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Diagnosis of mild Alzheimer disease through the analysis of eye movements during reading

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Reading requires the integration of several central cognitive subsystems, ranging from attention and oculomotor control to word identification and language comprehension. Reading saccades and fixations contain information that can be correlated with word properties. When reading a sentence, the brain must decide where to direct the next saccade according to what has been read up to the actual fixation. In this process, the retrieval memory brings information about the current word features and attributes into working memory. According to this information, the prefrontal cortex predicts and triggers the next saccade. The frequency and cloze predictability of the fixated word, the preceding words and the upcoming ones affect when and where the eyes will move next. In this paper we present a diagnostic technique for early stage cognitive impairment detection by analyzing eye movements during reading proverbs. We performed a case-control study involving 20 patients with probable Alzheimer's disease and 40 age-matched, healthy control patients. The measurements were analyzed using linear mixed-effects models, revealing that eye movement behavior while reading can provide valuable information about whether a person is cognitively impaired. To the best of our knowledge, this is the first study using word-based properties, proverbs and linear mixed-effect models for identifying cognitive abnormalities.

Keywords: Eyetracking signal analysis; Alzheimer disease; eye movements; cognitive impairment; linear mixed-effect models.

1. Introduction

When reading, healthy readers move their eyes every quarter of a second, on average. During the fixation, new information is brought into the processing system. The average fixation lasts for 150–250 ms, and the distance the eyes move in each saccade (a short rapid eye movement) is between 1 and 20 characters, with an average of 5–7 characters. A saccade's primary function is to bring a new region of text at the right of the fixated place into the foveal vision. The fovea is the depression in the inner retinal surface responsible for sharp central vision. Performing a saccade takes about 20–50 ms.

Reading requires the integration of several central cognitive subsystems, ranging from attention and oculomotor control to word identification and language comprehension. Reading saccades and fixations give us a considerable amount of information that can be correlated with word properties. When reading, the syntactic, semantic and morphological properties of the word affect how long the fixation lasts. Fixation duration increases with word length and decreases with the frequency and predictability of the word (Rayner, 1998; Kliegl *et al.*, 2006). Researchers agree that information about the length, orthography and phonology of the upcoming word is available during fixations on previous words. Indeed, some of this information is necessary for programming saccades. At the same time, there is strong evidence that the so-called high-level lexical properties (such as word frequency or predictability) of parafoveal words also influence fixation durations before the eyes reach these words (see, for example (Kliegl *et al.*, 2006; Kliegl, 2007; Kennedy *et al.*, 2013; Fernández *et al.*, 2014c)). Cloze predictability (Taylor, 1953)-i.e., the proportion of subjects that fill in a particular word as the most probable next word in a sentence from a previous context-is an important factor during fluent reading. Recent findings (Kennedy *et al.*, 2013; Fernández *et al.*, 2014c) suggest that the buildup of predictions is indeed a rapid process.

Data from language processing provide evidence not only that context directs expectations or predictions about the upcoming stimuli "on the fly", but also that these predictions are highly specific and enough elaborated to guide behavior. Thus, healthy readers skip high-predictability words more often than-low predictability ones; notably, they prolong fixation durations prior to high-predictability words. It has been hypothesized that these words are processed and retrieved from memory while the eyes are still on the preceding stimulus. In visual world paradigms, Altmann (2011) demonstrated that the context-based expectations of upcoming stimuli are fast enough and strong enough to trigger anticipatory saccades.

The frontal field of view, and its role in controlling eye movements, have received significant attention from the research community in the last decade. Studies suggest that this area controls decisional processes governing ocular motor behavior (Pierrot-Deseilligny *et al.*, 2004). A feedback and feedforward control approach within a systemic framework has been applied to study the visual dynamic system (Xu, 2010).

The visual system can be thought of as a feedback control system, as explained in Sec. 2. The bottom-up signal registered during an eye fixation is the key to obtaining the semantic information about the fixated word that is temporarily stored in working memory. The prefrontal cortex (PFC) processes this information, together with the contextual memory, in order to predict the location of the new saccade; the top-down signal goes to the muscles in order to move the eye to the next fixation (Fig. 1). This sequence is repeated in each fixation. Contextual information facilitates reading by improving predictions, allowing for performing longer saccades and word skipping.

