Learning and vulnerability to phonological and semantic interference in normal aging: an experimental study

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Learning and vulnerability to phonological and semantic interference in normal aging: an experimental study

Abstract. This study compares semantic and phonological interference vulnerability across the full range of learning processes. **Method**: 43 controls aged 61–88 underwent a neuropsychological examination, French adaptation of the LASSI-L, and an experimental phonological test, the TIP-A. Paired sample t-tests, factorial ANOVA and hierarchical regressions were conducted, psychometric properties were calculated. **Results:** TIP-A efficiently generated phonological interference between concurrent word lists and was associated with short-term memory, unlike LASSI-L. On LASSI-L, proactive interference was higher than retroactive interference; the opposite pattern was found on TIP-A. Memory performance was better explained by age in the semantic than in the phonological task. Age was not associated with interference vulnerability. Intrusions and false recognition were associated with cognitive functioning regardless of age, particularly in the semantic context. **Conclusion:** To our knowledge, this is the first study to assess phonological and semantic interference using homologous concurrent word list tasks, and not a working memory build-up or DRM paradigm. The pattern obtained illustrates the weak initial memory trace in a phonological context and results are discussed according to depth-of-processing and dual-process theories. Similar paradigms could be studied among various pathologies for a better understanding of generalised interference vulnerability vs. specific semantic or phonological impairment.

Keywords: phonological interference; semantic interference; memory; normal aging; LASSI-L

Introduction

Interference consists of a usually negative influence of the memorisation of a piece of information on the encoding, maintenance or retrieval of another piece of information. It is referred to as proactive interference (PI) when previously learned information interferes with learning new information (deleterious effect of A on B: A → B), and retro- active interference (RI) when new learning interferes with previously learned information, i.e., deleterious effect of

B on A: A → B →A. (Atkins et al., 2011, for classic studies see Keppel, 1968; Postman & Underwood, 1973; Wickens, 1970). Interference is most pronounced, or frequent, when there is a high degree of similarity between the target and interfering elements. This similarity may concern their semantic and/or perceptual proximity (Langevin et al., 2009). Semantic interference occurs when items are conceptually related, while perceptual interference occurs when they share common perceptual features, such as phonological or orthographic ones. Interference leads to impoverished memory performance both quantitatively and qualitatively, through the occurrence of intrusion and false recognition errors.

Dual-process theories of memory (Atkinson & Juola, 1974; Jacoby, 1991; Langevin et al., 2009; McClelland et al., 1995; O'Reilly et al., 1997; Yonelinas, 1994; Yonelinas & Jacoby, 2012) postulate that two qualitatively distinct processes underlie memory judgments, often a more associative/semantic one paired with a more detail- oriented/perceptual one. To explain the aforementioned interference-induced errors, one of these dual-process theories, the activation/monitoring theory (Gallo & Roediger, 2002), assumes that false recognition and intrusion errors result jointly from implicit knowledge activation mechanisms (IAR: Implicit associative response theory) and memory monitoring processes (Gallo & Roediger, 2002; Langevin et al., 2009; Roediger et al., 2001). The IAR theory (Roediger & McDermott, 1995; Underwood, 1965) is based on an associative conception of knowledge in memory as a network made up of more or less strong links between items according to their semantic associations. According to this theory, the presentation of semantically related items diffuses activation within the network, notably the activation of non-presented items. Following these automatic implicit memory processes, the presence of monitoring mechanisms enables control and verification of the accuracy and source of memory traces. Thus, following the implicit activation of multiple items in memory, these monitoring mechanisms (Gallo & Roediger, 2002; Johnson et al., 1993; Johnson & Raye, 1981; Koriat & Goldsmith, 1996; Langevin et al., 2009; Persson et al., 2013) manage interference and enable the selection of the target information and the inhibition of competing representations. These monitoring mechan- isms rely less on associative and more on item-specific characteristics (e.g. perceptual, spatiotemporal, emotional, contextual). Neuroimaging studies as well as various literature reviews have repeatedly reported the involvement of the same brain regions in the resolution of interference in memory, namely the ventrolateral prefrontal cortex (VLPFC; Badre & Wagner, 2007; Hamilton & Martin, 2007; Petrides & Pandya, 2002), more specifically, Brodmann's areas 44, 45, and 47 corresponding respectively to Pars Opercularis, Pars Triangularis, and Pars Orbitalis (Badre & Wagner, 2007; Hamilton & Martin, 2007).

