Journal of Neurolinguistics 68 (2023) 101144

Contents lists available at ScienceDirect

Journal of Neurolinguistics

journal homepage: www.elsevier.com/locate/jneuroling

Perceptual strength influences lexical decision in Alzheimer's disease

A. Miceli [a,b,c,*], E. Wauthia [a,b,c], K. Kandana Arachchige [a,b,c], L. Lefebvre [a,b,c], L. Ris [b,c,d], I. Simoes Loureiro [a,b,c]

[a] Department of Cognitive Psychology and Neuropsychology, Faculty of Psychology and Educational Science, University of Mons, Mons, Belgium
[b] Research Institute for Health Sciences and Technologies, University of Mons, Mons, Belgium
[c] Interdisciplinary Research Centre for Psychophysiology and Cognitive Electrophysiology, University of Mons, Mons, Belgium
[d] Department of Neurosciences, Faculty of Medicine and Pharmacy, University of Mons, Mons, Belgium

ARTICLE INFO

Keywords:
Alzheimer's disease
Conceptual knowledge
Perceptual strength
Semantics
Representations
Lexical decision

ABSTRACT

The multimodal approach where cognition is embodied in language, perceptual, motor, and emotional systems is a widely agreed theoretical framework for conceptual representations. However, the lack of work supporting this view of cognition in healthy and pathological aging stands in stark contrast with the ongoing need to understand the factors that uncover semantic degradation in brain pathologies. The aim of this study is to explore the impact of perceptual strength (PS) - i.e., the extent to which a word can be experienced by multiple sensory modalities - in visual word recognition in Alzheimer's disease (AD). Thirty-six healthy participants, 22 participants in the mild stage of AD (AD1) and 20 in the moderate stage (AD2) took part in a lexical decision task with two conditions: words with high vs low PS words. Results showed an interaction effect only between healthy controls and AD1 individuals, revealing that the latter were faster in processing high PS words in contrast to low PS words, while this was not the case for healthy individuals. Furthermore, it was specifically the ratings of the neuropsychological executive and lexical-semantic assessments that predicted these results. However, no results were observed for AD2 participants, suggesting that lexical-semantic degradation was too severe to reveal a PS effect. This study demonstrates the importance of considering the perceptual dimension when examining the conceptual system and opens up new avenues in the exploration of semantic impairment in AD.

1. Introduction

Semantic-lexical disorder appears systematically in early Alzheimer's disease (AD) (Altmann & McClung, 2008; Chertkow, Bub, Cosgrove, & Dixon, 1993; Hodges, Patterson, Graham, & Dawson, 1996; Hodges & Patterson, 1995; Nebes, 1989; Rogers & Friedman, 2008). This progressive degeneration affecting the conceptual-semantic representations of word meanings has been widely documented from various lexical-semantic tasks involving word recognition, retrieval, production, or comprehension. Indeed, pictures naming and other tasks show errors that progress from semantic or visual-perceptual paraphasia to pure anomia (Chertkow & Bub, 1990; Chertkow et al., 1993; Cuetos, Martinez, Martinez, Izura, & Ellis, 2003; Hodges, Salmon, & Butters, 1991; Silagi, Bertolucci, &

* Corresponding author. Place du Parc, 18, 7000, Mons, Belgium.
E-mail address: Aurelie.miceli@umons.ac.be (A. Miceli).

https://doi.org/10.1016/j.jneuroling.2023.101144
Received 12 January 2023; Received in revised form 9 May 2023; Accepted 19 May 2023

Ortiz, 2015) and these difficulties can also be evidenced by longer response times in lexical decision tasks (LDT) (Martínez-Nicolás, Carro, Llorente, & Meilán, 2019). However, not all words are affected in the same way. Indeed, it is known that performance is better for some aspects of word recognition in AD when some features of these words are controlled. On the lexical level, the role of the age of acquisition of words has been demonstrated in AD. As is the case for healthy individuals, words acquired early in life are more easily accessible than words acquired late (Cuetos et al., 2010, 2017; Holmes, Jane Fitch, & Ellis, 2006; Silveri, Cappa, Mariotti, & Puopolo, 2002). This is also the case for frequency and familiarity where patients perform better for highly frequent words (Kirshner, Webb, & Kelly, 1984; Skelton-Robinson & Jones, 1984; Thompson-Schill, Gabrieli, & Fleischman, 1999) or highly familiar words (Gainotti, Di Betta, & Silveri, 1996). The common interpretation of these results is that words that are more frequent, more familiar, and acquired earlier in life are more easily accessible or richer because the semantic representations of these concepts were learned early in life and have therefore been activated more often. This suggesting that the different meanings of these words would probably provide richer and stronger neurological connections. This make them less vulnerable to AD deterioration than words that are less frequent, less familiar, and acquired late, and thus less often activated (see Cuetos et al., 2017).

On the semantic level, although many studies have shown that semantic variables (such as number of semantic features, number of semantic associates) could modulate word processing in healthy subjects (e.g., Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; Pexman, Siakaluk, & Yap, 2014), only very few studies have been conducted in AD. Using the variable « number of features », Duarte and Robert (2014) investigated whether a concept with high semantic richness (i.e., a high number of features) is more robust than a concept with low semantic richness (i.e., a low number of features) in AD. The researchers investigated whether the retrieval difficulty experienced in AD in a picture naming task can be modulated by this semantic richness. The results showed that concepts were better named when they had a high rather than a low number of features, suggesting that the more semantic information a concept presents, the more accessible it is in memory and the more robust it is in AD. Indeed, processing an image with a high number of features would generate a greater semantic activation which would facilitate the transmission of the activation of semantic units to the phonological level in order to name the concept. Faster processing for words with dense associates neighborhoods compared to words with sparse neighborhoods in healthy control and AD participants were also highlighted in a LDT (Dunabeitia, Marín, & Carreiras, 2009). This faster processing means that the automatic activation of orthographic representations is intact in AD and leads to greater levels of global lexical activation for words with dense associates neighborhoods. The automatic semantic processing of words would therefore be preserved in normal aging as well as in AD (Dunabeitia et al., 2009). Duarte and Robert (2014) suggest that semantic richness therefore plays an important role in processing word production and accessibility in healthy aging and AD. However, we still only know little about what makes a word easier or harder to recognize (Cuetos et al., 2017).

Recently, an interest for the sensorimotor dimensions of word meaning in word recognition has also developed in the literature. This interest has emerged in the context of embodied cognition theories that suggest an intervention of sensorimotor processes in semantic representation. An increasing amount of behavioral and neurophysiological evidence supporting these theories can be found in the scientific literature. For example, numerous brain imaging studies showed that processing different properties of an object (e.g., color, action, sound) activated the same neural system as when these properties were actually perceived (e.g., González et al., 2006; Hsu, Kraemer, Oliver, Schlichting, & Thompson-Schill, 2011; Simmons et al., 2007; see Martin, 2007 for a review). It has also been shown that the simple comprehension of a sentence activates the representations related to the action (Boulenger, Hauk, & Pulvermüller, 2009; Glenberg & Kaschak, 2002; Stanfield & Zwaan, 2001). Studies investigating different visual recognition tasks also showed that words with more sensorimotor knowledge (i.e., words for which the body-object interaction is high, for example « belt ») generate a greater semantic activation, enabling faster responses than words with less sensorimotor knowledge (e.g., « boat ») in young adults (e.g., Siakaluk, Pexman, Sears, et al., 2008; Tillotson, Siakaluk, & Pexman, 2008; Xue, Marmolejo-Ramos, & Pei, 2015) and in children (Inkster, Wellsby, Lloyd, & Pexman, 2016; Wellsby & Pexman, 2014). The results have been interpreted in the context of semantic richness effects: words associated with richer semantic representations (in this case, sensorimotor information) provide stronger activation to semantic-level representations, allowing for faster responses (Siakaluk, Pexman, Aguilera, Owen, & Sears, 2008). These effects are explained from the activation feedback theory of visual word recognition (Balota, Paul, & Spieler, 1999; Hino & Lupker, 1996; Pexman, Lupker, & Hino, 2002): the visual word recognition system includes orthographic, phonological, and semantic units that are separate but interconnected such that the processing in one set of units can influence the processing in a different set of units (e.g., activation feedback from semantic units to orthographic units in a LDT, see Siakaluk, Pexman, Aguilera, et al., 2008). Hence, it is commonly accepted that the perceptual and motor information that the individual acquires through experience with his environment is an integral part of what constitutes concepts and can therefore be considered as a new semantic dimension (see Pexman, 2012). However, to the best of our knowledge, there are currently no studies that have investigated the importance of the sensorimotor dimension of concepts in AD in visual word recognition.

