objects, preferentially processing salient stimuli. Emotional stimuli may behave like salient stimuli, standing out from the background to be processed preferentially. Pourtois et al. (2013) suggest that emotional stimuli can engage dedicated brain networks that would rapidly influence perceptual and attentional networks, giving additional weight to emotional stimuli in the competition for cognitive resources. This enhanced processing of emotion would notably depend on the ability of the amygdala to quickly establish affective significance. This theory is supported by (a) patterns of neurophysiological responses in imaging studies involving healthy participants, suggesting interactions between the attentional network (and/or the visual areas) and the amygdala when emotional information is processed (Mohanty et al., 2009; Schwabe et al., 2011), and by (b) deficits in prioritizing emotional information in patients with amygdala lesions (Anderson and Phelps, 2001; Bach et al., 2015; Vuilleumier et al., 2004).

Several studies suggest that emotional stimuli—especially negative stimuli, supposedly because of their high arousal (Carretié et al., 2004; Kensinger, 2004)—may draw and hold spatial attention more strongly than neutral stimuli do (e.g., Pourtois and Vuilleumier, 2006). In other words, emotional information may affect the relative ease or speed with which attention is drawn to a given stimulus or location (which we denote as *engagement* processes) and the degree to which a stimulus holds attention and impairs attentional switching to another stimulus (which we denote as *disengagement* processes). At the brain level, the amygdala is thought to play a primary role in the early stages of emotional stimulus perception (Davis and Whalen, 2001; Sander et al., 2003; Vuilleumier, 2005). In consequence, the amygdala may be specifically involved in prioritized engagement toward

emotional information, whereas holding attention on that information may require frontoparietal areas (Schwabe et al., 2011).

In young adults (YAs), spatial attention is preferentially engaged on emotional stimuli, as reflected by quicker manual responses (Gerritsen et al., 2008; Hahn et al., 2006; Leclerc and Kensinger, 2008a; Notebaert et al., 2011; Öhman et al., 2001) or gaze orientation (Calvo and Nummenmaa, 2008; LoBue et al., 2014; Nummenmaa et al., 2009) toward these stimuli than toward neutral stimuli. In contrast, spatial attention is maintained on emotional stimuli, generating slower responses and longer eye fixations linked to the impact of affective salience on attentional disengagement processes (Brosch and Sharma, 2005; Fox et al., 2001; Huang and Yeh, 2011; Notebaert et al., 2011).

In normal aging, the integrity of the amygdala is largely preserved (Cherubini et al., 2009; Grieve et al., 2005; Mather, 2016), consistently with the developmental theory which states that regions first developed phylogenetically and ontogenetically (e.g., limbic system) are the most resistant to normal aging (Kalpouzos et al., 2009). In accordance with these data, most studies suggest that healthy older adults (HOAs) are able, as YAs are, to quickly orient their attention toward emotional information (Hahn et al., 2006; Leclerc and Kensinger, 2008a, 2010; Mather and Knight, 2006; Ruffman et al., 2009). Yet, they may also be better than YAs at inhibiting, avoiding, and ignoring negative emotional information at later stages of processing (Goeleven et al., 2010; Hahn et al., 2006; Mather and Carstensen, 2003; Monti et al., 2010; Rösler et al., 2005b; Samanez-Larkin et al., 2009; Sasse et al., 2014).

According to the *socioemotional selectivity theory*, with aging, individuals become more aware that their lifespan is limited, leading to an increasing prioritization of emotion-regulation goals (Carstensen et al., 2003). This mechanism, known as the *positivity bias*, could notably lead HOAs to look preferentially toward positive stimuli and away from

negative stimuli (Isaacowitz et al., 2006; Knight et al., 2007). For instance, Rösler et al. (2005b) showed that age did not influence the initial saccade toward emotional scenes, but that older adults had a shorter dwell time on negative rather than on positive or neutral scenes. Hahn et al. (2006) showed that when searching a target within an array of distracting faces, YAs were slower with angry distractors than with happy or neutral distractors. In contrast, HOAs' performance was not influenced by the emotional content of distractors. The Fronto-amygdalar Age-related Differences in Emotion (FADE) model (St. Jacques et al., 2009) conjectures that normal aging leads to a greater recruitment of frontal areas, and a reduced recruitment of the amygdala. This phenomenon may reflect emotional regulation processes mediated by the frontal cortex that decreases amygdala responses to emotional events (Dolcos et al., 2014; Mather, 2012; Nashiro et al., 2012), helping HOAs to engage preferentially with positive stimuli and to distract themselves from negative stimuli (Leclerc and Kensinger, 2008b, 2010, 2011). Together, these data suggest that, compared with YAs, HOAs may have improved their ability to disengage from or to suppress negative information.

Unlike normal populations, patients with Alzheimer's disease (AD) show alterations of amygdala's integrity (namely, atrophy, functional and structural connectivity disruption), which begin early in the course of the disease and increase in more severe stages (Jack et al., 1997; Klein-Koerkamp et al., 2014; Li et al., 2012; Yao et al., 2013). These alterations may be linked to neuropsychiatric symptoms and alterations of emotional processing present in the pathology (Landré et al., 2013; Mori et al., 1999; Poulin et al., 2011). Studies that specifically address attentional processing are, however, still scarce and have provided inconsistent findings. Previous works suggest that patients with AD may be impaired in orienting their attention toward emotional information (Asaumi et al., 2014; Bourgin et al., 2018; García-Rodríguez et al., 2012; Hot et al., 2013). Other studies showed that patients with AD present difficulties in inhibiting or disengaging from emotional distractors (Berger et al., 2015;

Doninger and Bylsma, 2007; Monti et al., 2010). Note that most of the previous studies (a) did not use purely attentional protocols (e.g., working memory tasks that involved emotional distractors) and/or (b) did not allow a clear dissociation between the different attentional processes that were potentially involved, namely, engagement and disengagement mechanisms. To our knowledge, the only study that involved a protocol that directly measured attentional processes used a pro-saccade/anti-saccade paradigm and showed impairment in early engagement processes in patients with AD (Bourgin et al., 2018). Taken as a whole, these data indirectly suggest that patients with AD may present impaired engagement processes toward emotional information, but are unaffected by (or even show an increase in) the influence of emotion on disengagement processes, consistently with a critical involvement of the amygdala in facilitating attentional orienting toward emotional stimuli.

To further explore the impact of emotional information on engagement and disengagement processes in normal and pathological aging, we conducted a visual search paradigm in which we implemented eye-tracking measures with YAs, HOAs, and patients with AD. This paradigm was chosen for several reasons. First, it mimics everyday situations in which individuals attempt to localize and identify a target among a varying number of distractors (Frischen et al., 2008). Second, it offers the possibility of directly measuring both engagement and disengagement mechanisms of spatial attention (Derakshan and Koster, 2010). Third, it allows the assessment of search efficiency, as indicated by the slope of the search function (detection time as a function of the number of distractors) for different targets. A flatter search slope for one type of stimulus indicates that the search is more efficient for that type of stimulus, meaning that the processing of the stimulus is prioritized. Finally, search behavior can be reliably measured by recording eye movements, even when dementia has progressed (Rösler et al., 2000). Eye movements are particularly suited for the measurement of attentional processes because they can be initiated quickly, in about 80 to 100 ms. They are

a more direct measure of attentional deployment than manual response latencies are because (a) they are not significantly biased by action plans as overt behavioral responses, and (b) there may be several shifts in attention during visual search before and after target detection that are not indexed by manual response latencies. Moreover, they are reliable measures of the degree of selective attention allocated to objects in the environment, imaging results showing a strong overlap between brain areas involved in the generation of saccades and those involved in covert orienting of attention (Corbetta, 1998).

In the present study, participants (YAs, HOAs, and patients with AD) had to find a vehicle (implicitly neutral or negative) among a display of two, four, or six images. They then had to report whether a break in the target frame was on the left or on the right side. Three types of measures were collected: (a) engagement delays, that is, the time between the onset of the stimulus display and the first gaze fixation on the target; (b) search slopes calculated from engagement delays as a function of the number of distractors present; and (c) disengagement delays, that is, the time between the beginning of the last fixation on the target and the manual response regarding the frame break.

If attentional engagement is facilitated for emotional targets, this will be reflected by more efficient localization, as assessed by earlier first fixation and flatter search slopes for emotional than for neutral targets. Conversely, if attentional disengagement is more difficult for emotional targets, this will be reflected by longer response times regarding the frame break after the last target fixation for emotional than for neutral targets. In accordance with previous works, we expected YAs and HOAs to engage their attention more quickly on negative than on neutral targets. We expected HOAs to show a smaller effect of emotion on disengagement delays compared with that of YAs, in line with the positivity bias hypothesis. We expected patients with AD to show, specifically, a diminution of emotional influence on engagement processes.

HOAs and, to a greater extent, patients with AD are both reported to be impaired in nonemotional visual search (Erel and Levy, 2016; Foster et al., 1999; Rösler et al., 2005a, 2000; Tales et al., 2004) and in scene processing (Boucart et al., 2014b, 2014a; Erel and Levy, 2016). More specifically, they may shift their attention and process information less rapidly and may show a decline in inhibition and disengagement abilities (Amieva et al., 2004; Erel and Levy, 2016; Rösler et al., 2000; Tales et al., 2004). Consequently, we expected HOAs and patients with AD, compared with YAs, to display longer engagement and disengagement delays regardless of the emotional content of the stimuli.

2. Material and methods

2.1. Participants

Eighty-six participants were recruited (20 patients with AD, 27 HOAs, and 39 YAs). The HOAs were recruited through advertisements on websites and in newspapers. The YAs were students of psychology and were recruited through advertisements at the University Savoie Mont Blanc and the University Grenoble Alpes. The patients were recruited by the Neurology Units at Grenoble Medical Centre and Saint-Etienne University Medical Center. They received a diagnosis of dementia of the Alzheimer's type on the basis of a standardized clinical investigation, including neurological and neuropsychological assessment, and brain imaging according to the National Institute on Aging and Alzheimer's Association criteria (McKhann et al., 2011). The main exclusion criteria were the use of antipsychotic medication, the existence of psychiatric depressive pathologies or neurological diseases (other than AD for patients), a history of brain damage, impaired vision or impaired image processing, inability to understand verbal instructions, and inability to concentrate for the duration of the experiment. In addition, individuals with depressive conditions (score above 9 on the Geriatric Depression Scale (GDS), Yesavage et al., 1982, or above 13 on the Beck Depression Inventory (BDI-II), Beck et al., 1996) were excluded from the study. Participants were also

administered the Montreal Cognitive Assessment (MoCA; Hobson, 2015; French version: Nasreddine and Patel, 2016) and the Frontal Assessment Battery (FAB; Dubois et al., 2000). All participants had normal or corrected-to-normal visual acuity. The local investigational review board (Chambéry, France) approved the study (n° C.E.R.E.U.S_2017_4). All participants gave their informed consent prior to study entry, and none received any remuneration.