There is growing interest in studying interference vulnerability in aging because it may be an early marker of pathological cognitive changes. Notably, Loewenstein and colleagues have created a semantic interference task, the *Loewenstein Acevedo Scale for Semantic Interference and Learning* (LASSI-L; Curiel et al., 2013a, 2013b), specifically designed to assess vulnerability to semantic interference. Studies using this paradigm have shown great promise. Crocco and colleagues (2014) demonstrated that it was possible to discriminate, with high sensitivity (87.9%) and high specificity (91.5%), individuals at risk for Alzheimer's disease (AD) from older controls with a correct classification rate of 90%, exceeding that of many other available cognitive tests. Furthermore, several of the error and interference subscores comprising the LASSI-L were reported to be highly correlated (r = -.36 to -.78, p < .001) with medial temporal lobe atrophy on MRI, as well as with total and local levels of beta-amyloid deposition, showing that this test is able to detect early cognitive markers of Alzheimer's disease-associated brain pathologies (Curiel et al., 2013a; Loewenstein et al., 2015, 2018a). In a population considered to be aging normally, the test showed a decrease in the release from proactive interference (release from PI effect) in 47% of individuals who would later develop further cognitive impairment, 33% who had subjective cognitive decline (SCD), and only 13% of subjects without SCD (Loewenstein et al., 2016). Despite equivalent performance on traditional memory measures, semantic proactive interference appears to distinguish individuals who do not yet meet the full criteria for MCI (pre-MCI) from older controls and is associated with reduced brain volume in many AD-associated brain regions (Crocco et al., 2018). Analyses of scores such as the percentage of semantic intrusion errors due to proactive interference have also been shown to discriminate individuals aging normally from those with aMCI with high sensitivity and specificity, across diverse cultural populations including Hispanic and African American (Capp et al., 2020).

LASSI-L is a learning paradigm of two competing word lists (A and B) that share common semantic features and generate interference. The advantage of this paradigm is that it is particularly comprehensive, allowing in-depth study of the impact of interference in different forms and at different levels; comparison of free and cued recall, presence of intrusion, effects of proactive and retroactive interference, release from proactive interference as well as the impact of interference on delayed recall. Unlike other verbal learning tasks, in LASSI-L, both word lists are learned twice, which further taxes the source control mechanisms since neither list has a higher frequency (as in RAVLT for example). Moreover, (1) at the beginning of the test, the participant is informed of the 3 semantic categories to which the 15 words belong, thus encouraging active and deep encoding, (2) all the words of the two lists (A and B) belong to the same 3 categories (5 words/category), (3) free and cued recall are compared for each of the two lists, and (4) the testing procedure assesses the ability to benefit from semantic cueing as well as the vulnerability to interference (proactive and retroactive) by controlling for the quality of the initial memory performance (Curiel et al., 2013a). Other studies on interference vulnerability in aging used the AB-AC paradigm. This classic task involves learning two lists of word pairs (often semantically related, such as moon-sky) in which the first word (stimulus word) is the same for both lists, while the second word changes. Among other things, AB-AC studies have demonstrated greater vulnerability to interference (PI & RI) in older adults compared to younger adults (Ebert & Anderson, 2009; Van der Linden et al., 1989) as well as more specific vulnerability to PI in subjects with cognitive impairments beyond normal aging (Ebert & Anderson, 2009; Winocur & Moscovitch, 1983).

However, a shortcoming of the literature on interference in normal and pathological aging, on the LASSI-L for example, is that vulnerability to a type of interference other than semantic is often not assessed. This is problematic, because in these cases, it is impossible to dissociate what is specifically attributable to the type of material (e.g., semantic memory integrity) from what is attributable to a more global vulnerability to interference that may be generalisable to material of a different type (executive mechanisms). Yet, the authors of these studies posit semantic network dysfunction as the main cause of the greater vulnerability to interference. This assumption is furthermore at odds with some theoretical models, including the Representational-Hierarchical model (Wilson et al., 2018), and the findings of several studies (Hamilton & Martin, 2007; Hanseeuw et al., 2010; Harris et al., 2014; Ly et al., 2013; Sommers & Huff, 2003) that conversely assume that a decrease in semantic network functioning may protect against vulnerability to semantic interference, at the expense of other types of interference, such as phonological. According to these studies, if the strength of the semantic links is lessened or disrupted, the interference vulnerability based on the strength of these links could also be weakened. The absence of a non-semantic control condition does not currently allow us to determine whether the populations studied (e.g., TCLa, Alzheimer's) would have been even more, or equally, vulnerable to another type of interference.