Since semantic-lexical disorders are one of the hallmarks of AD, it seems essential to know all the semantic dimensions potentially involved in this disease (whether they are affected or preserved), in order to improve the understanding of the evolution of lexical-semantic processing in AD. While studies investigating sensorimotor dimensions of word meaning in word recognition exist for young adults (e.g., Siakaluk, Pexman, Sears, et al., 2008; Hargreaves, Leonard, et al., 2012; Yap, Pexman, Wellsby, Hargreaves, & Huff, 2012) and are gradually developing for children (Inkster et al., 2016; Wellsby & Pexman, 2014), they are in fact still scarce for normal or pathological aging (see Vallet, 2015). Although also rare, investigations of imageability effects in AD do provide some information about the accessibility of perceptual information associated with concepts. Indeed, imageability is one of the first variables associated with sensorimotor information. It represents the ease with which a word evokes a mental image, i.e. a pictorial image, a sound or any other sensory experience (Bonin, Méot, Ferrand, & Roux, 2011; Paivio, Yuille, & Madigan, 1968). Several studies using naming tasks did not show any specific effect of imageability in AD (Albanese, 2007; Cuetos et al., 2005, 2012; Rodríguez-Ferreiro, Davies, González-Nosti, Barbón, & Cuetos, 2009). However, it has been suggested that naming fails to make clear predictions about the influence of imageability in AD because it does not allow for a wide range of imageability values, such as in a visual word recognition task for example (Cuetos et al., 2017). Indeed, better performances for highly imageable words, compared to poorly imageable words, have been shown in AD in a lexical selection task (Cuetos et al., 2017) as well as in a serial recall task investigating verbal short-term memory (Peters, Majerus, De Baerdemaeker, Salmon, & Collette, 2009). These results have been interpreted by researchers as a reflect of the decreased support of semantic knowledge associated with low imageability words (Peters et al., 2009), these being impoverished by their less detailed perceptual information and therefore being more vulnerable (Cuetos et al., 2017). However, it has been highlighted that the imageability variable does not reflect the perceptual basis of concepts as it rather represents the visual modality and underestimates the other perceptual modalities associated with concepts (Connell & Lynott, 2012). To overcome this limitation, Lynott and Connell (2009, 2013) developed perceptual strength (PS) norms specific to each modality (i.e., auditory, visual, gustatory, haptic, olfactory). The PS represents the extent to which a word can be experienced by separate sensory modalities, and is obtained by asking participants to rate the extent to which they experience a word in each of the five sensory modalities on a scale of 0 (not experienced at all) to 5 (highly experienced) (Lynott & Connell, 2009). A previous study highlighted the importance of PS in a lexical and semantic decision task of isolated words in healthy young and older adults (Miceli et al., in revision). Words with high PS (e.g., pineapple) were contrasted with words with low PS (e.g., moon). In the LDT, results comparing the performance of younger and older adults showed that high PS words tended to be processed faster than low PS words, regardless of group classification. However, this effect was most noticeable in the youth group. Words with high PS were therefore associated with greater semantic information because of greater activation feedback from semantic units to orthographic units (see also Balota, Ferraro, & Connor, 1991; Harm & Seidenberg, 2004; Siakaluk, Pexman, Sears, et al., 2008). The study showed that PS was an important part of the conceptual system and was accessible to the linguistic system both in healthy young adults and in healthy aging (Miceli et al., in revision).

It therefore seems interesting to know how concepts that have different PS will be processed in the case of pathological aging, in this case AD. A direct comparison between the lexical decision performance of adults with AD and healthy controls seems suitable for exploring perceptual semantic activation in dementia. Since the semantic richness effect has been demonstrated in AD in a few rare studies (e.g., Duarte & Robert, 2014), we aimed to explore whether high PS words would be more easily accessible than low PS words in this disease and if this effect is modulated according to the stage of deterioration. Hence, the aim of our study is to explore the impact of PS in the lexical processing of mild and moderate AD using the lexical decision task contrasting words with high vs. low PS words used by Miceli et al. (in revision). This question is totally exploratory and would allow to understand how semantic representations evolve in AD.

2. Method

2.1. Participants

Seventy-eight participants took part in the study. All participants were French native speakers, right-handed and had corrected-to-normal vision. None of the participants had a history of alcoholism, head trauma or known neurological or psychiatric disorder. A questionnaire (Likert scale) collecting the number of years of study (i.e., education level) allowed to determine their socio-cultural level. The socio-demographic data of the participants is shown in Table 1. All participants gave their consent before participating in the study. This study was conducted in line with the Declaration of Helsinki and in agreement with the ethics committee of the university of Mons.

Forty-two older adults with probable AD were selected on the basis of the National Institute of Neurological and Communicative Disorders and Stroke and the AD and Related Disorders Association criteria (McKhann et al., 1984). They were recruited in retirement homes and day care centers for older adults, in different francophone regions of Belgium. A short cognitive assessment including the Mini-Mental State Examination (MMSE) was used to determine the stage of the disease, according to the consensual limits of the GRECO (Groupe de Réflexion sur les Evaluations Cognitives). Besides the control group, two groups of patients were constituted. Twenty-two persons were at the mild stage of the disease (MMSE $\geq$20; AD1) and 20 persons were at the intermediate stage (MMSE between 15 and 19; AD2). They were compared to a control group of 36 healthy older adults whose data came from a previous study comparing young and older adults on the same current decision task (Miceli et al., in revision). Healthy older adults were recruited through word of mouth, social media ads, as well as through presentation of the study in a senior workshop.

Given the impact of anxiety and depression on cognitive functioning (e.g., Harvey, 2011; Maloney, Sattizahn, & Beilock, 2014), all participants completed a questionnaire assessing anxiety with the Geriatric Anxiety Inventory (GAI, Pachana et al., 2007) and depression with the Geriatric Depression Scale (GDS-15, Clément, Nassif, Léger, & Marchan, 1997). In addition to the MMSE, all participants also completed a short cognitive assessment that included the Dubois 5-words episodic memory test (Dubois et al., 2002), a semantic and phonological fluency test (Cardebat, Doyon, Puel, Goulet, & Joanette, 1990), the short version of the semantic knowledge questionnaire (Mini QCS, Simoes Loureiro, Taverne, & Lefebvre, 2018), a short image naming test (TCD-MA, Simoes

Table 1
Socio-demographic characteristics of participants.

Group	N	Gender	Age Mean (SD)	Years of education[a] Mean (SD)
Healthy participants	36	16 women	73.78 (7.26)	4.25 (1.18)
AD1 participants	22	17 women	77.50 (6.85)	3.77 (1.27)
AD 2 participants	20	14 women	80.80 (6.65)	3.55 (1.10)

[a] 1 = less than primary grades; 2 = primary grades; 3 = middle school; 4 = high school; 5 = bachelor's degree; 6 = master; 7 = PhD.

Loureiro et al., 2021) and a short test of frontal efficiency (BREF, Dartinet & Martinaud, 2005). The statistical data of the questionnaires and cognitive evaluations and the significance scores for the patients' groups compared with controls are reported in Table 4 in the results section.

2.2. Stimuli

Fifty-six concrete common nouns were selected from the PS norms collected by Miceli et al. from young (2021) and older adults (2022) and were the same used in a previous study (Miceli et al., in revision). In these studies, words were rated on a scale from 0 (not at all) to 5 (greatly), reflecting the extent to which they were experienced through each perceptual modality (i.e., visual, auditory, haptic, gustative, olfactory). These modalities were each scored separately. The 56 stimuli were divided into 2 groups: 28 words with high PS (e.g., horse) and 28 words with low PS (e.g., ant) (see appendix). The 2 groups of words were constituted from the summed PS variable (i.e., the sum of the 5 perceptual ratings) and divided from the median. We found the choice of the PS summed to be the most relevant because it allows each perceptual dimension to be considered equally valuable (Đurđević, PopovićStijačić, & Karapandžić, 2016). Furthermore, Đurđević et al. (2016) showed that the summed PS variable best predicts latency and accuracy of responses in a lexical decision experiment among other variables. Note that the 2 groups of experimental words also differ significantly ($p<.001$) in terms of modality exclusivity. This represents the extent to which a word is multimodal (score close to 0%) or unimodal (score close to 100%), and it is computed by dividing the rating range by the sum, as in the formula below, where M is a vector of mean ratings for each of the five perceptual modalities ($\max M - \min M / \Sigma M$) (Lynott & Connell, 2009, 2013; Lynott, Connell, Brysbaert, Brand, & Carney, 2019). Therefore, low PS words were more unimodal, while high PS words were more multimodal. The statistic characteristics of the experimental items are presented in Table 2.