Two individuals with AD, three HOAs, and four YAs had to be excluded from the analysis for one of the following reasons: a high blink rate, calibration issues, or a high error rate (>3 SDs of the group's mean). The analyzed group of patients with AD ($n = 18$) comprised 10 women and eight men, with a mean age (\pm SD) of 74.5 (\pm 7.94) years (range: 59–85). The analyzed group of HOAs ($n = 24$) comprised 13 women and 11 men, with a mean age (\pm SD) of 71.13 (\pm 4.83) years (range: 66–84). The analyzed group of YAs ($n = 35$) comprised 20 women and 15 men, with a mean (\pm SD) age of 21.29 (\pm 4.42) years (range: 18–39). The mean (\pm SD) score on the MoCA recorded for patients with AD was 20.03 (\pm 4.77; range: 10–29). Only HOAs with a MoCA score above 26 (indicating normal cognition; Hobson, 2015) were included (mean \pm SD MoCA score for the group: 28.15 \pm 1.41, range: 26–30). Demographic and neuropsychological data are summarized in Table 1.

[Insert Table 1 about here]

There were no significant differences between the three groups for gender ratio, $\chi^2(2, N = 77) = 0.05, p = .97$. There was a significant difference for educational level, $\chi^2(6, N = 77) = 24.66, p < .001$: Patients with AD had a lower educational level than did HOAs ($p < .05$) and YAs ($p < .001$). To further examine this difference, we assessed the differences in years of education. There was a significant difference for years of education, $F(2, 74) = 16.03, p < .001$: Patients with AD ($p < .05$) and YAs ($p < .001$) had fewer years of education than did

HOAs. There was no significant difference between HOAs and patients with AD regarding age, $t(40) = 1.60$, $p = .12$. Patients with AD and HOAs differed significantly on the MoCA score, $t(40) = 8.56$, $p < .001$, and on the FAB score, $t(40) = 4.10$, $p < .001$.

2.2. Stimuli

The stimuli were 300 gray-scaled scenes, presented against a black background, each picture sustaining a $12 \times 12^\circ$ visual angle. Some of the images (180) were emotionally neutral (e.g., buildings, landscapes) and were presented as distractors; half of the remaining images (60) were emotionally neutral vehicles (e.g., highway, parked car), and half were emotionally negative vehicles (e.g., car accident, plane crash). Most of the images were selected from the following databases: the Geneva Affective Picture Database (Dan-Glauser and Scherer, 2011), the International Affective Picture System (Lang et al., 1997), the Nencki Affective Picture System (Marchewka et al., 2014), the Open Affective Standardized Image Set (Kurdi et al., 2017), and the EmoMadrid affective picture database.¹ Some of the images were also selected from royalty-free websites² and were rated on arousal and valence by 14 participants during a pretest of the experiment. These participants were also presented with each stimulus at the center of a computer screen and had to press a key as quickly as possible each time they saw a vehicle. This pretest was conducted to anticipate any differences in manual responses between trials with emotional and neutral targets that may be due to categorization time rather than to difficulty of disengagement. Emotional targets produced quicker manual responses than neutral targets did, negative: 554.35 ± 82.21 , neutral: 588.26 ± 91.85 , $F(1, 13) = 58.80$, $p < .001$, $\eta_p^2 = .82$. There was no effect of emotional valence for miss errors, $F(1, 13) = 0.85$, $p = .38$. These data suggest that emotional targets would not be more difficult to identify than neutral targets. The quicker responses for emotional stimuli than for neutral stimuli are

¹ <http://www.uam.es/CEACO/EmoMadrid.htm>

² Such as <https://unsplash.com>

consistent with previous works that showed greater response speed for negative stimuli, suggesting that they might evoke faster action (Flykt and Caldara, 2006; LoBue et al., 2014).

Valence and arousal scores of each image were adjusted depending on the scale of their database and were rated on a scale from 1 to 9. Pictures were selected according to the following criteria for valence: mean ratings for negative valence had to be less than 3.5, and mean ratings for neutral pictures had to be between 3.5 and 6.5. To control the degree of semantic similarity between emotional categories, we ensured that the same number of images that showed humans and animals appeared in both groups of vehicle images; to the same end, we also controlled the variability of vehicle type.

Stimulus properties such as brightness, color, and distribution in spatial frequencies can guide the initial stages of search and thus affect the visual search independently from emotional information (Calvo and Nummenmaa, 2008; Delplanque et al., 2007). Moreover, absence of control of perceptive similarity between targets may lead to visual search effects that are erroneously attributed to emotional content (Quinlan, 2013). Therefore, to control for low-level image features, we used the Python Imaging Library module³ to characterize each picture with several values. Brightness corresponded to the image's mean pixel value when converted into grayscale. The root mean square contrast is defined as the standard deviation of the pixel intensities relative to the mean (for further details, see Bex and Makous, 2002; Peli, 1990). The number of edges gave the number of edge pixels (i.e., points at which the brightness changed sharply or had discontinuities) in one image. The number of lines gave the number of line segments (based on a Hough transform). The mean energy in spatial frequencies was obtained by performing a multiresolution decomposition analysis with Haar discrete bidimensional orthogonal wavelets (eight levels, MATLAB software; see Delplanque et al., 2007). Image characteristics are summarized in Table 2.

³<https://www.pythonware.com/products/pil/>

[Insert Table 2 about here]

After the experiment, the participants were asked to rate the valence and arousal of part of the stimuli on a scale from 1 to 9.⁴ Emotional targets were considered more negative (negative targets: 2.34 ± 1.21 , neutral targets: 5.48 ± 0.78 , $F(1, 63) = 146.75$, $p < .001$, $\eta_p^2 = .70$) and more arousing (negative targets: 6.81 ± 1.28 , neutral targets: 3.34 ± 1.32 , $F(1, 63) = 143.65$, $p < .001$, $\eta_p^2 = .70$) than were neutral targets. Interactions between group and emotional valence were not significant. Therefore, targets were considered as expected by the participants, regardless of their age and pathological state.

2.3. Procedure

The experiment was developed by using OpenSesame software 3.1.⁵ The participants were tested individually and performed the task on a 30.5-cm computer screen with a resolution of 1366×768 pixels and a refresh rate of 100 Hz. The participant's eyes were 70 cm away from the computer screen. To avoid movement during the task, we stabilized each participant's head by using a chin rest. The participant's eye movements were recorded with an EyeLink 1000⁶ or with an SMI 250⁷ eye-tracker with a time resolution of 250 Hz and theoretical spatial precision of 0.5° .

Before the start of the experiment, a 3×3 -point calibration sequence was run. Saccades were automatically detected by the eye-tracker software with thresholds for velocity ($30^\circ/s$), acceleration ($8,000^\circ/s^2$), and saccadic motion (0.15°).

The experiment comprised two blocks of 60 trials each, corresponding to the 120 target stimuli selected (2 valence levels \times 60 different objects). The order of the stimuli was

⁴Eleven participants did not complete this part of the experiment: Calibration took more time for these participants, leaving not enough time at the end of the experiment for stimulus rating.

⁵<http://osdoc.cogsci.nl/>

⁶SR Research, Kanata, ON, Canada, www.sr-research.com

⁷SensoMotoric Instruments, Teltow, Germany, <https://www.smivision.com/>

randomized. Each block began with a presentation of the task instructions, which was followed by six training trials (which could be repeated if necessary⁸) and then the recorded session of 60 trials. At the start of each trial, participants had to maintain their gaze on the center of the screen, where a fixation point appeared for a minimum of 1,600 ms, until the participant looked at the fixation point for 100 ms. Next, the target and one, three, or five distractors were presented on the screen (all at a visual angle of 12° from the center) until the participant gave a manual response (within a maximum of 5,000 ms). The target location was also randomized, so that participants could not predict where the target would appear in the next trial. In accordance with the method of Huang and Yeh (2011), each image was bordered by a white Landolt C frame with a break consisting of a 1° visual angle on the left or right side of the frame. The participants had to find the vehicle among the different stimuli and then determine the position of the frame break around the target stimulus by using the 1 (for a left position) and 2 (for a right position) keys of the keyboard. Participants had to answer with the index and middle finger of their dominant hand. After every 10 trials, eye-tracking was corrected for drift and the instructions repeated. Examples for each trial type are shown in Figure 1.

[Insert Figure 1 about here]

3. Results

Eye movement data were processed using a home-made software, available at <https://github.com/jbourgin/Boogui>. Data files and scripts are available from the public repository <https://osf.io/c5bgu/> (Bourgin, 2019).

⁸ Training trials were repeated until a minimal performance of 83% correct responses (5 correct trials out of 6) was achieved.

Trials containing blinks were discarded, as were trials with saccades that did not start within 1° of the central fixation cross. The raw data were then filtered to remove anticipation orientation toward the target (<100 ms after the presentation of the target and distractors) and trials with no saccades or with saccadic reaction times or response times greater than 2 SD above the mean for the given subject. This filtering resulted in the exclusion of 15% of the trials. In other words, we assessed a mean \pm SD of 17 ± 2 useable trials per experimental factor (two levels for valence and three levels for number of distractors). Further, for engagement and disengagement delay analyses, we considered only trials with correct responses. We considered only fixations of 80 ms or more (Kotowicz et al., 2010). For disengagement delay analysis, we discarded trials in which the participants were looking at a nontarget image when responding. Of the remaining trials, 12% were excluded in this way. For all analyses of variance (ANOVAs), we used the Greenhouse-Geisser epsilon correction to adjust the degrees of freedom of F ratios when appropriate.

Since two different eye-trackers were used in this experiment, we investigated the influence of eye-tracker (SMI vs. EyeLink) by including this factor as a covariate in our main analyses. In all analyses, there were no main effects of eye-tracker and no interactions between eye-tracker and other factors (all $ps > .1$). Given its lack of significant influence, we decided to not to include this variable in our subsequent statistical analyses.

Because the three groups differed regarding education, we investigated the influence of years of education by including this factor as a covariate in our main analyses. Since non-independence between education and group precluded us from conducting analyses of covariance (ANCOVAs; Lord, 1967; Wildt and Ahtola, 1978), we conducted independent analyses in the three experimental groups (YAs, HOAs, patients with AD) by using parametric ANCOVA when appropriate (Singmann et al., 2019) and robust regression otherwise (Venables and Ripley, 2002). In all analyses, there were no main effects of years of

education and no interactions between years of education and other factors (all $ps > .1$). Main effects and interactions reported in the following subsections remained significant.

Similarly, we investigated the influence of cognitive scores (namely, MoCA and FAB) and of emotional scores (namely, BDI-II and GDS) on visual search performances. Because of non-independence between cognitive scores and group and low variability of these scores in HOAs, the part of the analysis including these scores was conducted in patients with AD only. We used parametric ANCOVA (Singmann et al., 2019), or robust regression when appropriate (Venables and Ripley, 2002). In all analyses, there were no main effects of cognitive or emotional scores and no interactions with other factors (all $ps > .1$). Main effects and interactions reported in the following subsections remained significant.

Because we had no specific hypotheses regarding education, and cognitive and emotional scores, and given their lack of significant influence, we decided not to include these variables in our subsequent statistical analyses.

3.1. Errors

Errors reflect a response error regarding the location of the frame break. Error rates for YAs, HOAs, and patients with AD are shown in Table 3. Since the variance was not homogeneous and the residuals were not normally distributed, we conducted a robust mixed ANOVA (Wilcox, 2012) on the participants' error rates, with emotional valence (negative, neutral) and number of distractors (one, three, five) as within-participant factors and group (YA, HOA, AD) as a between-participant factor. There were no main effects of emotional valence, number of distractors, and there were no significant interactions (all $ps > .1$). There was a trend for the effect of group, $Q = 2.67, p = .06$.