Bollinger *et al.* (2010) and Gazzaley (2013) demonstrated that predictive cueing (e.g., upcoming words prediction in high-predictability sentences) can improve both working and long-term memory performances. They suggested that expectations act as attentional filters to facilitate the extraction of goal-directed information, resulting in performance benefits across multiple domains, prevailing activity of the PFC. There is substantial evidence suggesting that the PFC processes cortical processing in visual areas via top-down signals prior to the stimulus (Summerfield & Egner, 2009). Furthermore, the expectation that precedes a stimulus is a sort of top-down modulation that involves the PFC (Puri & Wojciulik, 2008). Since mild Alzheimer's disease (AD) affects cortical regions in the dorsolateral PFC (Salat *et al.*, 2001; Drzezga *et al.*, 2003; Pelak, 2010), it may impair the ability to predict upcoming words.

Altered visual exploration and the absence of contextual predictability effect might be related to an impairment in working memory and/or long term memory retrieval functions. In previous works we studied the differences between healthy readers and readers with mild AD (Fernández *et al.*, 2014a,b). We used linear mixed-effect models to evaluate the effect of current and incoming word predictability on *gaze duration*, i.e., the sum of all time fixations on a given word. In our study we compared low- vs. high-predictability sentences to show that readers with early-stage AD are less capable of predicting incoming words.

In this paper, we present new results on modeling gaze duration when reading proverbs. When reading a proverb, the expectations about the next incoming word are generated incrementally and confirmed in healthy readers, but not in AD subjects. Using proverbs as reading material should allow us to determine whether the readers used information stored in their memory. Previous work showed that older adults were more likely to switch to a retrieval strategy when the cost of visual scanning or the benefits of retrieval increased (Touron *et al.*, 2007; Stine-Morrow *et al.*, 2006; Lindenberger & Mayr, 2014; Olsen *et al.*, 2014). We hypothesize that, when the proverbs provide retrieval cues (e.g., reminders, contextual reinstatement), only control subjects improve their reading performance. Also, we augmented the model with two new variables: outgoing saccade amplitude (i.e., the distance from the last fixation to the next one) and launch site (i.e., the distance from the last fixation to the first letter of the upcoming fixated word). We use these new factors, together with word length, word frequency and word predictability, to model gaze duration when reading proverbs. Results show that our method is effective at diagnosing mild AD.

The paper is organized as follows. In Sec. 2 we describe the oculomotor system from a systemic point of view; in Sec. 3 we describe the experiment; in Sec. 4 we define the used model; in Sec. 5 we discuss the results. Finally, in Sec. 6 we draw some conclusions.

2. Oculomotor System

The visual system is part of complex input–output multivariable system, and constitutes an important challenge from the modeling point of view. Eye movements are a fundamental part of this visual system since they direct the attention of the fovea, according to different brain processes (e.g., working memory, semantic memory). Each one of these movements is controled by a different neural system and all these systems end in the optical nerve, which connects them to the brain for its command.

When reading, eye movements alternate with relative stillness: these movements are the saccades and the fixations, respectively. The former change the direction of the eyes and bring the image into the fovea in the least possible time, while the latter hold the image in the fovea. Before triggering a saccadic movement, the brain has to decide where to look at and program the oculomotor system to move in that direction. When reading a sentence, the decision of where to direct the next saccadic movement is based on what has been read up to the current fixation. In this process, the retrieval memory brings information about the word features and attributes into working memory. According to this information, the PFC predicts and triggers a saccade in order to move the gaze to the next word, which is not necessarily the

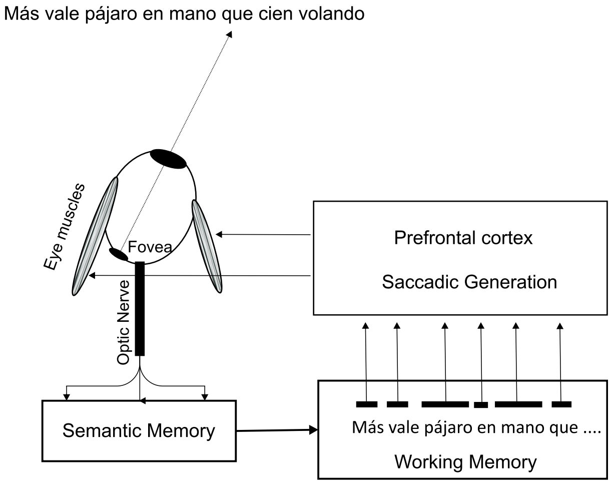

Fig. 1. Oculomotor system as a control feedback system. The Spanish proverb “Más vale pájaro en mano que cien volando”, is equivalent to the english one “A bird in the hand is worth two in the bush”.

upcoming one. So, the oculomotor system can be thought of as a feedback control system, as depicted in Fig. 1.