Certainly, a few studies on interference or associated errors (intrusions, false recognition) have compared vulnerability to interference by different types of material, including perceptual material such as phonologically related stimuli. Among these studies are those using a classical DRM paradigm (Roediger & McDermott, 1995), which usually involves presenting a list of words semantically related to an unpresented target word. When retention of the list items is evaluated, the recognition rates for the unpresented target words are generally identical to those obtained for the words presented. Thus, this procedure mainly allows for the analysis of false recognition, and traditionally focuses on semantic material (for a review of the literature, see Gallo, 2013). Some studies have adapted this paradigm to compare the effect of phonological material to that of semantic material. Thus, according to the IAR theory presented earlier, activation of a lexical representation produced by the presentation of many phonologically related words should increase the salience of other non-presented items belonging to these same lexical categories, generating phonological interference (Langevin et al., 2009; Sommers & Lewis, 1999; Wilson et al., 2018). This is precisely what Sommers and Lewis (1999) demonstrated by creating a DRM procedure with phonologically related words (e.g., hot, pot, got, etc.) to non-presented keywords (e.g., not). They obtained the same results as in the classical semantic DRM task and observed that errors increased as a function of the level of similarity of the phonological neighbours presented. In subsequent experiments, Sommers and Huff (2003) demonstrated that aging increases vulnerability to phonological interference, an effect that is thought to be mediated by impaired executive inhibition mechanisms. However, DRM studies produce discordant results when comparing semantic and perceptual material, with some reporting greater vulnerability in the semantic than in the perceptual condition with age (Koutstaal et al., 2003), others reporting equivalent deficits in both conditions (Budson et al., 2003; Pidgeon & Morcom, 2014), and still others observing specific vulnerability in the perceptual condition (Ly et al., 2013; Wilson et al., 2018). As addressed by Wilson and colleagues (2018), these discrepancies certainly arise from the variety of task designs (e.g., means of manipulating semantic and perceptual content, stimulus format) and analyses performed (e.g., dependent variable as false recognition rates or discriminability *d*') that prevent clear conclusions from being reached. Furthermore, these studies' protocols and ana- lyses (including those of Wilson et al., 2018) are very complex and not easily transferable to the clinical setting. Moreover, the DRM paradigm mainly allows conclusions to be drawn about recognition processes, to the detriment of all other memory processes observable in a concurrent word list learning test such as the LASSI-L. Finally, other studies have focused on phonological interference, but through paradigms that only allow for observation of working memory build-up and release of interference effects (Atkins et al., 2011; Baddeley et al., 2018; Brown, Peterson & Peterson, 1959; Wickens, 1970, 1973).

To conclude, the results of studies on interference in learning, especially those of more recent ones on vulnerability to semantic interference assessed by the LASSI-L, demonstrate that, at the expense of purely quantitative analysis of memory performance, analysis of interference effects and their consequences (intrusions, false recognition), constitutes a very promising field of research on characterising subtle effects of normal and pathological aging. These studies show the importance of investigating this cognitive phenomenon from all angles. A better characterisation and understanding of this phenomenon will enable more sensitive and accurate identification of pathological processes, as well as the creation of more targeted tools. A first step in this investigation is to determine whether it is possible to create a learning task of two concurrent word lists that would generate non-semantic interference, such as a phonological interference. This task should not be limited to the evaluation of false recognition or to the accumulation of interference in working memory in order to assess the vulnerability to, and impact of, interference across a wider range of memory processes (e.g., immediate recall, learning, proactive interference, release from proactive interference, retroactive interference, difference in interference vulnerability between cued and free recall, delayed recall and recognition). Such an overview will allow us to begin to reconcile the results of studies on interference that used very diverse paradigms (e.g., DRM studies, interference studies on immediate memory, interference in learning studies such as Loewenstein's).

Indeed, the availability of two conditions with different type of material (semantic and phonological) that can mutually act as a control condition for each other would make it possible to distinguish difficulties attributable to a generalised vulnerability to interference from those attributable specifically to the type of material. If successful, administration of these two tasks jointly could eventually help identify and characterise semantic and phonological disorders associated with various pathologies of aging, as well as their respective impacts on learning abilities. Thus, ultimately, this test should be constructed in such a way as to be more easily transferable to the clinical setting (unlike methods employed in more fundamental studies such as the procedure and analysis performed by Wilson et al., 2018). Testing the feasibility and applicability of a new phonological interference paradigm is therefore the main objective of the present study. This test will have to be constructed according to a procedure as similar as possible to a semantic test, to increase the comparability of the results obtained in both conditions. Since it is a complete, unique and promising tool, the LASSI-L procedure was chosen and adapted in

French. Secondly, the experimental induction of phonological interference poses a considerable logistical challenge. It is important to try to restrain semantic processing of the first list before the phonological interference caused by the second list of words comes into play. Indeed, since words are semantic entities per se, a semantic processing of words (their conceptual meaning) when learning the List A would increase the risk of semantic intrusions and errors confounding our results. The TIP-A, the experimental phonological learning and interference task we created, will be introduced in this paper. Furthermore, using the LASSI-L and the TIP-A, we will compare learning and vulnerability to interference in semantic and phonological con- texts in a population of older controls for a wider range of memory processes (e.g., immediate recall, learning, proactive interference, release from proactive interference, retroactive interference, difference in interference vulnerability between cued and free recalls, delayed recall and recognition), which was impossible with less comprehensive paradigms such as DRM or those testing working memory build-up of interference. Finally, since it has been little studied using such a complete paradigm, we would like to characterise the impact of phonological interference on learning and memory performance. We will attempt to identify the individual characteristics associated with performance (age, education, general cognitive functioning, etc.) as well as the influence of the test item characteristics (familiarity, concreteness, phonological similarity) on memorisation and interference. It is expected that phonological interference on the TIP-A will be successfully generated, and semantic interference reduced, by directing participants' attention to phonological features of the stimuli instead of their meaning, and by eliminating any semantic link between items. Considering classical theories of memory such as the level-of-processing theory (Craik & Lockhart, 1972) and the dual-process Fuzzy-trace theory (Brainerd et al., 2001; Brainerd & Reyna, 2002, 2004, 2005; Reyna & Brainerd, 1995; Reyna & Lloyd, 1997), it is also expected that performance will be globally poorer on TIP-A than on LASSI-L. Indeed, according to the first theory, phonological processing (TIP-A) results in a weaker, shallower memory trace while semantic processing results in a deeper, stronger memory trace (LASSI-L). Similarly, according to the second theory, *verbatim* trace (specific perceptual details of an episode, like phonological characteristics) is more difficult to process and less durable than *gist* trace (meaning, semantic characteristics), which is more resistant to forgetting.