[Insert Table 3 about here]

3.2. Engagement delays⁹

Recall that engagement delays reflect the time between the onset of the stimulus display and the first gaze fixation on the target. These delays for YAs, HOAs, and patients with AD are shown in Figure 2. We conducted a mixed ANOVA on the participants' engagement delays, with emotional valence (negative, neutral) and number of distractors (one, three, five) as within-participant factors and group (YA, HOA, AD) as a between-participant factor. Since the variance was not homogeneous, we applied a reciprocal transformation to the raw data (Howell, 2008).

The ANOVA revealed a significant main effect of group, $F(2, 73) = 22.79, p < .001, \eta_p^2 = .38$, reflecting faster engagement delays for YAs, 522 ± 141 ms, than for HOAs, 622 ± 205 ms, $b = 1.26e-4, t(73) = 3.93, p < .001, 95\%$ confidence interval (CI) $[6.21e-5, 1.90e-4], r = .42$, and faster engagement delays for HOAs than for patients with AD, 722 ± 257 ms, $b = 1.08e-4, t(73) = 2.82, p < .01, 95\%$ CI $[3.18e-5, 1.85e-4], r = .31$. The main effects of emotional valence, $F(1, 73) = 23.73, p < .001, \eta_p^2 = .25$, and of the number of distractors, $F(2, 146) = 766.09, p < .001, \eta_p^2 = .91$, were also significant, suggesting, respectively, longer engagement delays for neutral (622 ± 208 ms) than for negative targets (575 ± 205 ms) and an increase in engagement delays with the growing number of distractors, one: 395 ± 77 ms; three: 622 ± 136 ms; five: 778 ± 176 ms; one versus three: $b = 4.55e-4, t(146) = 27.95, p < .001, 95\%$ CI $[4.23e-4, 4.88e-4], r = .92$; three versus five: $b = 1.59e-4, t(146) = 9.75, p < .001, 95\%$ CI $[1.27e-4, 1.91e-4], r = .63$.

The interaction between emotional valence and group was significant, $F(2, 73) = 8.37, p < .001, \eta_p^2 = .19$. The planned contrast analysis of differences in engagement delays for negative and neutral images was significant between HOAs and patients with AD, $b = 9.00e-5, t(73) =$

⁹One patient with AD was removed because his performance led to variance inhomogeneity, even after transforming the data.

2.77, $p < .01$, 95% CI [2.53e-5, 1.55e-4], $r = .31$, but not between YAs and HOAs, $b = 3.36e-5$, $t(73) = 1.24$, $p = .22$, 95% CI [-2.05e-5, 8.77e-5], $r = .14$. In line with our starting hypotheses, we performed simple effect analyses for each emotional valence in order to further examine the impact of disease on emotional bias. Analyses of engagement delays for negative targets showed longer engagement delays for patients with AD than for HOAs, $b = 1.53e-4$, $t(73) = 3.65$, $p < .001$, 95% CI [6.97e-5, 2.37e-4], $r = .39$. In contrast, analyses of engagement delays for neutral targets did not show a significant contrast between HOAs and patients with AD, $b = 6.34e-5$, $t(73) = 1.53$, $p = .13$, 95% CI [-1.92e-5, 1.46e-4], $r = .18$. Finally, the interaction between the number of distractors and group was significant, $F(4, 146) = 2.74$, $p < .05$, $\eta_p^2 = .07$, suggesting a greater impact of the number of distractors on older groups than on YAs (see the analysis of search efficiency below for further details).

To further explore these data and to estimate the influence of emotional information on search efficiency, we calculated a single slope value per participant and per emotion condition. A slope represents the engagement delay as a function of the number of distractors present. More precisely, slopes were calculated as regression lines, with the following formula: $\frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2}$, where x represents mean engagement delays, y the number of distractors (one, three, or five), and n the number of mean engagement delays per participant (three). We conducted a mixed ANOVA on the participants' search slopes, with emotional valence (negative, neutral) as a within-participant factor and group (YA, HOA, AD) as a between-participant factor.¹⁰ Because the variance was not homogeneous, we applied a logarithmic transformation to the raw data (Howell, 2008).

The ANOVA revealed a significant effect of group, $F(2, 71) = 14.04$, $p < .001$, $\eta_p^2 = .28$, reflecting flatter slopes for YAs, 72 ± 21 ms, than for HOAs, 108 ± 29 ms, $b = 0.09$, $t(71) =$

¹⁰One HOA was removed because his performance led to a non-normal distribution of residuals. One patient with AD was removed because his slope had a negative value.

3.90, $p < .001$, 95% CI [0.04, 0.13], $r = .42$. The interaction between group and emotional valence was also significant, $F(2, 71) = 4.11$, $p < .05$, $\eta_p^2 = .10$, revealing a lower effect of emotion on search efficiency in patients with AD compared with HOAs, $b = 0.11$, $t(71) = 2.33$, $p < .05$, 95% CI [0.02, 0.20], $r = .27$. In line with our starting hypotheses, we performed simple effect analyses for each group to further explore the impact of normal and pathological aging on emotional bias. Slopes were significantly flatter for negative than for neutral targets in YAs, $F(1, 34) = 10.48$, $p < .01$, $\eta_p^2 = .24$, and in HOAs, $F(1, 22) = 4.67$, $p < .05$, $\eta_p^2 = .18$, but not in patients with AD, $F(1, 15) = 1.13$, $p = .30$, $\eta_p^2 = .07$.

Together, these data suggest (a) the presence of facilitated engagement toward negative compared with neutral targets (as reflected by the first target fixation time) in YAs and HOAs, and (b) a more efficient search of negative than of neutral targets (as reflected by flatter search slopes) in YAs and HOAs. These effects were both less important in patients with AD.

[Insert Figure 2 about here]

3.3. Disengagement delays¹¹

Recall that disengagement delays reflect the time between the beginning of the last fixation on the target and the manual response regarding the frame break. These delays for YAs, HOAs, and patients with AD are shown in Figure 3 and Table 4. We conducted an analysis on the participants' disengagement delays, with emotional valence (negative, neutral) and number of distractors (one, three, five) as within-participant factors and group (YA, HOA, AD) as a between-participant factor. Because the variance was not homogeneous, we conducted a robust mixed ANOVA (Wilcox, 2012).

¹¹Three patients with AD and one HOA were removed from this analysis because they demonstrated difficulties in responding according to the position of the frame break rather than to the position of the target on the screen. One patient with AD was also removed because he had no remaining data in one of the experimental conditions after data filtering.

The ANOVA revealed a significant effect of group, $Q = 34.96$, $p < .001$, reflecting longer disengagement delays for patients with AD ($1,301 \pm 156$ ms) than for HOAs, 994 ± 85 ms, $\hat{\psi} = 319.93$, $p < .001$, 95% CI [128.05, 511.81], and longer disengagement delays for HOAs than for YAs, 635 ± 57 ms, $\hat{\psi} = 338.69$, $p < .001$, 95% CI [234.52, 442.87]. The effect of emotional valence was also significant, $Q = 25.81$, $p < .001$, suggesting longer disengagement delays for negative (906 ± 290 ms) than for neutral (853 ± 260 ms) targets. There was no main effect of the number of distractors and there were no significant interactions (all $ps > .1$).

Taken together, these data suggest (a) more difficult disengagement from negative than from neutral targets in all groups and (b) an increase in disengagement delays in normal and pathological aging.

[Insert Figure 3 about here]

[Insert Table 4 about here]

4. Discussion

In the present study, we sought to determine how the impact of emotional content on spatial attention processes was modulated by normal aging and dementia of the Alzheimer type. To this end, we used an eye-tracking paradigm and a visual search task that involved emotional and neutral targets. On the basis of studies in AD that suggested (a) impairment of early engagement toward emotional stimuli in AD (Bourgin et al., 2018), (b) preservation of the impact of emotional information on delayed attentional processes in AD (Berger et al., 2015; Doninger and Bylsma, 2007; LaBar et al., 2000; Monti et al., 2010), and (c) early alterations of the amygdala, which seems preferentially involved in engagement processes, we expected to observe selective impairment of engagement mechanisms toward emotional information in patients with AD (relative to HOAs and YAs). Regarding normal aging, some

studies suggest that HOAs are more efficient than YAs at inhibiting negative information (Hahn et al., 2006; Mather and Carstensen, 2003). From these studies, we assumed that, compared with YAs, HOAs would show less influence of emotional target content on disengagement delays.

4.1. Selective impairment of attentional engagement toward negative information in AD

Unlike YAs and HOAs, patients with AD did not show facilitated engagement toward emotional information. By contrast, all groups showed similar difficulty in disengaging from emotional information than from neutral information. This finding strongly supports the relevance of performing a separate assessment of engagement and disengagement processes to investigate emotional attention in aging and neurodegenerative disorders. In addition, our findings are in agreement with (a) reports in which patients had difficulty in quickly focusing their attention on emotional information (Bourgin et al., 2018; Hot et al., 2013), and with (b) the presence of an early amygdala atrophy in AD, this area being particularly involved in early emotional attention (Pourtois et al., 2013; Schwabe et al., 2011; Vuilleumier, 2005). Yet, these patients may remain capable of processing this information after it is in their attentional focus, as is suggested by (a) the preserved influence of emotional content on disengagement delays in AD and (b) the valence and arousal ratings collected after the experiment, which were comparable among all experimental groups.

The fact that the patients were able to execute the task as correctly as the HOAs were suggests that our results on engagement delays are unlikely to be explained by other factors, such as altered visual search strategies (Foldi et al., 1992; Nebes and Brady, 1989; Porter et al., 2010; Rösler et al., 2000; Tales et al., 2004), lack of motivation (Modrego, 2010;

Starkstein, 2006), impaired object discrimination (Boucart et al., 2014a), scene categorization (Lee et al., 2007; Lenoble et al., 2015), or forgetfulness. In addition, patients with AD rated emotional targets as more negative and arousing than neutral targets, suggesting that, similar to the control groups, they were able to correctly discriminate target content. None of the patients included in the statistical analyses showed any signs of depression, as emphasized by the mean \pm SD score on the Geriatric Depression Scale (7.03 ± 3.42). More important, the patients displayed similar engagement delays toward neutral information as the HOAs did, but longer engagement delays toward emotional information. Crucially, these data suggest that altered engagement toward emotional information may exist in AD, independently from visual search impairments. In other words, the arousing properties of sensory stimuli did not influence the distribution of attention to extrapersonal targets in AD, despite the apparent preservation of engagement mechanisms in this patient sample.

Patients with AD displayed longer disengagement delays than HOAs did, in consistency with the literature (Crawford et al., 2015; Molitor, 2015; Parasuraman et al., 1992; Perry and Hodges, 1999; Rösler et al., 2000), and these disengagement delays were even longer for emotional targets. This result is consistent with previous works that showed an impact of emotional information on cognitive processes in AD (Berger et al., 2015; Doninger and Bylsma, 2007; Monti et al., 2010) and with neuroimaging data that showed a preserved (or even increased) amygdala response to emotional information in patients with AD or mild cognitive impairment (Berger et al., 2015; Burhan et al., 2016; Wright et al., 2007). An alternative explanation for the emotional influence on manual responses may be that semantic processing took longer for emotional than for neutral information. However, this explanation is unlikely because pretesting of our stimuli (in a normal and young population) did not reveal longer categorization times for emotional than for neutral stimuli. Moreover, we controlled our stimuli for low-level features (brightness, spatial frequencies, visual complexity), which

otherwise may have influenced processing time and more generally the distribution of attention.