During fluent reading, the duration of a fixation on a word is influenced by its syntactic, semantic and morphological properties. One of those properties, called *cloze predictability*, is the probability that the next word in a sentence can be guessed, given only the previous words in the sentence (Taylor, 1953). Both frequency and cloze predictability of the fixated or foveal word, the preceding words and the upcoming or parafoveal words, have a significant impact on when and where to move the eyes (Rayner, 1998; Kliegl *et al.*, 2006; Heister *et al.*, 2012; Hohenstein & Kliegl, 2014; Fernández *et al.*, 2014a,c). Their influence varies from one factor to the other, and is different in readers with some degree of cognitive impairment.

3. Experiment

During the experiment, when a person is reading a sentence with M words, we number each word $1, 2, \ldots, n-2, n-1, n, n+1, n+2, \ldots, M$ according to its position in the sentence. If n is the word the subject is reading at a time t_0, we call it the actual word; $n+1$, $n+2$ will be the two upcoming ones while $n-2$, $n-1$ are the two former words. In this section we describe the experiment we conducted to model the effect of the predictability of words $n-2, n-1, n, n+1, n+2$ on fixation duration.

3.1. *Participants*

Twenty patients participated in the experiment (12 female, 8 male, mean age 69 years, SD = 7.3 years). The patients were from the Hospital Municipal de Bahía Blanca, Bahía Blanca, Argentina, and were diagnosed with probable AD. Their diagnostic was based on the criteria for dementia outlined in the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) (American Psychiatric Association, 1994). According to it, patients were excluded if:

1. They suffered any medical condition that could account for, or interfere with, their cognitive decline;
2. Had evidence of vascular lesions in computed tomography or fMRI;
3. Had evidence for an Axis I diagnosis (e.g., major depression or drug abuse) as defined by DSM-IV (American Psychiatric Association, 1994);
4. They were taking cholinesterase inhibitors (ChE-I), hypnotics, sedative drugs or major tranquillizers.

The control group consisted of 40 elderly adults (29 female and 11 male; mean age 71 years old; SD = 6.1 years) with no known neurological nor psychiatric disease, and no evidence of cognitive decline or impairment in activities of daily living. A one-way ANOVA showed no significant difference between the age of the mild AD group and the control group ($F(1,56) < 1$). The mean school education in AD patients and controls was 15.2 (SD = 1.3) years and 15.1 (SD = 1.0) years, respectively. A one-way ANOVA showed no significant difference between the education of AD and control groups. The mean scores of controls and AD patients in the mini-mental state examination (MMSE) (Folstein *et al.*, 1975) were 27.8 (SD = 1.0) and 24.2 (SD = 0.8), respectively; the latter suggests an early mental impairment. A one-way ANOVA revealed significant differences between MMSE in AD patients and controls ($p < 0.001$). The mean score of AD patients in the ACE-R test (Mioshi *et al.*, 2006) was 84.4 (SD = 1.1), the cut-off being 86.

3.2. *Sentence corpus*

To perform the experiment, we used a set of 64 Spanish proverbs that are common in our Argentinian culture.

Word and Sentence Lengths. The proverbs ranged from 5 to 14 words in length; mean length being 7.3 (SD = 1.9) words. The words ranged from 1 to 14 letters in length; the mean word length was 4.0 (SD = 2) letters.

Word Frequencies. We used the Spanish Lexical Léxesp corpus CORCO (Sebastián-Gallés *et al.*, 1998) for assigning a *frequency* to each word of the sentence corpus. Since word frequency ranges from 1 to 264,721 per million, we transformed it to log(*frequency*). The mean log(*frequency*) for the proverbs was 3.47 (SD = 1.36).