Methods

Participants

A total of forty-three participants (N = 43) between the ages of 61 and 88 were included in this study. To participate, they had to have French as their first language. Potential participants were excluded if they had any of the following conditions: (1) meeting criteria for minor or major neurocognitive impairment as defined by the DSM-5, (2) scoring below (< 1.5 standard deviations) what is expected by age and education on the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005), (3) history of neuro- logical disease or metabolic condition that may interfere with current cognitive functioning, (4) history of multiple head injuries, or head injury with loss of consciousness in the past year, (5) history of current untreated psychiatric or mood disorder, (6) drug or alcohol abuse, (7) polypharmacy or general anesthesia in the past 6 months, (8) sensory or motor deficit that may invalidate the assessment. Participants' normal cognitive functioning by age and education level was corroborated by their scores on a battery of standardised neuropsychological tests.

Fifty participants were initially recruited. In total, seven were excluded; five on the basis of cognitive performance significantly below what was expected based on their age and education level, one on the basis of a medical condition influencing assessment, and one because of maternal bilingualism whose second language (English) was sufficiently predominant to influence their performance on verbal tests.

Procedures and measures

The present study is part of a larger research project investigating semantic memory disorders in normal and pathological aging. This project received approval from the Comité d'Éthique de la Recherche Vieillissement-Neuroimagerie (CER-VN) of the Institut Universitaire de Gériatrie de Montréal (CRIUGM) research centre and from the Centre Hospitalier de l'Université de Montréal (CHUM) ethics committee. All participants provided prior written consent. Subjects were recruited by telephone via the IUGM research centre's volunteer bank. The objectives and requirements of the study were explained to potential participants during this call, and a short demographic and medical questionnaire was administered to ensure their eligibility. Two assessment sessions of two hours each were conducted at one- to three-week intervals. They took place at the IUGM research centre or at the participant home. The phonological interference test (TIP-A) and the semantic interference test (LASSI-L), which have a very similar procedure, were administered at different meetings and the order in which these tests were administered was alternated to counter a possible order effect. Financial compensation of $20 per session was offered to participants, for a total of $40.

Interference tests

Loewenstein-Acevedo scales for semantic interference and learning (LASSI-L)

The LASSI-L was used to assess vulnerability to semantic interference. Participants' performance on this test was not used to determine their eligibility or exclusion from the study. The LASSI-L procedure consists of presenting an initial list (List A) of 15 words that refer to a fruit, a musical instrument or an item of clothing (5 words per category). The words are presented individually on cards for 4 s, and the participant must read them aloud. Immediately after the 15 words are read, the subject is asked to recall as many words as possible in 60 s regardless of the order (Free Recall A: FRA). Following this recall, the participant is asked to recall the words according to their category (20 sec./category): "I would like you to tell me again all the words in the list that were fruits" (Cued recall 1A: CRA1). Then, List A is presented again using the same procedure, and a second cue recall is performed (CRA2). A new list of 15 words (List B) belonging to the same semantic categories (fruits, musical instruments, clothes) is then presented in the same way, followed by a free recall (FRB), a cued recall (CRB1), a second presentation of List B, and a second cued recall (CRB2). Without further encoding, the participant is asked to recall as many words from list A as possible (Short-Term Free Recall A: STFA), followed by a recall by category (Short-Term Cued Recall A: STCA). Finally, after a 20- minute break, a delayed free recall (DR) of all words (list A and B) is performed. Correctly recalled words and intrusions are scored across recalls (Crocco et al., 2014).

For the purpose of this study, a French adaptation of the LASSI-L was designed based on the original English version. The following adaptations were made: the item "Coconut" was replaced by another exotic fruit (Kiwi) to avoid including a multi-word item in the list ("*noix de coco*" in French), "Sock" was translated as "*Chaussette*" instead of "*Bas*" (commonly used word in Quebec) to avoid confusion caused by the multiple meanings of the latter word in French (meaning both "down" and "sock"), "Shoe" was translated as "*Soulier*", commonly used in Quebec and less likely to interfere phonologically with the "*Chaussette*" item than "*Chaussure*" (also meaning "shoe"). A literal translation was used for all other words and instructions in the test. In addition, in order to allow for better assessment of the consolidation of information as well as the source memory of the participants, a List A word recognition condition was added at the end of the original test procedure. Participants had to recognise the 15 List A words among 30 distractors belonging either to List B (15 words), to the same semantic categories (8 words), or unrelated to the categories, e.g., television (7 words). As with the initial encoding, the words are presented on cards and participants must read them aloud before identifying whether “yes” or “no” they were part of List A. For a summary of the LASSI-L procedure, refer to Figure 1.