4.2. Difficulty in disengagement from negative information in normal aging

As expected, HOAs showed longer engagement and disengagement delays than YAs did. Consistent with the literature (Bourgin et al., 2018; Hahn et al., 2006; Leclerc and Kensinger, 2008a; Mather and Knight, 2006; Rösler et al., 2005b), HOAs engaged their attention more quickly (reflected by earlier fixation) and efficiently (reflected by flatter slope) on negative than on neutral content. This suggests that, in HOAs and in YAs, emotionally negative information is more likely to be perceived by covert attention, which preferentially guides overt attention to it.

Considering disengagement delays, several studies suggest that compared with YAs, HOAs are more able to inhibit negative information (Ebner and Johnson, 2010; Goeleven et al., 2010) and disengage from negative stimuli (Doninger and Bylsma, 2007; Hahn et al., 2006; Mather and Carstensen, 2003; Rösler et al., 2005b). However, in the present study, similar to YAs, HOAs showed longer disengagement delays for negative than for neutral targets, suggesting that sensitivity to negative information beyond engagement processes may still exist in aging. These data may be partially explained by the level of arousal of negative targets. Several studies suggest that HOAs may be motivated to disengage from negative information because aging leads to higher sensitivity to arousal (Charles, 2010) and disengagement is a strategy to down-regulate negative affect (Orgeta, 2011; Scheibe et al., 2015). In the present study, the negative targets were moderately arousing (mean of 6.75 on a scale of 1 to 9). In comparison, Hahn et al. (2006), who showed facilitated disengagement from negative information during a visual search task in aging, used schematic faces, which

are known for their low level of arousal. Because (a) arousal may enhance the effects of negative information in attention independently from aging (Sutherland and Mather, 2015) and (b) HOAs may be more likely to focus automatically on negative information (Charles, 2010; Kensinger et al., 2007; Wurm et al., 2004), the level of arousal of the stimuli may have prevented HOAs from using efficient regulation strategies. Consistently with this assumption, Dolcos et al. (2014) showed similar amygdala activation in response to high arousal negative stimuli in YAs and HOAs. Yet, for low arousal negative stimuli, HOAs showed decreased amygdala activity and increased activity in the anterior cingulate cortex (relative to YAs). These data suggest that HOAs' emotional functioning and amygdala activity differ from that of YAs when stimuli arousal is low, but not when it is high.

Another possible explanation for disengagement data is linked to the current paradigm. In most visual search studies, participants must determine whether a discrepant stimulus (or a stimulus from a discrepant category) is present or absent in an array of distractors. Stimuli used in these paradigms are most commonly schematic faces (Hahn et al., 2006; Mather and Knight, 2006; Ohrmann et al., 2007; Ruffman et al., 2009), real faces (Bach et al., 2015; Calvo and Nummenmaa, 2008; Gerritsen et al., 2008; Ruffman et al., 2009), or simple images (e.g., snakes, spiders, mushrooms, flowers; (Leclerc and Kensinger, 2008a, 2010; LoBue et al., 2014; Öhman et al., 2001)), which results in visually simple search displays and highly homogeneous distractor sets. In comparison, the present task required participants to search for a complex scene of a specific category (namely, a scene involving a vehicle) in a set of heterogeneous distractors. Distractors were visually dissimilar from one another, which is known to make a search more challenging (Frischen et al., 2008; Quinlan, 2013). We deliberately chose to display complex arrays to match participants' expectations with those of everyday life, where people must face complex situations and quickly select the most relevant information. Yet, these differences from previous works may have resulted in a more complex

task to achieve, which may explain the discrepancies between the present study and previous investigations regarding disengagement delays. Several studies suggest that, in conditions that tax their cognitive capacity, HOAs will not engage (or will engage less) in strategies of emotion regulation (Reed et al., 2014), which may reverse their avoidance of negative stimuli (Knight et al., 2007; Mather and Knight, 2005).

4.3. Limitations and perspectives

A first limitation of this study is linked to the educational level of our participants. Patients with AD had a lower educational level than age-matched controls, which may have had an impact on their performance, independently from dementia severity. For instance, educational level may influence categorization abilities (Barea and Mansur, 2007), which may boost target or distractor categorization time during visual search (Maier and Abdel Rahman, 2019; Reeder et al., 2016). However, ANCOVAs conducted in the three experimental groups showed no main significant effect of educational level on visual search performance, suggesting that this factor did not explain participants' performance.

Another limitation is linked to the assessment of cognitive impairment. Since executive functions were most likely to be involved in our task, all participants were screened for cognitive impairment by using the MoCA and FAB scales. Nonetheless, although MoCA is highly reliable, particularly useful for detecting early dementia, and superior to the Mini-Mental State Examination as a global assessment tool (Roalf et al., 2013), conducting a full neuropsychological battery may be preferable in future studies. For instance, memory span tests may be useful, since working memory may have an impact on visual search performance (Oh and Kim, 2004).

Basic vision tests such as visual acuity or the Pelli-Robson contrast sensitivity chart may also have been used to ascertain that our participants did not have issues in identifying targets that may explain group differences. However, images were equalized on low-level features to limit the impact of basic vision differences on performance. Further, the low error rate of our participants and the fact that they explicitly rated images as intended suggests that they had no particular difficulty in perceiving the scenes.

Regarding methodological issues, the possibility cannot be excluded that, compared with neutral stimuli, emotional stimuli are associated with different cognitive features. This hypothesis has received support from several studies on emotional memory (e.g. for a review: Ack Baraly et al., 2017). The works of Ack Baraly et al. suggest that emotional events recruit cognitive resources such as attention, distinctive processing, and organization more than neutral events do. More globally, appraisal models provide a useful theoretical frame to explain emotional influences. Thus, the decreased attention toward novel, unusual, or emotional stimuli observed in patients with AD can be understood from the point of view of the component process model (Grandjean and Scherer, 2008; Scherer, 2009). This model suggests that psychophysiological reactions may notably depend on early checks of the novelty, intrinsic pleasantness, or goal relevance of stimulus events. Depending on the results of these checks, a given stimulus will be considered as more or less relevant and will thus require more or less attention deployment. Interestingly, the amygdala, which is atrophied in the early stages of AD, is involved in all of these dimensions of affective relevance (Murray et al., 2014).

Taken together, our findings suggest that patients with AD show decreased attention toward relevant stimuli, whether their relevance is characterized by intrinsic unpleasantness, novelty, or unusualness. Notably, although our negative stimuli may have been both unusual and unpleasant, our results suggest that none of these dimensions is processed effectively by

patients with AD. Interestingly, Lenoble et al., 2018, showed that patients with AD were more attracted to unusual stimuli than were normal controls. In their study, stimuli were pictures of animals or pieces of furniture pasted against a natural or man-made background. The unusualness emerged from the interaction between the target and the background, which could be congruent (i.e., animal with natural background or piece of furniture with man-made background) or incongruent (i.e., animal with man-made background or piece of furniture with natural background). Crucially, their results suggest that patients with AD could still process unusual information when unusualness involves contextual processing and not target processing only, which was the case in the present study. These data stress that further investigation involving neuroimaging is needed to (a) improve our understanding of relevance processing in AD and the impact of amygdala atrophy in this process, and (b) disentangle the involvement of each dimension of relevance.

Finally, because engagement mechanisms toward emotional features have been repeatedly associated with amygdala activity (Anderson and Phelps, 2001; Kennedy and Adolphs, 2010; Vuilleumier, 2005; Vuilleumier et al., 2004), more particularly in increasing search efficiency for negative information (Bach et al., 2015; Jacobs et al., 2012; Ohrmann et al., 2007), our findings could reflect amygdala alterations, which have previously been reported in AD (Klein-Koerkamp et al., 2014; Poulin et al., 2011). The existence of emotional attention alterations in AD being established, it is now crucial to conduct emotional attention paradigms in functional magnetic resonance imaging studies to characterize the anatomical and functional sources of the impairment in AD.

5. Conclusion

To our knowledge, this is the first study to investigate spatial attention toward emotional stimuli in AD. HOAs and YAs demonstrated facilitated engagement toward emotional compared with neutral information and had more difficulty in disengaging from emotional than from neutral targets. Comparatively, patients with AD were selectively impaired in engaging their attention toward emotional content. The combination of eye-tracking and manual response latencies provided a precise analysis of emotional attention, highlighting the importance of dissociating between cognitive processes to improve the understanding of emotional processing changes in AD. The involvement of amygdala alterations in the impaired engagement toward emotional stimuli in AD needs further investigation.

Acknowledgements

Funding for this project was provided by a grant from la Région Auvergne Rhône-Alpes. The authors have no conflict of interest to report. This study was carried out in the Neuropsychology Units at Grenoble and Saint-Etienne University Hospitals, France. We are grateful to all the study participants for kindly giving us their time.