The 2 groups of 28 words were matched for the following linguistic and psycholinguistic variables known to be important in word processing ($p>.05$). Objective book and movie frequency, number of letters, number of phonemes, number of phonological and orthographic neighbours and orthographic Levenshtein distance (OLD 20) were collected from New, Brysbaert, Veronis, and Pallier (2007). The experimental words were also matched for age of acquisition, conceptual familiarity, concreteness, imageability, and valence intensity and arousal [2 affective variables also impacting word processing (e.g., Estes & Adelman, 2008; Ferrand et al., 2018; Kousta, Vinson, & Vigliocco, 2009)] from Miceli, Wauthia, Lefebvre, Ris, and Simoes Loureiro (2021). In order to match the 2 groups of words regarding the number of features, we collected the number of features (see Hargreaves et al., 2012; Pexman, Holyk, & Monfils, 2003) via the subjective method used by Siakaluak et al. (2008) and the instruction of Toglia and Battig (1978). This compilation was conducted with 122 young adults (93 women; Mean age 23.73, SD 4.87; socio-cultural level of bachelor's degree). Finally, it was also important to match high and low PS words on the body-object interaction. The descriptive statistics for the experimental items are presented in Table 3.

Fifty-six pronounceable non-words were also created and used as fillers in the lexical decision task. They were generated directly from the Wordgen program (Duyck, Desmet, Verbeke, & Brysbaert, 2004). Experimental words and non-words were matched on the number of letters, the number of phonemes, the number of phonological and orthographic neighbours, the orthographic Levenshtein distance (OLD 20) (New et al., 2007) and on bigram frequency (from Wordgen software, Duyck et al., 2004) so that the non-words respected the orthographic typicality.

Descriptive statistics of the stimuli are available via OSF, at https://osf.io/j35vd/?view_only=630eeab3b6bd47aa88d48329237f52ad.

2.3. Apparatus and procedure

We used the same material and procedure as in a previous study (Miceli et al., in revision). The E-prime 3.0 software was used for stimuli presentation on a 17-inch HP Probook computer. The task was a lexical decision of isolated words. Each trial began with a fixation cross (1000 ms), replaced by a word (or non-word in the LDT) until the participant gave their response. The inter-trial interval (ITI) was of 2000 ms (blank screen). The presentation of the stimuli was pseudo-randomized to control the precise order of appearance of the stimuli. Indeed, the presentation was such that no experimental word was followed by an experimental item of the same category to exclude potential semantic (taxonomic) priming effects. To exclude order effects, the list of 112 pseudo-randomized items was then divided into 4, allowing for 4 versions of the protocol to be created, each presenting the same items in 4 different orders. The protocol version was randomly assigned across participants. Each participant was asked to perform 10 training items, half of which were non-words.

The instruction was to decide whether the sequence of letters presented on the screen was a word of the French language or not. They had to answer yes or no by pressing the green (yes) or red (no) button on the answer box. To prevent AD participants from forgetting the instructions, the words "YES" and "NO" were written above the corresponding keys for the AD groups. The task lasted approximately 10–20 min depending on the speed of the participants. A break was offered halfway through the task and participants could decide to take it or simply continue the task.

Table 2
Mean and standard deviation (SD) characteristics for word stimuli rated by healthy older adults.

	Summed PS	Modality Exclusivity
Low PS	5.08 (.82)	49.02% (13.10)
High PS	10.74 (1.87)	26.20% (9.03)

Table 3
Descriptive statistics (Mean and SD) for matched variables for word stimuli and *U* test results.

	Low PS	High PS	*p*
Movie Frequency	13.81(24.43)	31.85(67.83)	.283
Book Frequency	24.45(61.37)	30.16(53.20)	.466
Number of letters	6.29(1.96)	5.64(1.85)	.205
Number of phonemes	4.55(1.65)	4.18(1.22)	.493
Phon. neighbours	8.36(9.51)	10.50(8.51)	.253
Orth. neighbours	4.32(5.11)	4.50(3.89)	.431
OLD	8.13(32.71)	1.75(.48)	.215
AoA	5.36(1.35)	5.57(1.71)	.664
Conceptual Fam.	2.94(.77)	3.01(.31)	.302
Concreteness	4.63(.20)	4.71(.22)	.053
Imageability	4.75(.19)	4.79(.18)	.254
Valence intensity	5.90 (1.49)	6.39(1.64)	.204
Arousal	2.04(.34)	2.25(.49)	.078
Number of features	2.61(.31)	2.56(.46)	.752
BOI	1.71(1.11)	2.24(.60)	.061

Note. Phon.neighbours, phonological neighbours; Orth.neighbours, orthographical neighbours; OLD, orthographic levenshtein distance; AoA, age of acquisition; Conceptual Fam., conceptual familiarity; BOI, body-object interaction.

2.4. Statistics

All analyses were conducted using R [3.5.1] (RStudio Team, 2015). The percentage of correct performance on the whole LDT was 97.8% for the control group, 97.7% for the AD1 group and 95% for the AD2 group. The following analyses were performed only on the correct answers for the 2 experimental conditions of interest, i.e., on the 56 experimental items (28 high PS and 28 low PS).

The outliers were excluded from the dataset. First, response latencies below 250 ms and above 3500 ms were removed from the data sets. Also, for each participant and for each of the 2 experimental conditions, responses deviating by 3 standard deviations from the mean of each condition were considered as outliers and removed. As such, 1.55% (31 observations of the control data set), 1.72% (21 observations of the AD1 data set), and 8.40% (92 observations of the AD2 data set) of the observation were removed.

We used linear mixed effects models (LMEM) to examine the conditions of interest while taking into account the variability within and across participants and items concurrently (see Baayen, Davidson, & Bates, 2008; Brown, 2021; Yu et al., 2021). We used the packages « lme4 » [version 1.1-18-1] (Bates et al., 2015) and « afex » [0.23-0] (Singmann, Bolker, Westfall, & Aust, 2015) to perform our statistical analysis in R [3.5.1] (RStudio Team, 2015). The R script used to generate the models described in this article are available via OSF, at https://osf.io/j35vd/?view_only=630eeab3b6bd47aa88d48329237f52ad.

First, we removed the influential values in each group, as suggested by Stefaniak (2018). As such, 17 influential observations in the control group, 10 in the AD1 group and 5 in the AD2 group were removed. In each group, we performed a power analysis to ensure that our sample size was sufficient. We used the online program proposed by Westfall, Kenny, and Judd (2014) using a *d* effect size at 0.4 as recommended by Brysbaert and Stevens (2018). The results showed that the power was greater than 0.90 for the three groups (control group = .989; AD1 = 1; AD2= .927).

Second, we ran a linear/logistic mixed effects model that predicted RTs and accuracy in order to compare 1) control group vs AD1 group and 2) control group vs AD2 group. We used condition (low or high PS) and group interaction as fixed effect with a dummy coding, where 0 was the control group and 1 was the AD group. Fixed and random intercepts for participants and items were included. Because our stimuli were different in each condition, we could not include by-item slope (Brown, 2021) but we included by-participant slope. We used the function *ranova(.)* to check the random effects and adjusted the model according to the results. We used the *mixed(.)* function with the argument *method* = *'LRT'* to conduct the likelihood-ratio tests (Brown, 2021). When the results of the variables of interest were significant, we presented the model summary in a table.

Third, because our study was exploratory, we conducted additional analyses to understand the results. We used the *coef(.)* function to obtain a value (which we called the "index") representing the difference in RTs between the high and low PS condition, for each participant individually. We then performed correlation analyses between this index and the results of the cognitive assessments. Since the data did not check the normality assumption, we performed a Spearman correlation. Finally, regression analyses were performed to observe which tests were the most relevant to predict the index.