Word Predictability. Word predictability was determined by performing an independent experiment with 18 researchers of the Departamento de Ingeniería Eléctrica y de Computadoras, Universidad Nacional del Sur. We used an incremental Cloze Task (Taylor, 1953) procedure in which participants had to guess the next word given only the prior words of the sentence. Participants were between 31 and 62 years of age and did not participate in the reading experiment. The academic background of the group involved in the reading experiment and the Cloze Task group was similar. The average predictability measured from the incremental Cloze Task was transformed using the logit function defined by:

$$\mathrm{logit}(\mathrm{pred}) = 0.5 \ln\left(\frac{\mathrm{pred}}{1 - \mathrm{pred}}\right), \tag{1}$$

being pred the determined word predictability. The term in parentheses is called *the odds.* In order to be well defined, pred = 0 or pred = 1 in the Cloze Task procedure were replaced by $\mathrm{logit}(\frac{1}{2N_p}) = -1.77$ and $\mathrm{logit}(\frac{1}{2N_p}) = 1.77$, respectively, being $N_p = 18$ the number of complete predictability protocols (18 subjects completing all the proverbs). The mean of logit predictability was 0.08 with SD = 1.23.

3.3. *Eye movement register*

Each proverb was displayed in the centerline of a 20-inch LCD Monitor (1024 × 768 pixels resolution; font: regular New Courier, 12 point, vertical size of one character: 0.2° in height). The participants were seated in front of the monitor at a distance of 60 cm. Head movements were minimized using a chin rest. The participants' eye movements were recorded with an EyeLink 1000 Desktop Mount (SR Research) eyetracker, with a sampling rate of 1000 Hz and an eye position resolution of 20-s arc. All recordings and calibration were binocular. Fixations shorter than 51 ms and longer than 750 ms and fixations on the first and last word of each sentence were removed for the analysis.

The participants' gaze was calibrated with a standard 13-point grid for both eyes. After validating the calibration, a fixation point appeared at the position where the first letter of the sentence was to be presented. As soon as both eyes were detected within a 1° radius relative to the fixation point, the proverb was presented. After reading it, participants had to move their eyes to a dot in the lower right corner of the screen to end the trial.

4. Model

The linear mixed-effect models (LMM) used to model the ln(gaze) is given by the following expression,

$$\ln(\text{gaze}) = \boldsymbol{\gamma}_i \mathbf{x}_i + \mathbf{c}_i \mathbf{z}_i, \tag{2}$$

being $\mathbf{x}_i$ a vector of fixed variables.

$$\begin{aligned}\mathbf{x}_i = [&\mathrm{AO}, \mathrm{LS}, L_{n-2}, L_{n-1}, L_n, L_{n+1}, L_{n+2},\\ &P_{n-2}, P_{n-1}, P_n, P_{n+1}, P_{n+2}, F_{n-2}, F_{n-1},\\ &F_n, F_{n+1}, F_{n+2}]_i,\end{aligned} \tag{3}$$

where AO is the amplitude of the outgoing saccade from word n to word $n+1$; LS is the launch site, that is, the distance from the last character of the actual fixated word to the first character of the next fixated one, measured in characters with spaces; L_k is the length of word k, P_k is the logit of the predictability of word k and F_k is the base-10 logarithm of the frequency of word k. And $\mathbf{z}_i$ defined as a vector of random effect variables

$$\mathbf{z}_i = \left[\frac{1}{\mathrm{IN}}, \frac{1}{\mathrm{SN}}\right]_i, \tag{4}$$

where IN is the person identification number and SN is the sentence number within the test (introduced to model the fatigue). Finally, $\boldsymbol{\gamma}_i$ and $\mathbf{c}_i$, are the vectors of fixed parameters and random parameters, respectively.

In order to estimate the fixed and random coefficients, we used the program *lmer* of the *lme4* package, version 0.999999 − 2 (Bates & Maechler, 2013), in the

R programming language (version 3.0.1; R Development Core Team, 2013) under the GNU general public license (version 2, June 1991).

For all practical purposes, given the large number of observations, subjects and *items* for the analysis, and the comparatively small number of estimated fixed and random effects, the t-distribution is generally equivalent to the normal distribution, i.e., the contribution of the degrees of freedom to the statistical test is negligible. If SE notes the standard error (SE), the criterion we used for referring to an effect as significant of the corresponding regressor is $t = \frac{b}{\mathrm{SE}} > 2$.