Phonological interference and learning test (TIP-A)

To assess vulnerability to phonological interference, we created an experimental task that resembles the semantic task as closely as possible. The TIP-A is constructed to reproduce the same procedure as the LASSI-L, but with induction of phonological interference rather than semantic interference. The two tasks thus consist of two lists of 15 words, the same instructions, procedures and recall times, material in the same format, and both require management of the interference induced by the competition in memory of two lists of words sharing similar characteristics. The tasks differ mainly in the type of the items used to generate the phonological versus semantic interference.

In developing the TIP-A, different strategies were implemented to increase the probability of induction of phonological processing, and to decrease as much as possible the probability of semantic processing. Often, tasks assessing phonological interference effects use pseudo- words to eliminate the meaning, and thus the semantic aspect. However, this alternative was excluded since it would make the task much too difficult (memorising two lists of 15 pseudowords is almost impossible), and would greatly decrease the comparability of performance on both tasks. Thus, we opted for the use of verbs. It seems to be more difficult to semantically categorise verbs than nouns (Plant et al., 2011), and verbs tend to be organised by grammatical group rather than by semantic group (Vigliocco et al., 2011), which lends itself well to a phonology- based task.

In order to induce phonological interference, Lists A and B consist of words that, rather than belonging to the same semantic categories, share several phonological features. To strictly adhere to the LASSI-L procedure in which participants are informed at the outset that the lists contain words belonging to three different semantic categories, in TIP-A, participants are informed that the verbs are of 3 different categories according to their initial letter (15 verbs, with 5 words beginning with letter C, 5 with letter A, and 5 with letter R). This instruction should also help to draw participants' attention to a phonological rather than a semantic characteristic.

TIP-A items were selected in several steps. First, a list of the verbs most frequently used in French was generated from the Lexique 3.1 database (New et al., 2005). From this list, we determined the possible initial letters to form the 3 categories. The initial letters C, A, and R were chosen because they offered the most phonologically similar verb alternatives to constitute the two lists. For each of the three groups (verbs beginning with C, A, R) we found two phonological neighbours (e.g., *Commencer* [to begin] & *Commander* [to order]) one of which we placed in each of the two lists. This resulted in 3 groups of 5 verbs (beginning with C, A, R) constituting List A that are phonologically similar to the 3 groups of 5 verbs (beginning with C, A, R) constituting List B. The final items constituting the lists were selected according to the best compromise of the following characteristics: (1) familiar verbs (as common, if not more so, than the LASSI-L items in millions of occurrences, according to Lexique 3.1), (2) the phonological neighbours of Lists A and B had to start with the same letter, have the same number of syllables (3 maximum), end with the same phoneme, have the smallest phonological and Levenshtein distance possible (the number of letters that one has to delete, insert or replace to form another word, e.g., Chanter [to sing]/Changer [to change] = distance of 1), (3) the verbs chosen (whether phonological neighbours or not) had to share no obvious semantic link with a verb from the other list as determined by a consensus of the research team that developed the task. Moreover, no semantic association was reported in a small preceding pilot study with 8 subjects. Finally, the TIP-A was con- structed so that there was no statistically significant difference between the average familiarity of the verbs constituting Lists A and B (equivalent total average frequencies in millions of occurrences between the two lists). We coded several characteristics of the selected items (familiarity, concreteness, phonological similarity, recency and primacy) to allow us to investigate whether these characteristics have an impact on memory processes and interference. The TIP-A procedure is exactly the same as the LASSI-L procedure (Figure 1), except that recall is done by phonological rather than semantic cueing. Recognition consists of the 15 target verbs from List A and 30 dis- tractors belonging either to List B (15 verbs), beginning with the target letters (C, A, R) (8 words), or not phonologically related to the target words (7 words).

[Insert Figure 1 here]

The following indices were calculated for each of the two interference tasks:

- FRPI: free recall proactive interference percentage ((FRA-FRB)/FRA) x 100
- CRPI: cued recall proactive interference percentage ((CRA-CRB)/CRA) x 100
- FRRI: free recall retroactive interference percentage ((FRA-STFA)/FRA) x 100
- CRRI: cued recall retroactive interference percentage ((CRA-STCA)/CRA) x 100
- PIE Pro: percentage of intrusions errors related to proactive interference (CRBintru/(CRB + CRBintru)) x 100
- PIE Retro: percentage of intrusions errors related to retroactive interference (STCAintru /(STCA + STCAintru)) x 100
- Total PIE: total percentage of intrusion errors on test (Total intrusions/(Total correct recalls + Total intrusions)) x 100
- Recognition accuracy (%Recognition + (100 - %FalseRecognition))/2

Neuropsychological assessment

Participants' global cognitive functioning was assessed using the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005), and by means of questionnaires and a comprehensive neuropsychological test battery. Among these, the following are of particular interest to the present study: standardised tests to assess attention and executive function (WAIS-III Code, Trail making test A & B, D-KEFS Stroop, the phonological and semantic verbal fluency: P & Animals), short-term and working memory (WAIS-III Digit Span), verbal episodic memory (RAVLT, WMS-III Logical Memory) and semantic memory (Pyramids and Palm trees test, the clock drawing test), as well as logo naming, object characteristics and unique semantic entities tests developed in our laboratory, e.g., famous personalities (POP-40: Benoit et al., 2018), media events (PUB-40: Langlois et al., 2015) and public places (Montembeault et al., 2017).