Furthermore, Mann-Whitney tests were carried out to compare the demographic, general cognitive and explicit semantic scores of the participant groups.

3. Results

3.1. Group characteristics

At a demographic level, AD1 participants were significantly older than the controls ($U = 252.5$, $p = .021$) and were significantly different in gender distribution (more men in the control group; $U = 266$, $p = .015$), but did not differ in education level ($U = 295$, $p = .095$). AD2 participants were significantly older than controls ($U = 163$, $p = .001$) and presented lower level of education ($U = 226$, $p =$

Table 4
Mean (and SD) of anxiety and depression questionnaires and cognitive assessments of 3 groups and significance score of *U* test comparing controls vs patients' groups and AD1 vs AD2.

	Control group	AD1 group	AD2 group	Controls vs AD1 *p* value	Controls vs AD2 *p* value	AD1 vs AD2
GAI	3.67(4.76)	4.09(5.49)	4.65(5.10)	.695	.621	.606
GDS	1.75(1.57)	2.27 (1.61)	2.10(1.55)	.229	.363	.535
MMSE	29.11(.79)	22.91(1.57)	16.65(1.39)	<.001	<.001	<.001
5 words	9.64(.90)	6.13(2.49)	3.35(1.73)	<.001	<.001	<.001
Phonologic fluency[a]	22.17(8.28)	17.14(6.74)	10.75(4.64)	<.001	<.001	.002
Semantic fluency[a]	30.03(8.37)	15.73(6.06)	9.45(4.33)	<.001	<.001	.001
Mini QCS	11.58(.69)	9.64(2.28)	7.95(2.76)	<.001	<.001	.036
TCD-MA	8.86(.93)	6.77(2.39)	4.30(2.66)	<.001	<.001	.003
BREF	17.03(1.23)	13.91(2.64)	11.35(2.08)	<.001	<.001	.002

Note. GAI, Geriatric Anxiety Inventory; GDS, Global Depression Scale; MMSE, Mini Mental State Examination; QCS, semantic knowledge questionnaire; TCD-MA, short naming test adapted to AD; BREF, short test of frontal efficiency.
[a] Raw scores.

.018) but did not differ in gender distribution ($U = 268$, $p = .069$). Given these significant differences, it was not possible to match participants on these variables (but see below for a control of these potential effects). Concerning anxiety and depression questionnaires, all the participants had low scores and did not differ from each other. Comparison of cognitive assessments between each AD group and the control group revealed significant differences, showing that AD participants had significantly lower scores than healthy ones in semantic memory, episodic memory and on the executive functioning (see Table 4). Comparison of cognitive assessments between AD1 and AD2 also show that AD2 had significantly lower scores than AD1 in these three domains.

3.2. Accuracy in the lexical decision task

3.2.1. AD1 group vs control group

We ran a LMEM that predicted accuracy using interaction between condition and group as fixed effect and the items and participants as random effects, as well as by-participant slope. As by-participant slope was found non-significant ($p = .063$), we removed it from the model. The likelihood-ratio test indicated that the model was non-significant for the condition [$\chi2(1) = 0.00$, $p = .956$], for the group [$\chi2(1) = 0.88$, $p = .349$], and the interaction between condition and group [$\chi2(1) = 1.26$, $p = .262$].

3.2.2. AD2 group vs control group

The likelihood-ratio test indicated that the model was non-significant for the condition [$\chi2(1) = 0.25$, $p = .617$] and the interaction between condition and group [$\chi2(1) = 0.47$, $p = .495$] but were significant for the group [$\chi2(1) = 5.74$, $p = .017$]. These latter results meant that the AD2 group participants were less successful at the task than the healthy group (β = -1.85, $SE = 0.78$, $z = -2.36$).

3.3. RTs in the lexical decision task

3.3.1. AD1 group vs control group

We ran a LMEM that predicted RTs using interaction between condition and group as fixed effect and the items and participants as random effects, as well as by-participant slope. Random effects testing revealed a non-significant result for the by-participant slope ($p = .059$). The model fitted without this slope was significant for participant random ($p < .001$) and item random effect ($p < .001$). Therefore, we fitted a model without this slope. The likelihood-ratio applied to this latter model indicated that the model was non-significant for the condition [$\chi2(1) = 1.82$, $p = .177$] but was significant for the group [$\chi2(1) = 23.86$, $p < .001$] and the interaction between condition and group [$\chi2(1) = 8.09$, $p = .004$]. The summary of the model is shown in Table 5. These results indicate that participants of the AD1 group were significantly slower than the healthy participants, with an estimated average slowdown of 226 ms

Table 5
LMEM estimates for the RTs interaction effect of PS in the lexical decision task.

	Coefficient	SE	df	t value	*p* value
Fixed effect					
Intercept	682.88	25.63	74.32	26.64	<.001
PS condition	−3.54	13.57	68.88	−0.26	.795
Group	225.57	39.23	60.00	5.75	<.001
PScondition:group	−28.35	9.96	3088.36	−2.85	.004
			Variance		SD
Random effect					
Participant Intercept			20340		142.62
Stimuli Intercept			2255		47.48
Residual			16890		129.96

(β = 225.57, *SE* = 39.23, *t* = 5.75). The interaction effect meant that while healthy participants processed the low and high PS condition equally (low PS = 683 ms; high PS = 679 ms), AD1 participants were faster for the high PS words than for the low PS words (low PS = 908 ms; high PS = 877 ms).

Because participants differed significantly in age and gender, we tested several models to examine if the inclusion of these variables changed the fitting of the model. Only the model including age as a fixed effect improves the likelihood of the model [$\chi2(1) = 8.09$, $p = .004$]. Indeed, when we tested the model including age, we observed a significant effect for this variable [$\chi2(1) = 11.04$, $p < .001$]. However, given that the AD participants were older than the healthy subjects, it was not surprising to obtain a significant age effect in this model. To ensure that the interaction effect observed between condition and group were not age-related, we tested a new model including interaction between group, condition, and age. Results showed no interaction between condition and age [$\chi2(1) = 0.18$, $p = .672$] but an interaction between group and age [$\chi2(1) = 7.58$, $p = .006$].

3.3.2. AD2 group vs control group

We used the same model as in the previous point, so that the model included this time the AD2 group. Given that all random and slope effects were significant ($p < .001$), we fitted a full model including theses effects. The results indicated that the model was non-significant for the condition [$\chi2(1) = 0.00$, $p = .971$] and the interaction between condition and group [$\chi2(1) = 0.03$, $p = .869$], but was significant for the group [$\chi2(1) = 60.46$, $p < .001$], meaning that the AD2 participants were significantly slower than the healthy participants (β = 698.22, *SE* = 64.46, *t* = 10.83).

Because participants differed significantly in age and educational level, we tested several models to examine whether the inclusion of these variables changed the fitting of the model. The model including age and educational level as a fixed effect improved the likelihood of the model [$\chi2(1) = 5.41$, $p = .020$]. The new likelihood-ratio test including age and educational level showed a significant effect for age [$\chi2(1) = 5.41$, $p = .020$] but not for the educational level [$\chi2(6) = 8.62$, $p = .196$]. To ensure that the lack of effect observed between condition and group were not age-related, we tested a new model including interaction between group, condition, and age. Results showed that there was no interaction between condition and age [$\chi2(1) = 1.30$, $p = .255$] but there was one between group and age [$\chi2(1) = 4.10$, $p = .043$], again confirming that although our groups differ by age, it was not age that was responsible for the interaction results between group and condition.

3.4. Complementary analysis

Because the LMEM that predicted RTs concerning AD1 participants group and healthy participants group was significant for the interaction effect between condition and group, we performed complementary analysis to better understand this result. We performed Spearman correlations between the PS index of both group (AD1 and healthy participants) and scores on preliminary cognitive assessments. As a reminder, the PS index represent the difference in RTs between the high and low PS condition, for each participant individually. According to the coding parameters selected in our analyses, the more negative the index was, the more there was an effect of PS (i.e., a difference between the RTs concerning the low and high conditions). Conversely, the more positive this difference was the weaker this effect was. All the results showed significant and positive correlation, except for the phonological fluency (see Table 6). This meant that the higher the scores on the questionnaires, the higher the index (thus positive) and therefore the less effect of PS was observed. Consistent with the results obtained in the LMEM, the level of cognitive deterioration seems to influence the effect of PS (i.e., a difference between the 2 conditions would appear only when cognitive scores fall).