5. Model Results Analysis and Discussion

In Table 1 we show, for both the control and AD groups, the values of the ln(gaze), standard error (SE) and t-value. An important difference between control and AD groups can be seen when considering mean gaze duration (317 ms (exp(5.76)) vs. 721 ms (exp(6.58)), respectively).

We then analyzed the effect of the predictability of words $n-2, n-1, n, n+1$ and $n+2$ on gaze duration during reading proverbs. The LMM results are summarized in Table 1. Both the predictability of word $n-2$ ($t = -3.05$) and word $n-1$ ($t = 6.01$) were significant only for controls. Thus, the cloze predictability of word $n-2$ reduced the mean gaze duration, suggesting that an increase in cloze predictability facilitated ongoing reading (Katz & Ferretti, 2001; Federmeier & Kutas, 2005; Fernández *et al.*, 2014a). On the other hand, word $n-1$ produced an increase of gaze duration only for controls. As we proposed before, this increase could reflect the time required for the brain to process the information in order to retrieve the possible upcoming word in a sentence. Interestingly, in controls this retrieval effect seems to affect word processing from word $n-1$ onward. Since predictable words in proverbs are clustered throughout the sentence — instead of being isolated moments of highly regular fragments of the sentence — previous words could exert a strong effect on gaze duration (Fernández *et al.*, 2014c).

Additionally, when considering the effect of word $n+2$, the gaze duration decreased with cloze predictability only in controls ($t = -2.02$) (see Table 1 and Fig. 2). Our results suggest that, in healthy readers, the predictability of the proverbs affects fixation durations until the complete sentence is retrieved from memory (see Table 1 and Fig. 2).

We also studied the effect of the frequency of words $n-2, n-1, n, n+1$ and $n+2$ on gaze duration during reading proverbs. The frequency of words $n-2$ ($t = 6.28$) and $n-1$ ($t = -2.24$) affected gaze duration in controls, probably due to a partial processing of the word n in the previous fixation, i.e., spillover. The frequency of words n ($t = -8.66$) and $n+2$ ($t = -3.13$) exerted a strong effect in controls, too. Conversely, in ADs only the frequency of word n ($t = -5.03$) affected gaze duration. These behaviors suggests that, in both groups, more frequent words require less processing and thus shorter gaze durations.

Table 1. Parameter estimates for fixed effects of LMM: logit predictability, 1/length and log of frequency corresponding to words $n-2, n-1, n, n+1$ and $n+2$. Random intercepts are participants and sentences. Threshold of significance set at $t = \pm 2.0$. Shadowed cells indicate main differences between groups.

	Control			AD			Interaction AD vs. Control		
Fixed Effects	Intercept	SE	*t*-value	Intercept	SE	*t*-value	Intercept	SE	*t*-value
Mean Gaze Duration (log)	5.76	0.10	60.33	6.58	0.13	58.05	−0.82	0.12	−6.74
AO: Amplitude of Outgoing saccade	−0.03	0.00	−12.95	−0.06	0.00	−19.60	0.04	0.00	9.72
Launch Site	0.02	0.00	9.66	0.00	0.00	1.36	0.01	0.00	5.15
Word Number	−0.01	0.01	−1.80	0.04	0.01	−4.56	0.02	0.01	2.86
1/(length word $n-2$)	−0.26	0.05	−5.60	−0.15	0.06	−2.53	−0.12	0.07	−1.77
1/(length word $n-1$)	0.08	0.06	1.37	0.08	0.07	1.06	0.00	0.08	0.05
1/(length word n)	−0.10	0.07	−1.41	−0.48	0.08	−6.08	0.38	0.09	4.05
1/(length word $n+1$)	−0.10	0.05	−1.90	−0.07	0.07	−0.99	−0.04	0.08	−0.49
1/(length word $n+2$)	0.06	0.06	1.04	−0.02	0.07	−0.21	0.08	0.09	0.92
Frequency word $n-2$	0.05	0.01	6.28	−0.01	0.01	−0.77	0.06	0.01	4.82
Frequency word $n-1$	−0.02	0.01	−2.24	−0.02	0.01	−1.89	0.00	0.01	0.00
Frequency word n	−0.07	0.01	−8.66	−0.05	0.01	−5.03	−0.02	0.01	−1.64
Frequency word $n+1$	−0.01	0.01	−1.08	0.01	0.01	1.18	−0.02	0.01	−1.78
Frequency word $n+2$	−0.03	0.01	−3.13	−0.01	0.01	−0.70	−0.02	0.01	−1.63
Predictability word $n-2$	−0.03	0.01	−3.05	0.00	0.01	0.01	−0.03	0.02	−2.10
Predictability word $n-1$	0.06	0.01	6.01	0.00	0.01	0.20	0.06	0.01	3.82
Predictability word n	0.01	0.01	0.68	0.00	0.01	0.07	0.01	0.02	0.39
Predictability word $n+1$	0.02	0.01	1.72	0.02	0.02	1.18	0.00	0.02	0.12
Predictability word $n+2$	−0.03	0.01	−2.02	0.03	0.02	−1.63	0.00	0.02	0.01