References

- Ack Baraly, K.T., Hot, P., Davidson, P.S.R., Talmi, D., 2017. How Emotional Arousal Enhances Episodic Memory, in: *Learning and Memory: A Comprehensive Reference*. Elsevier, pp. 295–324. <https://doi.org/10.1016/B978-0-12-809324-5.21051-1>
- Amieva, H., Phillips, L.H., Della Sala, S., Henry, J.D., 2004. Inhibitory functioning in Alzheimer's disease. *Brain* 127, 949–964. <https://doi.org/10.1093/brain/awh045>
- Anderson, C.D., Phelps, R.E., 2001. Lesions of the human amygdala impair enhanced perception of emotionally salient events. *Nature* 411, 302–305.
- Asaumi, Y., Morita, K., Nakashima, Y., Muraoka, A., Uchimura, N., 2014. Evaluation of P300 components for emotion-loaded visual event-related potential in elderly subjects, including those with dementia. *Psychiatry Clin. Neurosci.* 68, 558–567. <https://doi.org/10.1111/pcn.12162>
- Bach, D.R., Hurlmann, R., Dolan, R.J., 2015. Impaired threat prioritisation after selective bilateral amygdala lesions. *Cortex* 63, 206–213. <https://doi.org/10.1016/j.cortex.2014.08.017>
- Barea, K.S., Mansur, L.L., 2007. Knowledge of semantic categories in normal aged: Influence of education. *Dement. Neuropsychol.* 1, 166–172. <https://doi.org/10.1590/s1980-57642008dn10200009>
- Beck, A.T., Steer, R.A., Ball, R., Ranieri, W., 1996. Comparison of Beck Depression Inventories -IA and -II in psychiatric outpatients. *J. Pers. Assess.* 67, 588–597.
- Berger, C., Erbe, A.-K., Ehlers, I., Marx, I., Hauenstein, K., Teipel, S., 2015. Effects of task-irrelevant emotional stimuli on working memory processes in mild cognitive impairment. *J. Alzheimers Dis.* 44, 439–453.
- Bex, P., Makous, W., 2002. Spatial frequency, phase, and the contrast of natural images. *J. Opt. Soc. Am. A Opt. Image Sci. Vis.* 19, 1096–1106.
- Boucart, M., Bubbico, G., Szaffarczyk, S., Pasquier, F., 2014a. Animal spotting in Alzheimer's disease: an eye tracking study of object categorization. *J. Alzheimers Dis.* 39, 181–189.
- Boucart, M., Calais, G., Lenoble, Q., Moroni, C., Pasquier, F., 2014b. Differential processing of natural scenes in posterior cortical atrophy and in Alzheimer's disease, as measured with a saccade choice task. *Front. Integr. Neurosci.* 8:60. <https://doi.org/10.3389/fnint.2014.00060>
- Bourgin, J., 2019. Impact of emotionally negative information on attentional processes in normal aging and Alzheimer's disease - Data & Analyses [WWW Document]. URL <https://doi.org/10.17605/OSF.IO/C5BGU>
- Bourgin, J., Guyader, N., Chauvin, A., Juphard, A., Sauvée, M., Moreaud, O., Silvert, L., Hot, P., 2018. Early emotional attention is impacted in Alzheimer's disease: an eye-tracking study. *J. Alzheimers Dis.* 63, 1445–1458. <https://doi.org/10.3233/JAD-180170>
- Brosch, T., Sharma, D., 2005. The Role of Fear-Relevant Stimuli in Visual Search: A Comparison of Phylogenetic and Ontogenetic Stimuli. *Emotion* 5, 360–364. <https://doi.org/10.1037/1528-3542.5.3.360>
- Burhan, A.M., Anazodo, U.C., Chung, J.K., Arena, A., Graff-Guerrero, A., Mitchell, D.G.V., 2016. The Effect of Task-Irrelevant Fearful-Face Distractor on Working Memory Processing in Mild Cognitive Impairment versus Healthy Controls: An Exploratory fMRI Study in Female Participants. *Behav. Neurol.* 2016, 1–13. <https://doi.org/10.1155/2016/1637392>
- Calvo, M.G., Nummenmaa, L., 2008. Detection of emotional faces: Salient physical features guide effective visual search. *J. Exp. Psychol. Gen.* 137, 471–494. <https://doi.org/10.1037/a0012771>
- Carretié, L., Hinojosa, J.A., Martín-Loeches, M., Mercado, F., Tapia, M., 2004. Automatic attention to emotional stimuli: Neural correlates. *Hum. Brain Mapp.* 22, 290–299. <https://doi.org/10.1002/hbm.20037>
- Carstensen, L.L., Fung, H.H., Charles, S.T., 2003. Socioemotional Selectivity Theory and the Regulation of Emotion in the Second Half of Life. *Motiv. Emot.* 27, 103–123. <https://doi.org/10.1023/A:1024569803230>

- Charles, S.T., 2010. Strength and vulnerability integration: A model of emotional well-being across adulthood. *Psychol. Bull.* 136, 1068–1091. <https://doi.org/10.1037/a0021232>
- Cherubini, A., Péran, P., Caltagirone, C., Sabatini, U., Spalletta, G., 2009. Aging of subcortical nuclei: Microstructural, mineralization and atrophy modifications measured in vivo using MRI. *NeuroImage* 48, 29–36. <https://doi.org/10.1016/j.neuroimage.2009.06.035>
- Corbetta, M., 1998. Frontoparietal cortical networks for directing attention and the eye to visual locations: Identical, independent, or overlapping neural systems? *Proc. Natl. Acad. Sci.* 95, 831–838. <https://doi.org/10.1073/pnas.95.3.831>
- Crawford, T.J., Devereaux, A., Higham, S., Kelly, C., 2015. The disengagement of visual attention in Alzheimer's disease: a longitudinal eye-tracking study. *Front. Aging Neurosci.* 7:118. <https://doi.org/10.3389/fnagi.2015.00118>
- Dan-Glauser, E.S., Scherer, K.R., 2011. The Geneva affective picture database (GAPED): a new 730-picture database focusing on valence and normative significance. *Behav. Res. Methods* 43, 468–477. <https://doi.org/10.3758/s13428-011-0064-1>
- Davis, M., Whalen, P.J., 2001. The amygdala: vigilance and emotion. *Mol. Psychiatry* 6, 13.
- Delplanque, S., N'diaye, K., Scherer, K., Grandjean, D., 2007. Spatial frequencies or emotional effects? *J. Neurosci. Methods* 165, 144–150. <https://doi.org/10.1016/j.jneumeth.2007.05.030>
- Derakshan, N., Koster, E.H.W., 2010. Processing efficiency in anxiety: Evidence from eye-movements during visual search. *Behav. Res. Ther.* 48, 1180–1185. <https://doi.org/10.1016/j.brat.2010.08.009>
- Dolcos, S., Katsumi, Y., Dixon, R.A., 2014. The role of arousal in the spontaneous regulation of emotions in healthy aging: a fMRI investigation. *Front. Psychol.* 5:681. <https://doi.org/10.3389/fpsyg.2014.00681>
- Doninger, N.A., Bylsma, F.W., 2007. Inhibitory control and affective valence processing in dementia of the alzheimer type. *J. Neuropsychol.* 1, 65–83. <https://doi.org/10.1348/174866407X180828>
- Dubois, B., Slachevsky, A., Litvan, I., Pillon, B., 2000. The FAB: A frontal assessment battery at bedside. *Neurology* 55, 1621–1626. <https://doi.org/10.1212/WNL.55.11.1621>
- Ebner, N.C., Johnson, M.K., 2010. Age-group differences in interference from young and older emotional faces. *Cogn. Emot.* 24, 1095–1116. <https://doi.org/10.1080/02699930903128395>
- Erel, H., Levy, D.A., 2016. Orienting of visual attention in aging. *Neurosci. Biobehav. Rev.* 69, 357–380. <https://doi.org/10.1016/j.neubiorev.2016.08.010>
- Flykt, A., Caldara, R., 2006. Tracking fear in snake and spider fearful participants during visual search: A multi-response domain study. *Cogn. Emot.* 20, 1075–1091. <https://doi.org/10.1080/02699930500381405>
- Foldi, N.S., Jutagir, R., Davidoff, D., Gould, T., 1992. Selective attention skills in Alzheimer's disease: Performance on graded cancellation tests varying in density and complexity. *J. Gerontol. Psychol. Sci.* 47, 146–153.
- Foster, J.K., Behrmann, M., Stuss, D.T., 1999. Visual attention deficits in Alzheimer's disease: Simple versus conjoined feature search. *Neuropsychology* 13, 223–245.
- Fox, E., Russo, R., Bowles, R., Dutton, K., 2001. Do threatening stimuli draw or hold visual attention in subclinical anxiety? *J Exp Psychol Gen* 130, 681–700.
- Frischen, A., Eastwood, J.D., Smilek, D., 2008. Visual search for faces with emotional expressions. *Psychol. Bull.* 134, 662–676. <https://doi.org/10.1037/0033-2909.134.5.662>
- García-Rodríguez, B., Vincent, C., Casares-Guillén, C., Ellgring, H., Frank, A., 2012. The Effects of Different Attentional Demands in the Identification of Emotional Facial Expressions in Alzheimer's Disease. *Am. J. Alzheimers Dis. Dementias*® 27, 530–536. <https://doi.org/10.1177/1533317512459797>
- Gerritsen, C., Frischen, A., Blake, A., Smilek, D., Eastwood, J.D., 2008. Visual search is not blind to emotion. *Percept. Psychophys.* 70, 1047–1059. <https://doi.org/10.3758/PP.70.6.1047>

- Goeleven, E., De Raedt, R., Dierckx, E., 2010. The positivity effect in older adults: The role of affective interference and inhibition. *Aging Ment. Health* 14, 129–137.
<https://doi.org/10.1080/13607860903228754>
- Grandjean, D., Scherer, K.R., 2008. Unpacking the cognitive architecture of emotion processes. *Emotion* 8, 341–351. <https://doi.org/10.1037/1528-3542.8.3.341>
- Grieve, S.M., Clark, C.R., Williams, L.M., Peduto, A.J., Gordon, E., 2005. Preservation of limbic and paralimbic structures in aging. *Hum. Brain Mapp.* 25, 391–401.
<https://doi.org/10.1002/hbm.20115>
- Hahn, S., Carlsson, C., Singer, S., Gronlund, S.D., 2006. Aging and visual search: Automatic and controlled attentional bias to threat faces. *Acta Psychol. (Amst.)* 123, 312–336.
<https://doi.org/10.1016/j.actpsy.2006.01.008>
- Hobson, J., 2015. The Montreal Cognitive Assessment (MoCA). *Occup. Med.* 65, 764–765.
<https://doi.org/10.1093/occmed/kqv078>
- Hot, P., Klein-Koerkamp, Y., Borg, C., Richard-Mornas, A., Zsoldos, I., Paignon Adeline, A., Thomas Antérion, C., Baciú, M., 2013. Fear recognition impairment in early-stage Alzheimer’s disease: When focusing on the eyes region improves performance. *Brain Cogn.* 82, 25–34.
<https://doi.org/10.1016/j.bandc.2013.02.001>
- Howell, D., 2008. *Méthodes statistiques en sciences humaines.*, 16 ed.; translated by M. Rogier, V. Yzerbyt & Y. Bestgen. ed. De Boeck, Bruxelles, France.
- Huang, Y.-M., Yeh, Y.-Y., 2011. Why does a red snake in the grass capture your attention? *Emotion* 11, 224–232. <https://doi.org/10.1037/a0022578>
- Isaacowitz, D.M., Wadlinger, H.A., Goren, D., Wilson, H.R., 2006. Is there an age-related positivity effect in visual attention? A comparison of two methodologies. *Emotion* 6, 511–516.
<https://doi.org/10.1037/1528-3542.6.3.511>
- Jack, C.R.J., Petersen, R.C., Xu, Y.C., Waring, S.C., O’Brien, P.C., Tangalos, E.G., Smith, G.E., Ivnik, R.J., Kokmen, E., 1997. Medial temporal atrophy on MRI in normal aging and very mild Alzheimer’s disease. *Neurology* 49, 786–794.
- Jacobs, R.H.A.H., Renken, R., Aleman, A., Cornelissen, F.W., 2012. The amygdala, top-down effects, and selective attention to features. *Neurosci. Biobehav. Rev.* 36, 2069–2084.
<https://doi.org/10.1016/j.neubiorev.2012.05.011>
- Kalpouzos, G., Chételat, G., Baron, J.C., Landeau, B., Mevel, K., Godeau, C., Barré, L., Constans, J.M., Viader, F., Eustache, F., Desgranges, B., 2009. Voxel-based mapping of brain gray matter volume and glucose metabolism profiles in normal aging. *Neurobiol. Aging* 30, 112–124.
<https://doi.org/10.1016/j.neurobiolaging.2007.05.019>
- Kennedy, D.P., Adolphs, R., 2010. Impaired fixation to eyes following amygdala damage arises from abnormal bottom-up attention. *Neuropsychologia* 48, 3392–3398.
<https://doi.org/10.1016/j.neuropsychologia.2010.06.025>
- Kensinger, E.A., 2004. Remembering emotional experiences: The contribution of valence and arousal. *Rev. Neurosci.* 15, 241–251.
- Kensinger, E.A., Gutchess, A.H., Schacter, D.L., 2007. Effects of aging and encoding instructions on emotion-induced memory trade-offs. *Psychol. Aging* 22, 781–795.
<https://doi.org/10.1037/0882-7974.22.4.781>
- Klein-Koerkamp, Y., A Heckemann, R., T Ramdeen, K., Moreaud, O., Keignart, S., Krainik, A., Hammers, A., Baciú, M., Hot, P., Initiative, A.D.N., others, 2014. Amygdalar atrophy in early Alzheimer’s disease. *Curr. Alzheimer Res.* 11, 239–252.
- Knight, M., Seymour, T.L., Gaunt, J.T., Baker, C., Nesmith, K., Mather, M., 2007. Aging and goal-directed emotional attention: Distraction reverses emotional biases. *Emotion* 7, 705–714.
<https://doi.org/10.1037/1528-3542.7.4.705>
- Kotowicz, A., Rutishauser, U., Koch, C., 2010. Time course of target recognition in visual search. *Front. Hum. Neurosci.* 4:31. <https://doi.org/10.3389/fnhum.2010.00031>