We then performed regression analyses to determine which cognitive questionnaires were most relevant to explain the index. In the first step, we performed the analysis including all preliminary cognitive assessments. In a second step, we focused only on the lexical-

Table 6
Spearman correlations between the PS index and cognitive assessment questionnaires.

	MMSE	BREF	5 words test	Mini QCS	TCDMA	Phonological fluency (z scores)	Semantic fluency (z scores)
Spearman correlations	.581	.410	.281	.313	.353	.157	.311
p value	<.001	.001	.033	.017	.007	.240	.018

Table 7
Mean (and SD) of BREF, TCDMA and mini QCS and index, according to the distribution of threshold scores for each questionnaire and results of the Mann-Whitney test.

	N	Index Mean (SD)	Questionnaire scores Mean (SD)	Results
BREF				
Below threshold (16)	19	−26.80(25.48)	13.11(2.18)	$U = 236$, $p = .026$
Above threshold	39	−13.58(17.70)	17.18(.94)	
TCDMA				
Below threshold (7)	12	−44.17(34.30)	5(1.95)	$U = 123$, $p = .003$
Above threshold	46	−11.06(7.38)	8.87(.75)	
Mini QCS				
Below threshold (9)	11	−40.49(28.26)	7.82(1.89)	$U = 97$, $p = .001$
Above threshold	47	−12.63(15.41)	11.55(.62)	

semantic assessments. The first regression analysis (stepwise method) including all questionnaires showed that the model that best explained the index included the TCD-MA ($\beta = .534$, $t = 4.91$, $p < .001$) and the BREF ($\beta = .252$, $t = 2.31$, p .025). The second regression analysis involving only the lexical-semantic tests (phonological and semantic fluency, TCDMA, mini QCS) showed that the TCD-MA ($\beta = .461$, $t = 3.55$, $p = .001$) and the Mini QCS ($\beta = .278$, $t = 2.15$, $p = .036$) best explained the index.

To further investigate this latter point, we examined whether there were significant differences between our participants regarding the index depending on whether the participants had scores above or below the cut-off scores of the BREF, TCD-MA and Mini QCS questionnaires. Indeed, due to the high sensitivity and specificity of these questionnaires, threshold scores are used to determine whether participants' results are considered pathological (below threshold) or not (above threshold). The participants were therefore divided according to the subdivision of each of the cut-off scores of the questionnaires and no longer according to belonging to the AD or healthy group. A Mann-Whitney test was performed for each questionnaire. See Table 7 for a summary of the data and results. The results showed that the index was significantly different depending on whether the participants had a score above or below the threshold of the 3 questionnaires tested individually. In fact, participants with a score below the threshold of the BREF (threshold of 16), the TCDMA (threshold of 7) and the Mini QCS (threshold of 9) had a significantly lower index (i.e., very negative, showing a significant effect of PS) regardless of whether they were in the AD1 or healthy group.

Although the results for the LMEM involving the control group and the AD2 participants were non-significant, we still explored the existence of correlations between the participants' index and the questionnaires. However, the results were unequivocally non-significant ($p > .05$) for each of the neuropsychological assessments.

4. Discussion

The purpose of this study was to explore the effect of PS in AD in a LDT. Specifically, we were interested in whether high PS words would generate greater semantic activation than words with less PS in this disease, resulting in faster responses to high PS words than to low PS words. To this end, we investigated the performance of a group of healthy participants in comparison to a group of patients in the early stages of the disease and in the moderate stages of the disease.

The most interesting results concerned the RTs for the comparison of healthy and AD1 individuals. Indeed, the interaction effect between group and condition (low vs. high PS) showed that the AD1 participants presented a clear distinction between high vs. low PS words, whereas this was not the case in the healthy individuals who processed the 2 conditions in a similar way. Thus, the semantically less rich words (low PS words) were processed slower by the AD1 while the richer words (high PS words) were processed faster. In line with the activation feedback theory discussed in the introduction, these results can be explained by a feedback loop from semantic units to orthographic units (Balota et al., 1999; Hino & Lupker, 1996; Pexman et al., 2002) with greater activation occurring for high PS words as opposed to low PS words, because the connections between semantic and orthographic units are greater for these words. This would mean that in the mild stage of AD, these connections are present and are reinforced by the sensorimotor weight of the concepts. The more a concept contains semantic information (here perceptual), the more easily it will be accessible in the mild stage of the disease. Conversely, this means that low PS words are potentially more vulnerable given their impoverished semantic representation. These results are consistent with those of Duarte and Robert (2014) and Dunabeita et al. (2009) that showed that semantic richness also plays an important role in word processing in AD.

However, in contrast to these studies, our results show that this differentiated processing is specific to early-stage AD and not to healthy aging. In particular, further analyses revealed that the effect of PS was correlated with neuropsychological assessments; it occurred precisely when subjects' cognitive performance declined. The importance of 3 questionnaires (BREF, TCDMA and Mini QCS) was highlighted in determining the coefficient allowing to quantify this effect (which we called the index). These short assessments of executive and lexical-semantic functioning enabled us to show that there were significant differences in the index depending on whether the participant had a higher or lower score than the cut-off scores of the questionnaires, regardless of whether the participant belonged to the healthy group or to the AD group. These results corroborate the fact that it is indeed cognitive deterioration, in particular lexical-semantic and executive deterioration, that influences the results. This means that, in the early stage, lexical-semantic and executive performance, which are impaired in the disease, influence PS processing in terms of facilitating high PS words and defacilitating low PS word. Several elements are therefore relevant to discuss herein. First, the fact that this effect is present in AD1 and not in healthy participants and second, the fact that it is specific to the mild stage of the disease and not to the moderate.

At first glance, it may be surprising that healthy older people do not show this PS effect. In their study, Miceli et al. (in revision) suggested that healthy older adults would exhibit a probable ceiling effect reflected by a lack of distinction between the 2 conditions. This effect could occur because older adults have such an extensive sensorimotor experience with the concepts that even those with high PS would not show a processing benefit. Healthy older adults would therefore have reached the maximum level of experience - the most complete conceptual system - and the PS protocol as proposed in this study would not be fine-grained enough to observe a PS effect. In contrast, in the case of AD, deterioration of cognitive abilities (especially lexico-semantic and executive abilities) is observed, and we claim that these influence PS processing. Moreover, the analyses showed, in a very interesting way, that it was only for the AD1 group that this effect was observed. Indeed, the model evaluating the healthy and AD2 participants proved to be non-significant. The effect of PS thus appears in this study to be specific to AD1 individuals.

In order to understand these results as a whole, it is important to consider what is involved in the LDT. Barsalou, Santos, Simmons, and Wilson (2008) suggest that when the LDT is simple (i.e., no phonological and orthographic similarity between words and non-words), access to meaning is not necessary; the retrieval of the linguistic form and its associated statistical information is sufficient to correctly perform a task, without necessarily having to retrieve deep conceptual information (see also Plaut, 1997). However, if the task is finer (i.e., phonological and orthographic compliance), it requires deeper processing because meaning must be retrieved to verify that the stimulus is a word (e.g., James, 1975; Joordens & Becker, 1997; Shulman & Davidson, 1977; Yap, Balota, Cortese, & Watson, 2006). Specifically, we used a methodology in which the non-words respected orthographic typicality and were orthographically and phonologically plausible. We therefore assume that our task required access to meaning rather than superficial processing guided by statistical association information. We can, therefore, suppose that meaning was more easily reached by the participants in the mild stage of AD, contrary to AD2 who had more lexical-semantic difficulties. This was particularly corroborated by the fact that AD2 participants were significantly less accurate than controls (unlike AD1 who did not differ from controls in accuracy). The PS effect observed in AD1 and not in AD2 group would therefore be related to a difference in access to word meaning, which was itself related to a mark of lexical-semantic degradation in AD.

Therefore, if we consider that the task is potentially not fine enough to observe an effect in healthy adults or that healthy adults exhibit a semantic « ceiling effect », we notice that it becomes fine enough for the mild stage of AD. This demonstrates that it is indeed the decrease in abilities that causes the PS effect. By contrast, at the moderate stage, we postulate that the lexical-semantic impairment is too severe for the effect to emerge. Numerous studies have, in fact, highlighted lexical-semantic deficits that became more important as the severity of the disease increased (e.g., Humbert & Chainay, 2006; Salehi, Reisi, & Ghasisin, 2017; Silagi et al., 2015).