Statistical analyses

Our data were analysed using the Statistical Package for the Social Sciences (IBM SPSS 27) with an alpha significance level of $p < .05$. Preliminary analyses identified three extreme values (+4 *SD*s), two on LASSI-L scores (CRRI & total PIE) and one on TIP-A (CRPI). A Winsorization was performed on these three scores to retain them while reassigning them to a lesser extreme (3.29 *SD*). All scores on both tests were then normally distributed. Prior to each analysis, statistical and visual inspection was per- formed to ensure compliance with the preliminary assumptions of the ANOVA and the regression model.

Internal consistency was measured by Cronbach's Alpha. Convergent validity, as well as any other correlations, was estimated by the Pearson correlation coefficient (*r*). To compare memory performance on the various indices of the TIP-A and LASSI-L, we performed paired sample *t*-

tests on each of the common scores of the tests. To study the interactions between the test condition and the type of interference, we performed repeated measures factorial ANOVA with the Condition (2 levels: semantic, phonological) as the first within-sub- jects variable, and the Type of interference (2 levels: proactive, retroactive) as the second within-subjects variable, followed by multiple comparisons with Bonferroni correction. To estimate the respective impact of age and global cognitive functioning (MoCA) on performance, hierarchical regressions were performed on each of the TIP-A and LASSI-L scores. Finally, correlational analyses were used to determine the association between certain characteristics of the TIP-A items (familiarity, recency, primacy, concreteness, etc.), the number of recalls, and the errors (e.g., number of intrusion and false recognition errors).

Results

Demographic Characteristics

The participants (n = 43) were between 61 and 88 years old (M = 75.8, SD = 7.02), with between 10 and 20 years of education (M = 14.3, SD = 2.70). The sample consisted of 30 women and 13 men, and in terms of overall cognitive functioning, mean score on the MoCA was 27.35/30 (SD = 2.06, range 23-30).

Psychometric properties

The internal consistency of the memory indices of the French version of the LASSI-L was α = 0.887 and that of the TIP-A was α = 0.866, it was α = 0.936 for the proactive interference indices of the LASSI-L and α = 0.887 for those of the TIP-A, then α = 0.876 for the retroactive interference indices of the LASSI-L and α = 0.902 for the TIP-A. Convergent validity between the TIP-A and LASSI-L was $r = .368$ ($p < .01$) for free recall from List A, $r = .556$ ($p < .001$) for free recall from List B, $r = .551$ ($p < .001$) for delayed recall, and $r = .692$ ($p < .001$) for total percentage of intrusions that occurred on test. Convergent validity between the TIP-A, RAVLT, and Logical Memory (WMS-III) ranged from $r = .317$ ($p < .01$) to r = .407 ($p < .001$) for immediate recalls A, from $r = .361$ ($p < .01$) to $r = .515$ ($p < .001$) for immediate recalls B, and from $r = .510$ ($p < .001$) to $r = .519$ ($p < .001$) for delayed recalls.

Correlations between TIP-A, LASSI-L and other cognitive tests

Concerning episodic memory, both tests were similarly correlated with the RAVLT, with correlations ranging from $r = .330$ ($p < .05$) to $r = .648$ ($p < .001$) for the LASSI- L, and from $r = .316$ ($p < .05$) to $r = .548$ ($p < .001$) for the TIP-A. Furthermore, the LASSI-L and TIP-A were generally correlated with the same scores, and both were uncorrelated with recall 1 (first learning trial) and recall B (recall of the interference list) of the RAVLT. The two tests were also similarly correlated with Logical Memory, with correlations between $r = .310$ ($p < .05$) and $r = .631$ ($p < .001$) for the LASSI-L, and between $r = .302$ ($p < .05$) and $r = .540$ ($p < .001$) for the TIP-A.

For short-term memory, only the TIP-A correlated with the forward digit span scores, with correlations of $r = .398$ ($p < .01$) between free recall A and the longest digit span, and $r = .468$ ($p < .01$) between free recall A and the total digit span forward score. As for the LASSI-L, the correlations between its free recall A and the longest digit span forward were r = .282, ns., and r = .260, ns. for the total forward score. Thus, performance on the TIP-A was more strongly associated with indices of short-term memory than was performance on the LASSI-L. On the executive level, the correlations obtained between the LASSI-L, the TIP-A, and tests assessing executive functions were similar and weak overall. Notably, however, phonological verbal fluency (generating the most words beginning with the letter P in one minute) correlated with free recall on the TIP-A, $r = .313$ ($p < .05$), but not on the LASSI-L, $r = 249$, ns. Semantic verbal fluency (generating words belonging to a category) was highly correlated with all LASSI-L recalls (free and cued recalls of A and B, short- term recalls, delayed recall), ranging from r = .430 ($p < .005$) to $r = .633$ ($p < .001$), and more moderately correlated with the TIP-A, i.e., only on free and cued recall A and delayed recall, r = .352 ($p < .05$) to r = .439 ($p < .005$). For the other semantic tests, there were some scattered mild to moderate correlations between LASSI-L performance and semantic tasks (naming faces and logos, associative gnosias, knowledge about public events and places) in the range of r = .305 ($p < .05$) to r = .431 ($p < .005$), whereas these tests were globally uncorrelated with TIP-A.