- Kurdi, B., Lozano, S., Banaji, M.R., 2017. Introducing the Open Affective Standardized Image Set (OASIS). *Behav. Res. Methods* 49, 457–470. <https://doi.org/10.3758/s13428-016-0715-3>
- LaBar, K.S., Mesulam, M.-M., Gitelman, D.R., Weintraub, S., 2000. Emotional curiosity: modulation of visuospatial attention by arousal is preserved in aging and early-stage Alzheimer's disease. *Neuropsychologia* 38, 1734–1740.
- Landré, L., Sava, A.-A., Krainik, A., Lamalle, L., Krolak-Salmon, P., Chainay, H., 2013. Effects of emotionally-rated material on visual memory in Alzheimer's disease in relation to medial temporal atrophy. *J. Alzheimers Dis.* 36, 535–544.
- Lang, P.J., Bradley, M.M., Cuthbert, D., 1997. International Affective Picture System (IAPS): Technical Manual and Affective Ratings.
- Leclerc, C.M., Kensinger, E.A., 2011. Neural processing of emotional pictures and words: a comparison of young and older adults. *Dev. Neuropsychol.* 36, 519–538. <https://doi.org/10.1080/87565641.2010.549864>
- Leclerc, C.M., Kensinger, E.A., 2010. Age-related valence-based reversal in recruitment of medial prefrontal cortex on a visual search task. *Soc. Neurosci.* 5, 560–576. <https://doi.org/10.1080/17470910903512296>
- Leclerc, Christina M., Kensinger, E.A., 2008. Effects of age on detection of emotional information. *Psychol. Aging* 23, 209–215. <https://doi.org/10.1037/0882-7974.23.1.209>
- Leclerc, C. M., Kensinger, E.A., 2008. Age-related differences in medial prefrontal activation in response to emotional images. *Cogn. Affect. Behav. Neurosci.* 8, 153–164. <https://doi.org/10.3758/CABN.8.2.153>
- Lee, A., Levi, N., Davies, R., Hodges, J., Graham, K., 2007. Differing profiles of face and scene discrimination deficits in semantic dementia and Alzheimer's disease. *Neuropsychologia* 45, 2135–2146. <https://doi.org/10.1016/j.neuropsychologia.2007.01.010>
- Lenoble, Q., Bubbico, G., Szaffarczyk, S., Pasquier, F., Boucart, M., 2015. Scene Categorization in Alzheimer's Disease: A Saccadic Choice Task. *Dement. Geriatr. Cogn. Disord. Extra* 5, 1–12. <https://doi.org/10.1159/000366054>
- Lenoble, Q., Corveleyn, X., Szaffarczyk, S., Pasquier, F., Boucart, M., 2018. Attentional capture by incongruent object/background scenes in patients with Alzheimer disease. *Cortex* 107, 4–12. <https://doi.org/10.1016/j.cortex.2018.06.002>
- Li, J., Pan, P., Huang, R., Shang, H., 2012. A meta-analysis of voxel-based morphometry studies of white matter volume alterations in Alzheimer's disease. *Neurosci. Biobehav. Rev.* 36, 757–763. <https://doi.org/10.1016/j.neubiorev.2011.12.001>
- LoBue, V., Matthews, K., Harvey, T., Stark, S.L., 2014. What accounts for the rapid detection of threat? Evidence for an advantage in perceptual and behavioral responding from eye movements. *Emotion* 14, 816–823. <https://doi.org/10.1037/a0035869>
- Loftus, G.R., Masson, M.E.J., 1994. Using confidence intervals in within-subject designs. *Psychon. Bull. Rev.* 1, 476–490. <https://doi.org/10.3758/BF03210951>
- Lord, F.M., 1967. A paradox in the interpretation of group comparisons. *Psychol. Bull.* 68, 304–305. <https://doi.org/10.1037/h0025105>
- Maier, M., Abdel Rahman, R., 2019. No matter how: Top-down effects of verbal and semantic category knowledge on early visual perception. *Cogn. Affect. Behav. Neurosci.* <https://doi.org/10.3758/s13415-018-00679-8>
- Marchewka, A., Żurawski, Ł., Jednoróg, K., Grabowska, A., 2014. The Nencki Affective Picture System (NAPS): Introduction to a novel, standardized, wide-range, high-quality, realistic picture database. *Behav. Res. Methods* 46, 596–610. <https://doi.org/10.3758/s13428-013-0379-1>
- Mather, M., 2016. The Affective Neuroscience of Aging. *Annu. Rev. Psychol.* 67, 213–238. <https://doi.org/10.1146/annurev-psych-122414-033540>
- Mather, M., 2012. The emotion paradox in the aging brain. *Ann. N. Y. Acad. Sci.* 1251, 33–49. <https://doi.org/10.1111/j.1749-6632.2012.06471.x>

- Mather, M., Carstensen, L.L., 2003. Aging and Attentional Biases for Emotional Faces. *Psychol. Sci.* 14, 409–415. <https://doi.org/10.1111/1467-9280.01455>
- Mather, M., Knight, M., 2005. Goal-directed memory: The role of cognitive control in older adults' emotional memory. *Psychol. Aging* 20, 554–570. <https://doi.org/10.1037/0882-7974.20.4.554>
- Mather, M., Knight, M.R., 2006. Angry faces get noticed quickly: Threat detection is not impaired among older adults. *J. Gerontol. Psychol. Sci.* 61B, 54–57.
- McKhann, G.M., Knopman, D.S., Chertkow, H., Hyman, B.T., Jack, C.R., Kawas, C.H., Klunk, W.E., Koroshetz, W.J., Manly, J.J., Mayeux, R., Mohs, R.C., Morris, J.C., Rossor, M.N., Scheltens, P., Carrillo, M.C., Thies, B., Weintraub, S., Phelps, C.H., 2011. The diagnosis of dementia due to Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimers Dement.* 7, 263–269. <https://doi.org/10.1016/j.jalz.2011.03.005>
- Modrego, P.J., 2010. Depression in Alzheimer's Disease. *Pathophysiology, Diagnosis, and Treatment. J. Alzheimers Dis.* 21, 1077–1087. <https://doi.org/10.3233/JAD-2010-100153>
- Mohanty, A., Egner, T., Monti, J.M., Mesulam, M.-M., 2009. Search for a Threatening Target Triggers Limbic Guidance of Spatial Attention. *J. Neurosci.* 29, 10563–10572. <https://doi.org/10.1523/JNEUROSCI.1170-09.2009>
- Molitor, R.J., 2015. Eye movements in Alzheimer's disease. *J. Alzheimers Dis.* 44, 1–12. <https://doi.org/10.3233/JAD-141173>
- Monti, J.M., Weintraub, S., Egner, T., 2010. Differential age-related decline in conflict-driven task-set shielding from emotional versus non-emotional distracters. *Neuropsychologia* 48, 1697–1706. <https://doi.org/10.1016/j.neuropsychologia.2010.02.017>
- Mori, E., Ikeda, M., Hirono, N., Kitagaki, H., Imamura, T., Shimomura, T., 1999. Amygdalar volume and emotional memory in Alzheimer's disease. *Am. J. Psychiatry* 156, 216–222.
- Murray, R.J., Brosch, T., Sander, D., 2014. The functional profile of the human amygdala in affective processing: Insights from intracranial recordings. *Cortex* 60, 10–33. <https://doi.org/10.1016/j.cortex.2014.06.010>
- Nashiro, K., Sakaki, M., Mather, M., 2012. Age Differences in Brain Activity during Emotion Processing: Reflections of Age-Related Decline or Increased Emotion Regulation? *Gerontology* 58, 156–163. <https://doi.org/10.1159/000328465>
- Nasreddine, Z.S., Patel, B.B., 2016. Validation of Montreal Cognitive Assessment, MoCA, Alternate French Versions. *Can. J. Neurol. Sci. J. Can. Sci. Neurol.* 43, 665–671. <https://doi.org/10.1017/cjn.2016.273>
- Nebes, R.D., Brady, C.B., 1989. Focused and Divided Attention in Alzheimer's Disease. *Cortex* 25, 305–315. [https://doi.org/10.1016/S0010-9452\(89\)80045-0](https://doi.org/10.1016/S0010-9452(89)80045-0)
- Notebaert, L., Crombez, G., Van Damme, S., De Houwer, J., Theeuwes, J., 2011. Signals of threat do not capture, but prioritize, attention: A conditioning approach. *Emotion* 11, 81–89. <https://doi.org/10.1037/a0021286>
- Nummenmaa, L., Hyönä, J., Calvo, M.G., 2009. Emotional scene content drives the saccade generation system reflexively. *J. Exp. Psychol. Hum. Percept. Perform.* 35, 305–323. <https://doi.org/10.1037/a0013626>
- Oh, S.-H., Kim, M.-S., 2004. The role of spatial working memory in visual search efficiency. *Psychon. Bull. Rev.* 11, 275–281. <https://doi.org/10.3758/BF03196570>
- Öhman, A., Flykt, A., Esteves, F., 2001. Emotion drives attention: detecting the snake in the grass. *J. Exp. Psychol. Gen.* 130, 466.
- Ohrmann, P., Rauch, A.V., Bauer, J., Kugel, H., Arolt, V., Heindel, W., Suslow, T., 2007. Threat sensitivity as assessed by automatic amygdala response to fearful faces predicts speed of visual search for facial expression. *Exp. Brain Res.* 183, 51–59. <https://doi.org/10.1007/s00221-007-1022-0>