More generally, a major limitation of our study was the demographic and socio-cultural differences between the groups. We were specifically concerned about the age differences between the groups that improved the likelihood of the model, the control group being significantly younger than the AD1 group which itself was significantly younger than AD2. While this was not surprising given that advancing age is the leading risk factor for AD ((Alzheimer's Association, 2010)), we had to exclude this potential bias. However, the various analyses ruled out an effect of age, gender, and educational level between groups. We have therefore shown that it was not the demographic or socio-cultural differences between the groups that influenced the results but rather the effect of the group.

Concerning the absence of PS effect in healthy controls, we suggested the existence of a ceiling effect on semantic processing, which could potentially be specific to the protocol. Indeed, a limitation of our study is that the protocol may not be sufficiently sensitive in healthy aging. In the design of the Miceli et al. (in revision) protocol, the stimuli were selected considering the evaluation of young and older healthy people:

> Since it was shown that the PS ratings of the older adults were different from the young people for some modalities (Miceli et al., 2022), it seemed necessary to select 2 groups of words that correspond to the evaluation of the 2 populations studied. The 2 groups of words were constituted from the summed PS variable (the sum of the 5 perceptual ratings) and divided from the median. The division from the median was made taking into account the results for the 2 groups. (Miceli et al., in revision)

Since healthy older adults had higher PS rating (especially for certain word categories), the selection of stimuli is potentially less salient for older adults from the outset. It is therefore possible that the effect does not appear in older adults for strictly methodological reasons.

Also, the lack of effect for AD2 has been interpreted as a difficulty in accessing the meaning of words but a limitation of our study that can be pointed out is that we have no information concerning the participants' ability to access the orthographic system or even low-level perceptual processing that could have impacted lexical processing. It would therefore be relevant to take these elements into account in other investigations to ensure that the lack of PS effect is indeed related to lexical-semantic degradation and not to low-level lexical processing.

5. Conclusion

This study showed that PS influences visual word recognition in the mild stage of the disease, with mild stage (but not moderate stage) patients differing significantly from healthy controls. More specifically, it was the ratings of the executive neuropsychological (BREF) and lexical-semantic (TCD-MA, Mini QCS) assessments that influenced this effect. In particular, these results showed that, while the patients' abilities are always observed in relation to the stage of the disease (usually assessed with the MMSE), in this case it was mainly the level of executive and lexical-semantic performance that influenced the result, rather than the stage of the disease alone.

These results provide new information about the processing of embodied (sensorimotor) semantic information in AD and demonstrate the importance of considering the perceptual dimension when examining the conceptual system. They encourage further investigations with an embodied perspective in order to contribute to the understanding of the factors involved in the cognitive preservation/deterioration of patients with neurodegenerative diseases.

CRediT author statement

Aurélie Miceli: Conceptualization, Methodology, Investigation, Writing – Original Draft, Reviewing and Editing; **Erika Wauthia**: Methodology; **Kendra Kandana Arachchige:** Reviewing and Editing; **Laurence Ris**: Resources, Funding acquisition, Supervision; **Laurent Lefebvre**: Resources, Supervision; **Isabelle Simoes Loureiro**: Resources, Funding acquisition, Project administration, Supervision, Conceptualization, Methodology, Reviewing and Editing.

Funding

This study was funded by a program of *Actions de Recherches Concertées* financed by the Ministry of the French Community – Directorate General for Non-Compulsory Education and Scientific Research (reference: ARC-19/23 UMONS3).

Declaration of competing interest

None.

Data availability

The data code used in the study and the stimuli of the protocol used are available with the OSF link shared in the manuscrit.

Appendix

Items used in the experiments

Low PS

Aigle, ampoule, araignée, ballon, bavoir, bobine, botte, bulle, casquette, chimpanzé, coccinelle, escarpin, étoile, fourmi, grenouille, jupe, limace, lune, nid, ours, panda, pile, pinceau, pot, soleil, souris, tabouret, tournevis

English traduction

Eagle, light bulb, spider, balloon, bib, spool, boot, bubble, cap, chimpanzee, ladybug, pump, star, ant, frog, skirt, slug, moon, nest, bear, panda, battery, paintbrush, pot, sun, mouse, stool, screwdriver.

High PS

Alcool, ambulance, ananas, blé, bougie, canard, champignon, cheval, cochon, coq, croissant, feu, kiwi, lapin, larme, maïs, mangue, moustique, pêche, piano, poivron, poney, poule, radis, rose, sang, sucette, vague.

English traduction. Alcohol, ambulance, pineapple, wheat, candle, duck, mushroom, horse, pig, cock, croissant, fire, kiwi, rabbit, tear, corn, mango, mosquito, peach, piano, pepper, pony, chicken, radish, rose, blood, lollipop, wave.

Abstract words

Absent, destin, chagrin, colère, confort, conseil, courage, crainte, crise, culte, danger, enfer, ennui, espoir, fatigue, faute, faveur, fidélité, force, gêne, gloire, hâte, humeur, humor, illusion, justice, louange, maîtrise, manque, mensonge, méthode, miracle, morale, mythe, nuance, opinion, pacte, paix, pardon, passion, puissance, regret, rêve, thème, effort, santé, sens, échange, soif, songe, stabilité, tendance, théorie, usure, vitesse, zèle.

English traduction

Absent, fate, sorrow, anger, comfort, advice, courage, fear, crisis, cult, danger, hell, boredom, hope, fatigue, fault, favor, fidelity, strength, embarrassment, glory, haste, mood, humor, illusion, justice, praise, mastery, lack, lie, method, miracle, morality, myth, nuance, opinion, pact, peace, forgiveness, passion, power, regret, dream, theme, endeavor, health, meaning, exchange, thirst, dream, stability, tendency, theory, wear, velocity, zeal.

Non-words

Giln, machoitont, loudiez, laxon, habel, vantolige, japolisan, béhari, aborvant, gabaliroin, agréo, mainés, zoster, vuesta, lic, muiler, cralloure, superve, volven, goumonf, sung, puotasse, porse, ronk, unibames, kiot, hiche, gouie, cotie, ade, lica, biader, traplo, bax, harité,troje, caralet, quarmi, gecq, oflat, saveux, aublonnar, huvel, rapota, tunilier, irom, neceriable, baquis, idcie, ménové, kuib, couge, kadob, stecen, nuron, bla.

References

Albanese, E. (2007). The “hidden” semantic category dissociation in mild-moderate Alzheimer’s disease patients. *Neuropsychologia, 45*(4), 639–643.

Altmann, L. J., & McClung, J. S. (2008). Effects of semantic impairment on language use in Alzheimer’s disease. *Paper presented at the Seminars in speech and language*.

Alzheimer’s Association. (2010). Alzheimer’s disease facts and figures. *Alzheimer’s and Dementia, 6*(2), 158–194.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*(4), 390–412.

Balota, D. A., Cortese, M. J., Sergent-Marshall, S. D., Spieler, D. H., & Yap, M. J. (2004). Visual word recognition of single-syllable words. *Journal of Experimental Psychology: General, 133*(2), 283.

Balota, D. A., Ferraro, F. R., & Connor, L. T. (1991). On the early influence of meaning in word recognition: A review of the literature. *The psychology of word meanings*, 187–222.

Balota, D. A., Paul, S. T., & Spieler, D. H. (1999). Attentional control of lexical processing pathways during word recognition and reading. *Language processing*, 15–57.

Barsalou, L. W., Santos, A., Simmons, W. K., & Wilson, C. D. (2008). Language and simulation in conceptual processing. *Symbols, embodiment, and meaning*, 245–283.

Bonin, P., Méot, A., Ferrand, L., & Roux, S. (2011). L'imageabilité: Normes et relations avec d'autres variables psycholinguistiques. *L'Année Psychologique, 111*(2), 327–357.

Boulenger, V., Hauk, O., & Pulvermüller, F. (2009). Grasping ideas with the motor system: Semantic somatotopy in idiom comprehension. *Cerebral Cortex, 19*(8), 1905–1914.

Brown, V. A. (2021). An introduction to linear mixed-effects modeling in R. *Advances in Methods and Practices in Psychological Science, 4*(1), Article 2515245920960351.

Brysbaert, M., & Stevens, M. (2018). Power analysis and effect size in mixed effects models: A tutorial. *Journal of cognition, 1*(1).