Analyses of TIP-A recalls and intrusions

Descriptive analyses were performed to characterise the pattern of errors made on the TIP-A and thus ensure that it served its purpose of generating primarily phonological interference, limiting the likelihood of semantic errors and interference. A total of 363 intrusion errors occurred. Of these, 95 were considered ambiguous (often similar to telescoping, which is merging parts of presented words into one unpresented word, and these resulting words were not semantically related to the targets). Of the remaining 268 errors, 167 (62.3%) were inversion errors of items from the two lists (source memory), 89 (33.2%) were phonological intrusions, and only 12 (4.5%) were semantic intrusions (words sharing a semantic link with one of the learned targets). Of the 89 phonological intrusions, 23 (25.8%) consisted of saying a List B item before being exposed to it (saying a phonological neighbour of an A-list item), 23 (25.8%) were modifications of targets by adding an *R-, Re-, Ra-* (e.g., "*recourir*" [to appeal] rather than "*courir*" [to run]), and 43 (48.3%) were words not presented in the test but phonologically related to targets (e.g., "*rapporter*" [to report] rather than "remporter" [to win]). For the LASSI-L, a total of 285 intrusion errors occurred. Of these, 231 (81.1%) were inversion errors of items from the two lists (source memory), 51 (17.9%) were semantic intrusions, and only 3 (1%) might be considered phonological errors (the same error made by 3 different participants; "*chaussure*" [shoe] which might be a phonological intrusion of the target item "*chaussette*" [socks]) but could also be a semantic intrusion of the target item "soulier" [shoe], a synonym of "chaussure".

To determine the item characteristics associated with false recognition, correlational analyses were performed with average word frequency in the French language (in millions of occurrences), concreteness, recency and primacy in the list, and phonological similarity (Levenshtein or phoneme distance). The results show that occurrences of false recognition of List B items as belonging to List A were correlated with their average frequency in the French language (r = .659, p < .01). False recognitions of non-presented items were negatively correlated with Levenshtein distance (r = -.892, p < .001) phonological distance (r = -.877, p < .001) and concreteness (r = -.666, p < .01).

Performance analysis

Order effect

Paired samples t-tests were performed on the set of LASSI- L and TIP-A scores, comparing the subgroup of participants who had order 1 (LASSI-L in session 1, TIP-A in session 2) and order 2 (conversely). No significant differences were observed.

Memory performance

To ensure equivalence between our French adaptation of the LASSI-L and the original English version, we performed independent-samples t-tests between our data and those of a sample similar in size and demographics that per- formed the original test (Crocco et al., 2014). These data are presented in Table 1. The results show no significant difference between the results obtained in the present French adaptation and those obtained in the original English version.

[Insert Table1 here]

The mean number of words recalled and standard deviations for each trial of the LASSI-L and TIP-A are shown in Figure 2. T-tests (42 df) show a significant difference ($p < .001$) in performance between LASSI-L and TIP-A for all recall indices, with lower performance at TIP-A: FRA ($t = 12.58$), CR1A ($t = 16.76$), CR2A ($t = 23.43$), FRB ($t = 9.71$), CR1B ($t = 9.97$), CR2B ($t = 16.51$), STFA ($t = 10.58$), STCA ($t = 15.21$), DR ($t = 17.83$). These results confirm the significant effect of condition on memory performance, learning words in the phonological condition being more difficult than learning words in the semantic condition.

Regarding the recognition of List A words, the results show a significant difference in recognition accuracy (%) between LASSI-L ($M = 78.48$, $SD = 10.73$) and TIP-A ($M = 66.63$, $SD = 9.24$), $t(42) = 7.12$, $p < .001$. On the other hand, no significant difference was observed in the total percentage of false recognition, LASSI-L ($M = 21.63$, $SD = 12.92$) TIP-A ($M = 23.95$, $SD = 14.05$), $t(42) = -1.16$, $p = .252$, or, more specifically, in the number of occurrences of false recognition of List B, LASSI-L ($M = 4.98$, $SD = 2.15$) TIP-A ($M = 5.60$, $SD = 2.90$), $t(42) = -1.28$, $p = .208$, of words belonging to the same categories (semantic or phonological) as the targets, LASSI-L ($M = 1.16$, $SD = 1.52$) TIP-A ($M = 1.32$, $SD = 1.55$), $t(42) = -0.82$, $p = .413$, or of words unrelated to the targets, LASSI-L ($M = 0.33$, $SD = 1.49$) TIP-A ($M = 0.26$, $SD = 1.14$), $t(42) = 0.553$, $p = .583$.