- Orgeta, V., 2011. Avoiding Threat in Late Adulthood: Testing Two Life Span Theories of Emotion. *Exp. Aging Res.* 37, 449–472. <https://doi.org/10.1080/0361073X.2011.590759>
- Parasuraman, R., Greenwood, P.M., Haxby, J.V., Grady, C.L., 1992. Visuospatial attention in dementia of the Alzheimer type. *Brain* 115, 711–733.
- Peli, E., 1990. Contrast in complex images. *J. Opt. Soc. Am. A* 7, 2032–2040. <https://doi.org/10.1364/JOSAA.7.002032>
- Perry, R.J., Hodges, J.R., 1999. Attention and executive deficits in Alzheimer’s disease: A critical review. *Brain* 122, 383–404.
- Porter, G., Leonards, U., Wilcock, G., Haworth, J., Troscianko, T., Tales, A., 2010. New insights into feature and conjunction search: II. Evidence from Alzheimer’s disease. *Cortex* 46, 637–649. <https://doi.org/10.1016/j.cortex.2009.04.014>
- Poulin, S.P., Dautoff, R., Morris, J.C., Barrett, L.F., Dickerson, B.C., 2011. Amygdala atrophy is prominent in early Alzheimer’s disease and relates to symptom severity. *Psychiatry Res. Neuroimaging* 194, 7–13. <https://doi.org/10.1016/j.psychres.2011.06.014>
- Pourtois, G., Schettino, A., Vuilleumier, P., 2013. Brain mechanisms for emotional influences on perception and attention: What is magic and what is not. *Biol. Psychol.* 92, 492–512. <https://doi.org/10.1016/j.biopsycho.2012.02.007>
- Pourtois, G., Vuilleumier, P., 2006. Dynamics of emotional effects on spatial attention in the human visual cortex. *Prog. Brain Res.* 156.
- Quinlan, P.T., 2013. The visual detection of threat: A cautionary tale. *Psychon. Bull. Rev.* 20, 1080–1101. <https://doi.org/10.3758/s13423-013-0421-4>
- Reed, A.E., Chan, L., Mikels, J.A., 2014. Meta-analysis of the age-related positivity effect: Age differences in preferences for positive over negative information. *Psychol. Aging* 29, 1–15. <https://doi.org/10.1037/a0035194>
- Reeder, R.R., Stein, T., Peelen, M.V., 2016. Perceptual expertise improves category detection in natural scenes. *Psychon. Bull. Rev.* 23, 172–179. <https://doi.org/10.3758/s13423-015-0872-x>
- Roalf, D.R., Moberg, P.J., Xie, S.X., Wolk, D.A., Moelter, S.T., Arnold, S.E., 2013. Comparative accuracies of two common screening instruments for classification of Alzheimer’s disease, mild cognitive impairment, and healthy aging. *Alzheimers Dement.* 9, 529–537. <https://doi.org/10.1016/j.jalz.2012.10.001>
- Rösler, A., Mapstone, M., Hays-Wicklund, A., Gitelman, D., Weintraub, S., 2005a. The “Zoom Lens” of Focal Attention in Visual Search: Changes in Aging and Alzheimer’s Disease. *Cortex* 41, 512–519. [https://doi.org/10.1016/S0010-9452\(08\)70191-6](https://doi.org/10.1016/S0010-9452(08)70191-6)
- Rösler, A., Mapstone, M.E., Hays, A.K., Mesulam, M.-M., Rademaker, A., Gitelman, D.R., Weintraub, S., 2000. Alterations of visual search strategy in Alzheimer’s disease and aging. *Neuropsychology* 14, 398–408. <https://doi.org/10.1037/0894-4105.14.3.398>
- Rösler, A., Ulrich, C., Billino, J., Sterzer, P., Weidauer, S., Bernhardt, T., Steinmetz, H., Frölich, L., Kleinschmidt, A., 2005b. Effects of arousing emotional scenes on the distribution of visuospatial attention: changes with aging and early subcortical vascular dementia. *J. Neurol. Sci.* 229–230, 109–116. <https://doi.org/10.1016/j.jns.2004.11.007>
- Ruffman, T., Ng, M., Jenkin, T., 2009. Older Adults Respond Quickly to Angry Faces Despite Labeling Difficulty. *J. Gerontol. B. Psychol. Sci. Soc. Sci.* 64B, 171–179. <https://doi.org/10.1093/geronb/gbn035>
- Samanez-Larkin, G.R., Robertson, E.R., Mikels, J.A., Carstensen, L.L., Gotlib, I.H., 2009. Selective attention to emotion in the aging brain. *Psychol. Aging* 24, 519–529. <https://doi.org/10.1037/a0016952>
- Sander, D., Grafman, J., Zalla, T., 2003. The human amygdala: An evolved system for relevance detection. *Rev. Neurosci.* 14, 303–316.
- Sasse, L.K., Gamer, M., Büchel, C., Brassens, S., 2014. Selective control of attention supports the positivity effect in aging. *PLoS One* 9, e104180.

- Scheibe, S., Sheppes, G., Staudinger, U.M., 2015. Distract or reappraise? Age-related differences in emotion-regulation choice. *Emotion* 15, 677–681. <https://doi.org/10.1037/a0039246>
- Scherer, K.R., 2009. Emotions are emergent processes: they require a dynamic computational architecture. *Philos. Trans. R. Soc. B Biol. Sci.* 364, 3459–3474. <https://doi.org/10.1098/rstb.2009.0141>
- Schwabe, L., Merz, C.J., Walter, B., Vaitl, D., Wolf, O.T., Stark, R., 2011. Emotional modulation of the attentional blink: The neural structures involved in capturing and holding attention. *Neuropsychologia* 49, 416–425. <https://doi.org/10.1016/j.neuropsychologia.2010.12.037>
- Singmann, H., Bolker, B., Westfall, J., Aust, F., 2019. afex: Analysis of Factorial Experiments.
- St. Jacques, P.L., Bessette-Symons, B., Cabeza, R., 2009. Functional neuroimaging studies of aging and emotion: Fronto-amygdalar differences during emotional perception and episodic memory. *J. Int. Neuropsychol. Soc.* 15, 819–825. <https://doi.org/10.1017/S1355617709990439>
- Starkstein, S.E., 2006. A prospective longitudinal study of apathy in Alzheimer’s disease. *J. Neurol. Neurosurg. Psychiatry* 77, 8–11. <https://doi.org/10.1136/jnnp.2005.069575>
- Sutherland, M.R., Mather, M., 2015. Negative Arousal Increases the Effects of Stimulus Salience in Older Adults. *Exp. Aging Res.* 41, 259–271. <https://doi.org/10.1080/0361073X.2015.1021644>
- Tales, A., Muir, J., Jones, R., Bayer, A., Snowden, R.J., 2004. The effects of saliency and task difficulty on visual search performance in ageing and Alzheimer’s disease. *Neuropsychologia* 42, 335–345. <https://doi.org/10.1016/j.neuropsychologia.2003.08.002>
- Venables, W.N., Ripley, B.D., 2002. *Modern Applied Statistics with S*, Fourth Edition. ed. Springer, New York.
- Vuilleumier, P., 2005. How brains beware: neural mechanisms of emotional attention. *Trends Cogn. Sci.* 9, 585–594. <https://doi.org/10.1016/j.tics.2005.10.011>
- Vuilleumier, P., Richardson, M.P., Armony, J.L., Driver, J., Dolan, R.J., 2004. Distant influences of amygdala lesion on visual cortical activation during emotional face processing. *Nat. Neurosci.* 7, 1271–1278. <https://doi.org/10.1038/nn1341>
- Wilcox, R., 2012. *Introduction to Robust Estimation and Hypothesis Testing* 3rd Edition. Elsevier.
- Wildt, A.R., Ahtola, O., 1978. *Analysis of covariance*, Sage University Paper Series on Quantitative Applications in the Social Sciences. Sage, Newbury Park, CA.
- Wright, C.I., Dickerson, B.C., Feczko, E., Negeira, A., Williams, D., 2007. A Functional Magnetic Resonance Imaging Study of Amygdala Responses to Human Faces in Aging and Mild Alzheimer’s Disease. *Biol. Psychiatry* 62, 1388–1395. <https://doi.org/10.1016/j.biopsych.2006.11.013>
- Wurm, L.H., Labouvie-Vief, G., Aycock, J., Rebucal, K.A., Koch, H.E., 2004. Performance in Auditory and Visual Emotional Stroop Tasks: A Comparison of Older and Younger Adults. *Psychol. Aging* 19, 523–535. <https://doi.org/10.1037/0882-7974.19.3.523>
- Yao, H., Liu, Y., Zhou, B., Zhang, Z., An, N., Wang, P., Wang, L., Zhang, X., Jiang, T., 2013. Decreased functional connectivity of the amygdala in Alzheimer’s disease revealed by resting-state fMRI. *Eur. J. Radiol.* 82, 1531–1538. <https://doi.org/10.1016/j.ejrad.2013.03.019>
- Yesavage, J.A., Brink, T.L., Rose, T.L., Lum, O., Huang, V., Adey, M., Leirer, V.O., 1982. Development and validation of a geriatric depression screening scale: a preliminary report. *J. Psychiatr. Res.* 17, 37–49.

Table 1.

Demographic and Neuropsychological Data for the Three Groups of Participants: Young Adults (YAs), Healthy Older Adults (HOAs), and Patients With Alzheimer’s Disease (AD).

Characteristic	Participant Group		
	YAs	HOAs	Patients With AD
Number	35	24	18
Women	20 (57%)	13 (54%)	10 (56%)
Age (years) ^a	21.29 ± 4.42	71.13 ± 4.83	74.50 ± 7.94
Education (years) ^{a,b}	12.80 ± 0.67	15.25 ± 2.69	12.33 ± 4.54
Educational level ^b			
Level 1	0%	0%	11%
Level 2	0%	0%	17 %
Level 3	3%	8%	22%
Level 4	97%	92%	50%
MoCA ^b	-- ^c	28.15 ± 1.41	20.03 ± 4.77
FAB ^b	-- ^c	17.80 ± 0.51	15.22 ± 2.56
GDS	-- ^c	5.85 ± 3.47	7.03 ± 3.42
BDI-II	7.34 ± 4.86	-- ^d	-- ^d
Laterality	32R/3L	23R/1L	16R/1L/1A

Note. Age, education, Montreal Cognitive Assessment (MoCA), Frontal Assessment Battery (FAB), Geriatric Depression Scale (GDS), and Beck Depression Inventory (BDI-II) scores are shown as mean ± SD. ^aSignificant difference between YAs and HOAs. ^bSignificant difference between HOAs and patients with AD. ^cFAB, GDS, and MoCA tests were not administered to YAs. ^dBDI-II was not administered to older group. Education: level 1 = no formal education; level 2 = primary education; level 3 = secondary education; level 4 = high school diploma and above.

Table 2

Characteristics of the Three Groups of Stimuli^a

Characteristic	Stimuli Group		
	Negative	Neutral	Distractors
Valence ^{b,c}	2.35 ± 0.41	5.38 ± 0.43	5.29 ± 0.44
Arousal ^{b,c}	6.75 ± 0.72	3.58 ± 1.03	3.30 ± 1.09
Brightness	110.42 ± 7.95	110.18 ± 12.81	110.40 ± 9.76
RMS contrast	0.58 ± 0.11	0.54 ± 0.15	0.53 ± 0.18
Number of edges	4,291 ± 1,216	3,812 ± 1,358	3,796 ± 2,531
Number of lines	8.32 ± 2.82	8.42 ± 2.82	7.96 ± 3.98
Images with humans (%)	31.7%	31.7%	0%
Images with animals (%)	13.3%	13.3%	0%
Spatial frequencies			
112–224 p/cb	867 ± 437	664 ± 319	624 ± 568
56–112 p/cb	4,531 ± 2,001	3,561 ± 1,569	3,477 ± 2,701
28–56 p/cb	2.30e4 ± 9.38e3	1.82e4 ± 8.22e3	1.83e4 ± 1.26e4
14–28 p/cb	1.14e5 ± 4.27e4	9.03e4 ± 4.70e4	9.69e4 ± 6.64e4
7–14 p/cb	5.30e5 ± 1.87e5	4.87e5 ± 2.59e5	5.02e5 ± 3.44e5
4–7 p/cb	2.52e6 ± 1.19e6	1.97e6 ± 1.19e6	2.05e6 ± 1.52e6
2–4 p/cb	1.19e7 ± 6.50e6	1.12e7 ± 9.64e6	9.68e6 ± 7.71e6
1–2 p/cb	4.73e7 ± 4.58e7	5.13e7 ± 5.10e7	4.08e7 ± 4.97e7

Note. ^aShown as mean ± SD except where otherwise indicated. ^bSignificant difference between negative and neutral targets. ^cSignificant difference between negative targets and distractors. All tests yielded a *p*-value above .05, except for valence, $F(2, 297) = 1133.94$, $p < .001$, and arousal tests, $F(2, 297) = 271.73$, $p < .001$, which revealed higher valence for target ($p < .001$) and distracting ($p < .001$) neutral images than for target negative images, and stronger arousal for target negative images than for target ($p < .001$) and distracting ($p < .001$) neutral images. RMS = root mean square; p/cb = pixels/cycle band.