Cardebat, D., Doyon, B., Puel, M., Goulet, P., & Joanette, Y. (1990). Evocation lexicale formelle et sémantique chez des sujets normaux. Performances et dynamiques de production en fonction du sexe, de l'âge et du niveau d'étude. *Acta Neurologica Belgica, 90*(4), 207–217.

Chertkow, H., & Bub, D. (1990). Semantic memory loss in alzheimer-type. *Modular deficits in Alzheimer-type dementia*, 207.

Chertkow, H., Bub, D., Cosgrove, R., & Dixon, R. (1993). Des troubles sémantiques dans la maladie d'Alzheimer à la description de l'architecture fonctionnelle de la mémoire sémantique. *Revue de Neuropsychologie*.

Clément, J., Nassif, R., Léger, J., & Marchan, F. (1997). Development and contribution to the validation of a brief French version of the yesavage geriatric depression scale. *L'encephale, 23*(2), 91–99.

Connell, L., & Lynott, D. (2012). Strength of perceptual experience predicts word processing performance better than concreteness or imageability. *Cognition, 125*(3), 452–465.

Cuetos, F., Arce, N., Martínez, C., & Ellis, A. W. (2017). Word recognition in A lzheimer's disease: Effects of semantic degeneration. *Journal of Neuropsychology, 11*(1), 26–39.

Cuetos, F., Gonzalez-Nosti, M., & Martínez, C. (2005). The picture-naming task in the analysis of cognitive deterioration in Alzheimer's disease. *Aphasiology, 19*(6), 545–557.

Cuetos, F., Herrera, E., & Ellis, A. W. (2010). Impaired word recognition in Alzheimer's disease: The role of age of acquisition. *Neuropsychologia, 48*(11), 3329–3334.

Cuetos, F., Martinez, T., Martinez, C., Izura, C., & Ellis, A. W. (2003). Lexical processing in Spanish patients with probable Alzheimer's disease. *Cognitive Brain Research, 17*(3), 549–561.

Cuetos, F., Rodríguez-Ferreiro, J., Sage, K., & Ellis, A. W. (2012). A fresh look at the predictors of naming accuracy and errors in Alzheimer's disease. *Journal of Neuropsychology, 6*(2), 242–256.

Dartinet, V., & Martinaud, O. (2005). La BREF, une batterie rapide d'évaluation frontale. *NPG Neurologie-Psychiatrie-Gériatrie, 5*(29), 43–46.

Duarte, L. R., & Robert, C. (2014). Semantic richness influences naming pictures in old age and in Alzheimer's disease. *Journal of Neurolinguistics, 31*, 55–68.

Dubois, B., Touchon, J., Portet, F., Ousset, P.-J., Vellas, B., & Michel, B. (2002). Les 5 mots, épreuve simple et sensible pour le diagnostic de la maladie d'Alzheimer. *La Presse Médicale, 31*(36), 1696–1699, 1983.

Dunabeitia, J. A., Marín, A., & Carreiras, M. (2009). Associative and orthographic neighborhood density effects in normal aging and Alzheimer's disease. *Neuropsychology, 23*(6), 759.

Đurđević, D. F., Popović Stijačić, M., & Karapandžić, J. (2016). A quest for sources of perceptual richness: Several candidates. *Studies in language and mind*, 187–238.

Duyck, W., Desmet, T., Verbeke, L. P., & Brysbaert, M. (2004). WordGen: A tool for word selection and nonword generation in Dutch, English, German, and French. *Behavior Research Methods, Instruments, & Computers, 36*(3), 488–499.

Estes, Z., & Adelman, J. S. (2008). *Automatic vigilance for negative words is categorical and general*.

Ferrand, L., Méot, A., Spinelli, E., New, B., Pallier, C., Bonin, P., et al. (2018). MEGALEX: A megastudy of visual and auditory word recognition. *Behavior Research Methods, 50*(3), 1285–1307.

Gainotti, G., Di Betta, A. M., & Silveri, M. C. (1996). The production of specific and generic associates of living and nonliving, high-and low-familiarity stimuli in Alzheimer's disease. *Brain and Language, 54*(2), 262–274.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review, 9*(3), 558–565.

González, J., Barros-Loscertales, A., Pulvermüller, F., Meseguer, V., Sanjuán, A., Belloch, V., et al. (2006). Reading cinnamon activates olfactory brain regions. *NeuroImage, 32*(2), 906–912.

Hargreaves, I. S., Leonard, G., Pexman, P. M., Pittman, D., Siakaluk, P. D., & Goodyear, B. (2012). The neural correlates of the body-object interaction effect in semantic processing. *Frontiers in Human Neuroscience, 6*, 22.

Hargreaves, I. S., Pexman, P. M., Johnson, J. S., & Zdrazilova, L. (2012). Richer concepts are better remembered: Number of features effects in free recall. *Frontiers in Human Neuroscience, 6*, 73.

Harm, M. W., & Seidenberg, M. S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review, 111*(3), 662.

Harvey, P. D. (2011). Mood symptoms, cognition, and everyday functioning: In major depression, bipolar disorder, and schizophrenia. *Innovations in clinical neuroscience, 8*(10), 14.

Hino, Y., & Lupker, S. J. (1996). Effects of polysemy in lexical decision and naming: An alternative to lexical access accounts. *Journal of Experimental Psychology: Human Perception and Performance, 22*(6), 1331.

Hodges, J. R., & Patterson, K. (1995). Is semantic memory consistently impaired early in the course of Alzheimer's disease? Neuroanatomical and diagnostic implications. *Neuropsychologia, 33*(4), 441–459.

Hodges, J. R., Patterson, K., Graham, N., & Dawson, K. (1996). Naming and knowing in dementia of Alzheimer's type. *Brain and Language, 54*(2), 302–325.

Hodges, J. R., Salmon, D. P., & Butters, N. (1991). The nature of the naming deficit in Alzheimer's and Huntington's disease. *Brain, 114*(4), 1547–1558.

Holmes, S. J., Jane Fitch, F., & Ellis, A. W. (2006). Age of acquisition affects object recognition and naming in patients with Alzheimer's disease. *Journal of Clinical and Experimental Neuropsychology, 28*(6), 1010–1022.

Hsu, N. S., Kraemer, D. J., Oliver, R. T., Schlichting, M. L., & Thompson-Schill, S. L. (2011). Color, context, and cognitive style: Variations in color knowledge retrieval as a function of task and subject variables. *Journal of Cognitive Neuroscience, 23*(9), 2544–2557.

Humbert, S., & Chainay, H. (2006). L'effet d'amorçage sémantique dans la Maladie d'Alzheimer: l'origine du déficit sémantique. *Revue de Neuropsychologie, 16*(1), 251–287.

Inkster, M., Wellsby, M., Lloyd, E., & Pexman, P. M. (2016). Development of embodied word meanings: Sensorimotor effects in children's lexical processing. *Frontiers in Psychology, 7*, 317.

James, W. (1975). *The meaning of truth* (Vol. 2). Harvard University Press.

Joordens, S., & Becker, S. (1997). The long and short of semantic priming effects in lexical decision. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*(5), 1083.

Kirshner, H. S., Webb, W. G., & Kelly, M. P. (1984). The naming disorder of dementia. *Neuropsychologia, 22*(1), 23–30.

Kousta, S.-T., Vinson, D. P., & Vigliocco, G. (2009). Emotion words, regardless of polarity, have a processing advantage over neutral words. *Cognition, 112*(3), 473–481.

Loureiro, I. S., Taverne, M., & Lefebvre, L. (2018). Le mini-QCS: Un outil de dépistage rapide des troubles de la mémoire sémantique de la maladie d'Alzheimer. *Gériatrie et Psychologie Neuropsychiatrie du Vieillissement, 16*(4), 429–438.

Loureiro, I. S., Taverne, M., Malou, V., Basaglia-Pappas, S., Besin, R., Invernizzi, S., et al. (2021). Présentation du test court de dénomination adapté à la maladie d'Alzheimer (TCD-MA). *Revue de Neuropsychologie, 13*(3), 214–222.

Lynott, D., & Connell, L. (2009). Modality exclusivity norms for 423 object properties. *Behavior Research Methods, 41*(2), 558–564.

Lynott, D., & Connell, L. (2013). Modality exclusivity norms for 400 nouns: The relationship between perceptual experience and surface word form. *Behavior Research Methods, 45*(2), 516–526.