Random Effect	Var.	SD
SN ($n = 64$)	0.008	0.092
IN ($n = 60$)	0.038	0.195
Residual ($n = 7423$)	0.175	0.418

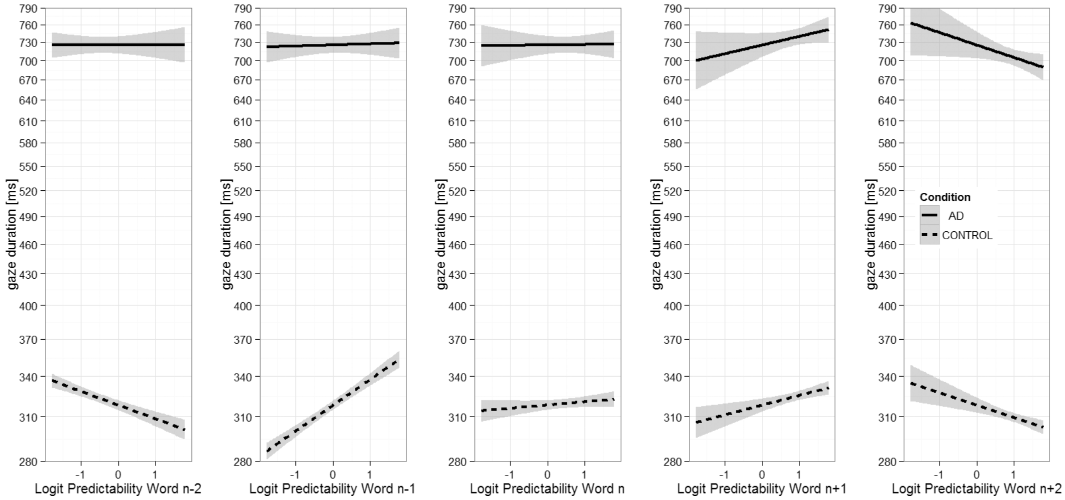

Fig. 2. Predictability effects of words $n-2, n-1$ and $n+1$ on gaze duration on word n, for Controls and for mild AD. Panels show partial effects of LMM (i.e., after removal of other fixed effects and variance components for mean fixation durations of subjects). Shaded areas are 95% confidence intervals.

6. Conclusions

Our results suggest that while reading seems to be preserved in AD patients at an early phase of the disease, semantic content processing might already be distorted. To our knowledge, this is the first study in which word based properties, proverbs and linear mixed-effect models were used to identify cognitive abnormalities.

The semantic context of the fixated word, portrayed by the predictability of the preceding words $n-2$ and $n-1$, has an impact on reading behavior. That is the reason why the greater word predictability in proverbs expands the differences in word processing between the control group and the AD group. The predictability of word $n+1$ increases gaze periods in the control group, confirming that they are performing a prediction upon the upcoming words; this process is absent (or lost) in AD patients, suggesting an impairment in their capacity for making word predictions. By applying this discovery to the memory field, recent work (Gazzaley, 2013; Fernández *et al.*, 2014b) proved that working and long term memory in healthy elderly readers can be improved by predictive clueing; expectations serves as a filter to attention that simplifies the extraction of information, resulting in benefits in performance across multiple domains. Proverbs are well-known and therefore serve as a cue for more efficient reading in the control group. It was interesting to prove that this process did not occur in mild AD patients, according to our data. This is consistent with previous evidence that AD patients show visual memory recognition deficits (Iachini *et al.*, 2009) and in their processing speed and visual short-term memory, even at an early phase of the disease (Bublak *et al.*, 2011).