Table 3

Mean \pm SD Proportion (%) of Error Rates as a Function of Group (YAs vs. HOAs vs. Patients With AD), Emotional Valence (Negative vs. Neutral), and Number of Distractors (One vs. Three vs. Five)

Group/Emotional Valence		Number of Distractors		
		One	Three	Five
YAs				
	Negative	1.38 \pm 2.89	1.11 \pm 2.42	0.86 \pm 2.39
	Neutral	3.35 \pm 3.15	2.28 \pm 3.24	2.15 \pm 3.25
HOAs				
	Negative	4.06 \pm 2.77	2.72 \pm 5.00	3.82 \pm 3.47
	Neutral	6.39 \pm 4.04	3.12 \pm 3.27	4.56 \pm 3.94
Patients with AD				
	Negative	21.10 \pm 6.75	23.70 \pm 8.85	20.80 \pm 9.36
	Neutral	22.59 \pm 8.97	18.29 \pm 6.99	19.35 \pm 7.89

Note. YA: young adult; HOA: healthy older adult; AD: Alzheimer's disease.

Table 4

Mean ± SD of Disengagement Delays as a Function of Group (YAs vs. HOAs vs. Patients With AD), Emotional Valence (Negative vs. Neutral), and Number of Distractors (One vs. Three vs. Five)

Group/Emotional Valence		Number of Distractors		
		One	Three	Five
YAs				
	Negative	612 ± 51	680 ± 40	660 ± 51
	Neutral	592 ± 46	619 ± 56	650 ± 45
HOAs				
	Negative	998 ± 90	1,025 ± 68	1,041 ± 87
	Neutral	969 ± 88	954 ± 80	975 ± 63
Patients with AD				
	Negative	1,335 ± 182	1,360 ± 141	1,370 ± 165
	Neutral	1,305 ± 144	1,189 ± 65	1,247 ± 151

Note. YA: young adult; HOA: healthy older adult; AD: Alzheimer's disease.

Figure 1. Examples of trials used during the visual search task. Left: Examples with neutral targets. Right: Examples with negative targets. From top to bottom: Examples with one, three, and five distractors.

Figure 2. Scatterplot of engagement delays as a function of emotional valence (negative and neutral), number of distractors (one, three, and five), and study group (YAs, HOAs, and patients with AD). Engagement delays increased with the number of distractors for all groups. YAs had faster engagement delays than older groups did. HOAs had faster engagement delays than patients with AD did for emotional targets only. Error bars represent the corrected standard deviation (Loftus and Masson, 1994).

Figure 3. Scatterplot of disengagement delays as a function of emotional valence (negative and neutral) and study group (YAs, HOAs, and patients with AD). Disengagement delays were longer for negative than for neutral targets for all groups. Disengagement delays were longer in patients with AD than in HOAs, and they were longer in HOAs than in YAs. Error bars represent the corrected standard deviation (Loftus and Masson, 1994). * $p < .05$ ** $p < .01$.

Figure 1

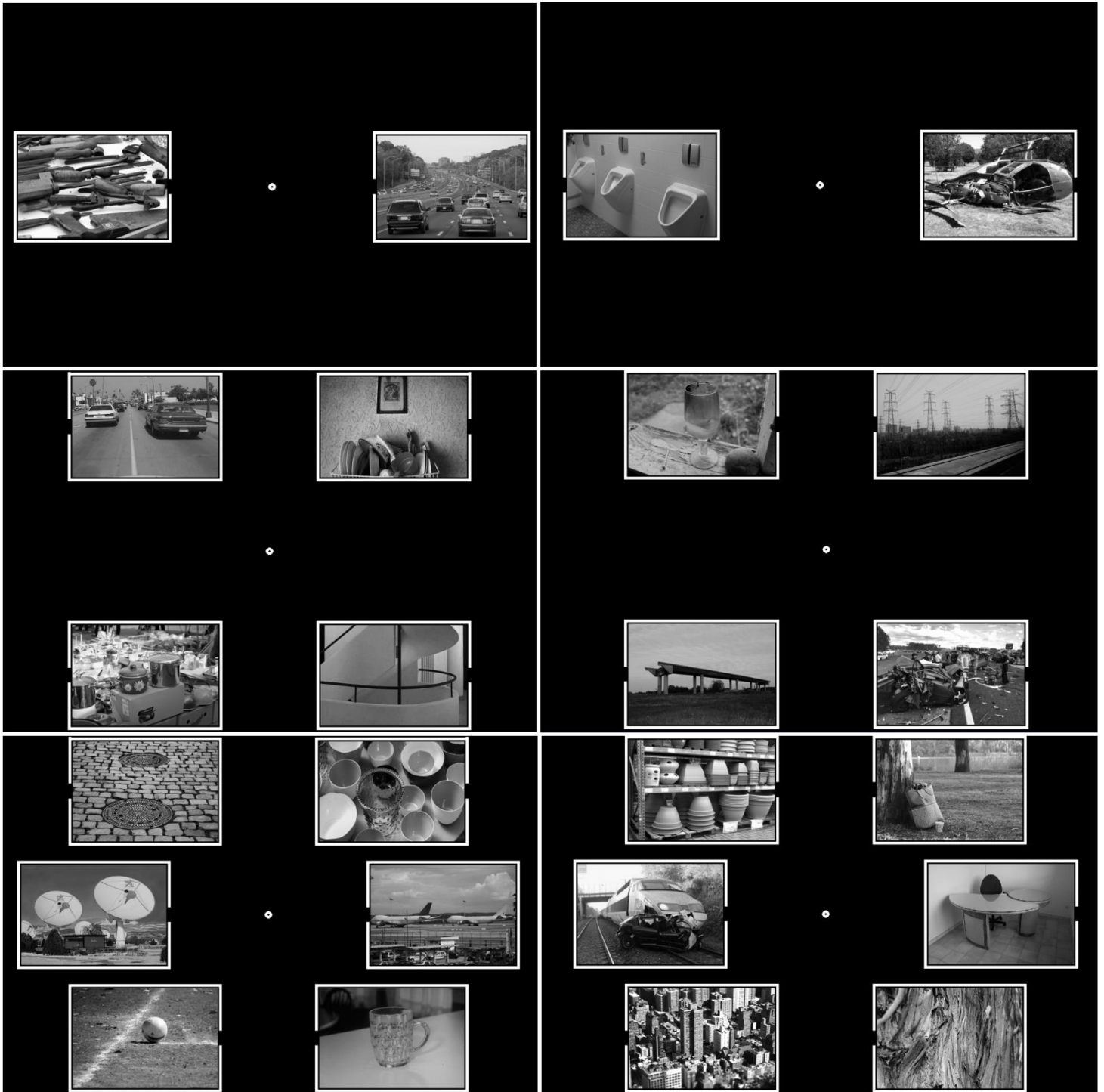


Figure 2

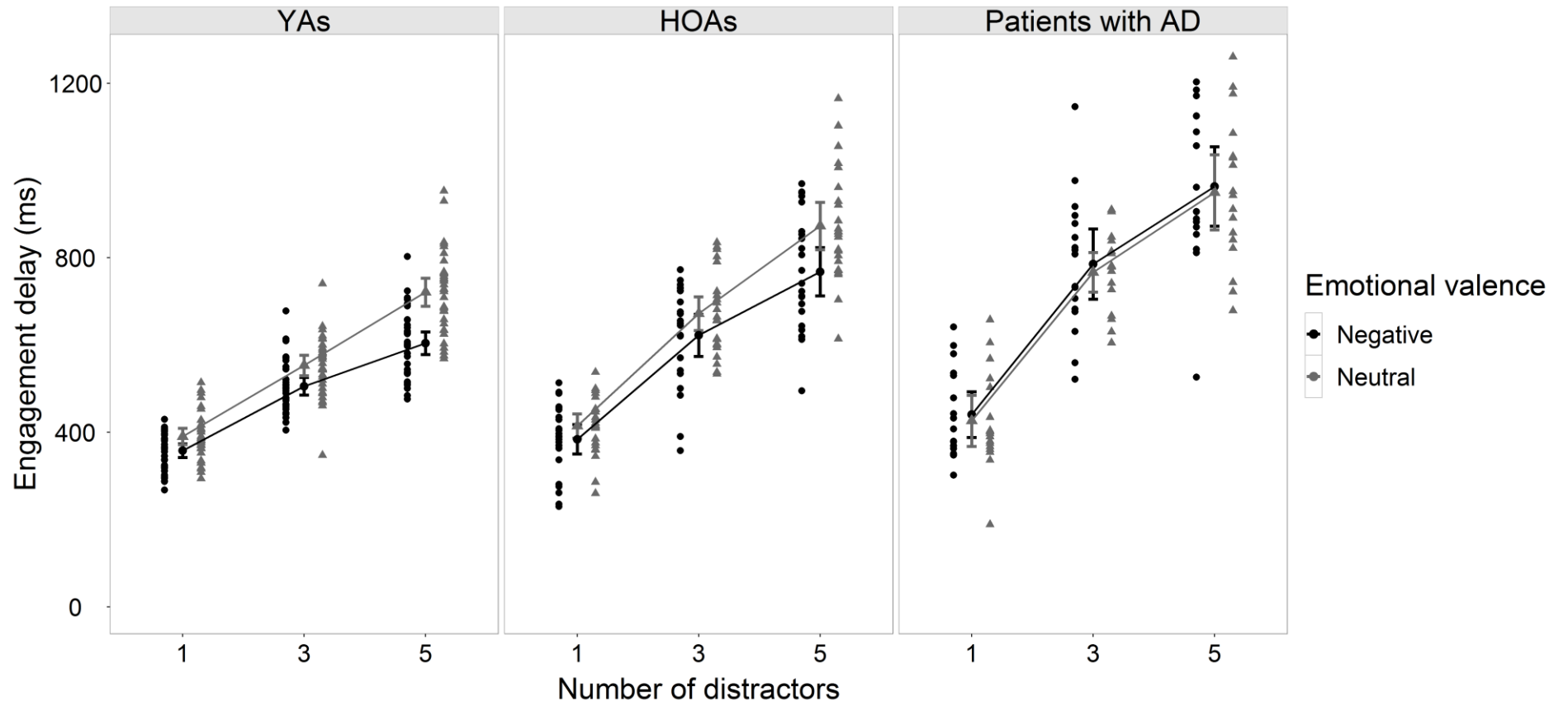


Figure 3