Lynott, D., Connell, L., Brysbaert, M., Brand, J., & Carney, J. (2019). The lancaster sensorimotor norms: Multidimensional measures of perceptual and action strength for 40,000 English words. *Behavior Research Methods*, 1–21.

Maloney, E. A., Sattizahn, J. R., & Beilock, S. L. (2014). Anxiety and cognition. *Wiley Interdisciplinary Reviews: Cognitive Science, 5*(4), 403–411.

Martin, A. (2007). The representation of object concepts in the brain. *Annual Review of Psychology, 58*, 25–45.

Martínez-Nicolás, I., Carro, J., Llorente, T. E., & Meilán, J. J. G. (2019). *The deterioration of semantic networks in Alzheimer's disease*. Exon Publications.

McKhann, G., Drachman, D., Folstein, M., Katzman, R., Price, D., & Stadlan, E. (1984). Clinical diagnosis of alzheimer's disease: Report of national Institute of neurological and communicative disorders and Stroke and the alzheimer disease and related disorders association (now known as the alzheimer's association, (NINCDS-ADRDA) work group under the auspices of department of health and human services task force on alzheimer's disease. *Neurology, 34*(939), 8.

Miceli, A., Wauthia, E., Kandana Arachchige, K., Lefebvre, L., Ris, L., & Simoes Loureiro, I. (2022). Influence of perceptual strength on conceptual processing : Investigation in aging and in lexical-semantic decisions. *Acta Psychologica* (in revision).

Miceli, A., Wauthia, E., Lefebvre, L., Ris, L., & Simoes Loureiro, I. (2021). Perceptual and interoceptive strength norms for 270 French words. *Frontiers in Psychology, 12*, 2018.

Nebes, R. D. (1989). Semantic memory in Alzheimer's disease. *Psychological Bulletin, 106*(3), 377.

New, B., Brysbaert, M., Veronis, J., & Pallier, C. (2007). The use of film subtitles to estimate word frequencies. *Applied PsychoLinguistics, 28*(4), 661–677.

Pachana, N. A., Byrne, G. J., Siddle, H., Koloski, N., Harley, E., & Arnold, E. (2007). Development and validation of the geriatric anxiety inventory. *International Psychogeriatrics, 19*(1), 103–114.

Paivio, A., Yuille, J. C., & Madigan, S. A. (1968). Concreteness, imagery, and meaningfulness values for 925 nouns. *Journal of Experimental Psychology, 76*(1p2), 1.

Peters, F., Majerus, S., De Baerdemaeker, J., Salmon, E., & Collette, F. (2009). Impaired semantic knowledge underlies the reduced verbal short-term storage capacity in Alzheimer's disease. *Neuropsychologia, 47*(14), 3067–3073.

Pexman, P. M. (2012). Meaning-based influences on visual word recognition. *Visual word recognition, 2*, 24–43.

Pexman, P. M., Holyk, G. G., & Monfils, M.-H. (2003). Number-of-features effects and semantic processing. *Memory & Cognition, 31*(6), 842–855.

Pexman, P. M., Lupker, S. J., & Hino, Y. (2002). The impact of feedback semantics in visual word recognition: Number-of-features effects in lexical decision and naming tasks. *Psychonomic Bulletin & Review, 9*(3), 542–549.

Pexman, P. M., Siakaluk, P. D., & Yap, M. J. (2014). *Meaning in mind: Semantic richness effects in language processing*. Frontiers E-books.

Plaut, D. C. (1997). Structure and function in the lexical system: Insights from distributed models of word reading and lexical decision. *Language & Cognitive Processes, 12*(5–6), 765–806.

Rodríguez-Ferreiro, J., Davies, R., González-Nosti, M., Barbón, A., & Cuetos, F. (2009). Name agreement, frequency and age of acquisition, but not grammatical class, affect object and action naming in Spanish speaking participants with Alzheimer's disease. *Journal of Neurolinguistics, 22*(1), 37–54.

Rogers, S. L., & Friedman, R. B. (2008). The underlying mechanisms of semantic memory loss in Alzheimer's disease and semantic dementia. *Neuropsychologia, 46*(1), 12–21.

Salehi, M., Reisi, M., & Ghasisin, L. (2017). Lexical retrieval or semantic knowledge which one causes naming errors in patients with mild and moderate alzheimer's disease. *Dementia and Geriatric Cognitive Disorders Extra, 7*(3), 419–429.

Shulman, H. G., & Davidson, T. C. (1977). Control properties of semantic coding in a lexical decision task. *Journal of Verbal Learning and Verbal Behavior, 16*(1), 91–98.

Siakaluk, P. D., Pexman, P. M., Aguilera, L., Owen, W. J., & Sears, C. R. (2008). Evidence for the activation of sensorimotor information during visual word recognition: The body–object interaction effect. *Cognition, 106*(1), 433–443.

Siakaluk, P. D., Pexman, P. M., Sears, C. R., Wilson, K., Locheed, K., & Owen, W. J. (2008). The benefits of sensorimotor knowledge: Body–object interaction facilitates semantic processing. *Cognitive Science, 32*(3), 591–605.

Silagi, M. L., Bertolucci, P. H. F., & Ortiz, K. Z. (2015). Naming ability in patients with mild to moderate alzheimer's disease: What changes occur with the evolution of the disease? *Clinics, 70*, 423–428.

Silveri, M. C., Cappa, A., Mariotti, P., & Puopolo, M. (2002). Naming in patients with Alzheimer's disease: Influence of age of acquisition and categorical effects. *Journal of Clinical and Experimental Neuropsychology, 24*(6), 755–764.

Simmons, W. K., Ramjee, V., Beauchamp, M. S., McRae, K., Martin, A., & Barsalou, L. W. (2007). A common neural substrate for perceiving and knowing about color. *Neuropsychologia, 45*(12), 2802–2810.

Singmann, H., Bolker, B., Westfall, J., & Aust, F. (2015). *Package 'afex': Vienna*.

Skelton-Robinson, M., & Jones, S. (1984). Nominal dysphasia and the severity of senile dementia. *The British Journal of Psychiatry, 145*(2), 168–171.

Stanfield, R. A., & Zwaan, R. A. (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychological Science, 12*(2), 153–156.

Team, R. (2015). *RStudio: Integrated development for R*. Boston, MA: RStudio: Inc.

Thompson-Schill, S. L., Gabrieli, J. D., & Fleischman, D. A. (1999). Effects of structural similarity and name frequency on picture naming in Alzheimer's disease. *Journal of the International Neuropsychological Society, 5*(7), 659–667.

Tillotson, S. M., Siakaluk, P. D., & Pexman, P. M. (2008). Body—object interaction ratings for 1,618 monosyllabic nouns. *Behavior Research Methods, 40*(4), 1075–1078.

Toglia, M. P., & Battig, W. F. (1978). *Handbook of semantic word norms*. Lawrence Erlbaum.

Vallet, G. T. (2015). Embodied cognition of aging. *Frontiers in Psychology, 6*, 463.

Wellsby, M., & Pexman, P. M. (2014). Developing embodied cognition: Insights from children's concepts and language processing. *Frontiers in Psychology, 5*, 506.

Westfall, J., Kenny, D. A., & Judd, C. M. (2014). Statistical power and optimal design in experiments in which samples of participants respond to samples of stimuli. *Journal of Experimental Psychology: General, 143*(5), 2020.

Xue, J., Marmolejo-Ramos, F., & Pei, X. (2015). The linguistic context effects on the processing of body–object interaction words: An ERP study on second language learners. *Brain Research, 1613*, 37–48.

Yap, M. J., Balota, D. A., Cortese, M. J., & Watson, J. M. (2006). Single-versus dual-process models of lexical decision performance: Insights from response time distributional analysis. *Journal of Experimental Psychology: Human Perception and Performance, 32*(6), 1324.

Yap, M. J., Pexman, P. M., Wellsby, M., Hargreaves, I. S., & Huff, M. (2012). An abundance of riches: Cross-task comparisons of semantic richness effects in visual word recognition. *Frontiers in Human Neuroscience, 6*, 72.

Yu, Z., Guindani, M., Grieco, S. F., Chen, L., Holmes, T. C., & Xu, X. (2021). Beyond t test and ANOVA: Applications of mixed-effects models for more rigorous statistical analysis in neuroscience research. *Neuron*.