Our data suggests that the capacity of retrieving the plausible upcoming word in a sentence is possibly absent or deteriorated in AD patients, even at an early stage.

Ciaramelli *et al.* (2008) suggested that the inferior parietal lobe mediates the automatic allocation of attention to retrieved memory contents, while Olsen *et al.* (2014) proposed that overt shifts of attention through eye movements are associated with a higher accuracy in relational visuospatial memory performance tasks. Therefore, the activation of these partial lobe regions may reinforce and help to produce stronger relational spatial representations and consequently more accurate memory recognitions. The lack of the predictability effect suggests that the capacity of AD patients for integrative recollection of associative information from memory can be explained by early neuroanatomical changes, namely in hippocampus and entorhinal cortex (Pereira *et al.*, 2014).

Our study provides a test-bed for initial research on cognitive impairments linked to semantic, working and retrieval memory deficiencies. We were able to prove that deficits in the capacity for processing complex information are linked to memory-guided eye movements. Early detection and monitoring opportunities in AD patients will be improved by this test. Furthermore, the results obtained with this novel methodology could become in time a simple marker for early disease detection.

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REFERENCES

Altmann, R. (2011) Language can mediate eye movement control within 100 milliseconds, regardless of whether there is anything to move the eyes to. *Acta Psychologica*, **137**, 190–200.

American Psychiatric Association. (1994) *Diagnosis and Statistical Manual of Mental Disorders: DSM-IV*.

Bates, D. & Maechler, M. (2013) *Linear Mixed-Effect Models Using S4 Classes. lme4: R Package Version 2013*.

Bollinger, J., Rubens, M. T., Zanto, T. P. & Gazzaley, A. (2010) Expectation-driven changes in cortical functional connectivity influence working memory and long-term memory performance. *J. Neurosci.*, **30**, 14399–14410.

Bublak, P., Redel, P., Sorg, C., Kurz, A., Förstl, H., Müller, H., Schneider, W. & Finke, K. (2011) Staged decline of visual processing capacity in mild cognitive impairment and Alzheimer's disease. *Neurobiol. Aging*, **32**, 1219–1230.

Ciaramelli, E., Grady, C. & Moscovitch, M. (2008) Top-down and bottom-up attention to memory: A hypothesis (AtoM) on the role of the posterior parietal cortex in memory retrieval. *Neuropsychologia*, **46**, 1828–1851.

Drzezga, A., Lautenschlager, N., Siebner, H., Riemenschneider, M., Willoch, F., Minoshima, S., Schwaiger, M. & Kurz, A. (2003) Cerebral metabolic changes accompanying conversion of mild cognitive impairment into Alzheimer's disease: A PET follow-up study. *Eur. J. Nuclear Med. Mol. Imaging*, **30**, 1104–1113.

Federmeier, K.D. & Kutas, M. (2005) Aging in context: Age-related changes in context use during language comprehension. *Psychophysiology*, **42**, 133–141.

Fernández, G., Laubrock, J., Mandolsi, P., Colombo, O. & Agamennoni, O. (2014a) Registering eye movements during reading in Alzheimer disease: Difficultiesin predicting upcoming words. *J. Clin. Exper. Neuropsychol.*, Available at: http://dx.doi.org/10.1080/01690965.2012.760745.

Fernández, G., Manes, F., Rotstein, N., Colombo, O., Mandolesi, P., Politi, L. & Agamennoni, O. (2014b) Lack of contextual-word predictability during reading in patients with mild Alzheimer disease. *Neuropsychologia*, **62**, 143–151.

Fernández, G., Shalom, D., Kliegl, R. & Sigman, M. (2014c) Eye movements during reading proverbs and regular sentences: The incoming word predictability effect. *Language, Cognit. Neurosci.* **29**, 260–273.

Folstein, M., Folstein, S. & McHugh, P. (1975) 'Mini-mental state'. A practical method for grading the cognitive state of patients for the clinician. *J. Psychiatr. Res.*, **12**, 189–198.

Gazzaley, A. (2013) *Top-Down Modulation Deficit in the Aging Brain: An Emerging Theory of Cognitive Aging.* Chapter 35 (Oxford University Press, USA), pp. 593–608.

Heister, J., Würzner, K. & Kliegl, R. (2012) Analysis large datasets of eye movements during reading. In: J.S. Adelman ed. *Visual Word Recognition Volume 2: Meaning and Context, Individuals and Development*, Current Issues in the Psychology of Language (Psychology Press, London, United Kingdom), pp. 102–130.

Hohenstein, S. & Kliegl, R. (2014) Semantic preview benefit during reading. *J. Exper. Psychol.: Learn. Memory Cognit.*, **40**, 166–190.

Iachini, T., Iavarone, A., Senese, V., Ruotolo, F. & Ruggiero, G. (2009) Visuospatial memory in healthy elderly, AD and MCI: A review. *Curr. Aging Sci.*, **2**, 43–59.

Katz, A.N. & Ferretti, T. (2001) Moment-by-moment reading of proverbs in literal and nonliteral context. *Metaphor Symbol* **16**, 193–221.

Kennedy, J., Pynte, A., Murray, W. & Paul, S. (2013) Frequency and predictability effects in the Dundee corpus: An eye movement analysis. *J. Exper. Psychol.* **66**, 601–618.

Kliegl, R. (2007) Towards a perceptual-span theory of distributed processing in reading: A reply to Rayner, Pollatsek, Drieghe, Slattery and Reichle. *J. Exper. Psychol.*, **136**, 530–537.

Kliegl, R., Nuthaman, R. & Engbert, A. (2006) Tracking the mind during reading: The influence of past, present and future words on fixations duration. *J. Exper. Psychol.*, **135**, 12–35.

Lindenberger, U. & Mayr, U. (2014) Cognitive aging: Is there a dark side to environmental support? *Trend Cognit. Sci.*, **18**, 7–15.

Mioshi, E., Dawson, A., Mitchell, J., Arnold, R. & Hodges, J. (2006) The Addenbrooke's cognitive examination revised (ACE-R): A brief cognitive test battery for dementia screening. *Int. J. Geriatr. Psychiatr.*, **21**, 1078–1085.

Olsen, R., Chiew, M., Buchsbaum, B. & Ryan, J. (2014) The relationship between delay period eye movements and visuospatial memory. *J. Vis.*, **14**, 1–11.

Pelak, V. (2010) Ocular motility of aging and dementia. *Curr. Neurol. Neurosci. Rep.*, **10**, 440–447.

Pereira, M., von Zuben, A., Aprahamian, I. & Forlenza, O. (2014) Eye movement analysis and cognitive processing: Detecting indicators of conversion to Alzheimers disease. *Neuropsychiatr. Dis. Treat.*, **10**, 1273.

Pierrot-Deseilligny, C., Milea, D. & Müri, R. (2004) Eye movement control by the cerebral cortex. *Curr. Opin. Neurol.*, **17**, 17–25.

Puri, A. & Wojciulik, E. (2008) Expectation both helps and hinder object perception. *Vis. Res.*, **48**, 589–597.

Rayner, K. (1998) Eye movements in reading information processing: 20 years of research. *Psychol. Bull.*, **124**(3), 372–422.

Salat, D.H., Kaye, J. & Janowsky, J.S. (2001) Selective preservation and degeneration within the prefrontal cortex in aging and Alzheimer disease. *Arch. Neurol.*, **58**, 14031408.

Sebastián-Gallés, N., Martí, M., Cuetos, F. & Carreiras, M. (1998) *LEXESP: Léxico Informatizado del Español.* Barcelona, Spain: Universidad de Barcelona.

Stine-Morrow, E., Miller, L. & Hertzog, C. (2006) Aging and self-regulated language processing. *Psychol. Bull.*, **132**, 582–606.

Summerfield, C. & Egner, T. (2009) Expectation (and attention) in visual cognition. *Trends Cognit. Sci.*, **13**, 403–409.

Taylor, L. (1953) Cloze procedure: A new tool for measuring read ability. *J. Quart.*, **30**(4), 415–433.

Touron, D., Swaim, E. & Hertzog, C. (2007) Moderation of older adults' retrieval reluctance through task instructions and monetary incentives. *J. Gerontol. Seri. B: Psychol. Sci. Soc. Sci.*, **62**, P149–P155.

Xu, M. (2010) Adaptive control of saccades via internal feedback, PhD thesis, The John Hopkins University, Baltimore, Maryland.