[Insert Figure 2 here]

Interference and intrusions

The percentages of proactive, retroactive, and mean interference on the LASSI-L and TIP-A are presented in Figure 3. The results of the repeated measures factorial ANOVA performed to observe the interaction between the condition (phonological or semantic) and the type of interference (mean proactive interference and mean retroactive interference of free and cued recall) revealed a main effect of Type of interference, F (1, 42) = 19. 11, $p < .001$, $\eta^2 = 0.313$, as well as a significant interaction effect between the Condition and the Type of interference, F (1, 42) = 28.55, $p < .001$, $\eta^2 = 0.405$, but no main effect of Condition, F (1, 42) = 1.63, ns. Multiple comparisons with Bonferonni correction revealed a significant difference between the percentage of proactive and retroactive interference on TIP-A, with the latter being greater (p < .001, η^2 = 0.419), but no significant difference between the two types of interference is observed at LASSI-L (p = .814, ns.). The results also revealed a significantly higher percentage of proactive interference on LASSI-L than on TIP-A (p < .01, η^2 = 0.184) and, conversely, a significantly higher percentage of retroactive interference on TIP-A than on LASSI-L (p < .001, η^2 = 0.376).

Regarding the percentages of intrusion errors (PIE), the results show a proactive PIE significantly higher on TIP-A (*M* = 19.58, *SD* = 20.17) than on LASSI-L (*M* = 10.72, *SD* = 11.35), t (42) = −3.29, p < . 01, and similar to the retroactive PIE, LASSI-L (*M* = 23.41, *SD* = 14.78) TIP-A (*M* = 40.30, *SD* = 30.65), t (42) = −3.51, p = .001, and the total PIE, LASSI-L (*M* = 6.94, *SD* = 4.38) TIP-A (*M* = 17.63, *SD* = 9.77), t (42) = −9.42, $p < .001$.

[Insert Figure 3 here]

Performance and individual characteristics

Education and gender were not significantly correlated with performance on the LASSI-L and TIP-A. Although our sample consisted only of older controls, analyses were conducted to see if an effect of age and overall cognitive functioning on performance could be observed. The presence of acceptable variance in age and global cognitive functioning, as assessed by the MoCA, allowed us to analyse this effect. The correlations between age, global cognitive functioning (MoCA), and performance are presented in Table 2.

[Insert Table 2 here]

Since education and gender did not correlate significantly with performance, these variables were not included in the regression equations. The complete data from the regression analyses for the memory scores are presented in Table 3 and in Table 4 for the interference, intrusion, and false recognition indices. In summary, on memory (10 scores in total), on LASSI-L, the final models (significant for 8 scores) explained between 18.6% and 38% of the variance, including age (ΔR^2 = .126 to .203, for 7 scores) and MoCA (ΔR^2 = .134 to .211, for 5 scores). For TIP-A, the final models (significant for 5 scores) explained between 9.9% and 27.3% of the variance, including age (ΔR^2 = .101 to .133, for 2 scores) and MoCA (ΔR^2 = .093 to .236, for 5 scores). Regarding the interference, intrusion, and false recognition indices (9 indices in total), on the LASSI-L, age explained no significant percentage of the variance, whereas the MoCA explained between 11.8% and 16.8% of the variance on 4 indices [A-B intrusions, PIE pro, PIE retro, and total PIE]. On the TIP-A, age also explained no significant percentage of the variance, whereas the MoCA explained between 11.6% and 21.5% of the variance on 3 indices [CRPI, PIE Retro, A-B False Recognitions].

[Insert Tables 3 and 4 here]

Discussion

The main objective of the present study was to compare learning and vulnerability to semantic and phonological interference in normal aging across the full range of learning processes. To do so, it was first necessary to determine whether it was possible to create a learning task of two concurrent word lists that would generate phonological rather than semantic interference. Such a phonological task would ensure the availability of two condition with different type of material that could mutually act as a control condition for each other, and thus allow dis- sociation of difficulties attributable to a generalised interference vulnerability from those attributable specifically to the type of material used (semantic, phonological). If successful, this paradigm could eventually be administered to various clinical populations. To the best of our knowledge, this is the first study to assess phonological interference in learning using the same type of procedure as those commonly used to study semantic interference (Crocco et al., 2014; Kareken et al., 1996; Loewenstein et al., 2015; Loewenstein et al., 2016; Lohnas et al., 2015; Sánchez et al., 2017; Williams et al., 2020). Indeed, a large majority of studies that have investigated phonological interference have been conducted through tasks focused either on working memory build-up of phonological interference (Baddeley et al., 2018; Karlsen et al., 2007; Lian et al., 2004), or on the study of false recognition, for example in a phonological version of DRM paradigm (Ballou & Sommers, 2008; Wilson et al., 2018).

First, our results confirm that it is possible to induce phonology-based encoding and interference in a learning task of two competing word lists, even though the selected items (verbs) are inherently semantic entities (have meaning, as opposed to pseudowords). In particular, qualitative analysis of the errors made on TIP-A reveals that this task has very successfully fulfilled its function of eliminating the encoding and probability of semantic interference as much as possible, in favour of a phonological encoding and interference. Indeed, if the information learned in TIP-A was encoded on a semantic basis (e.g., the meaning of verbs), it would be expected that the errors made would be mostly associated with their meaning rather than their sound (e.g., say walk or jog rather than *run*). As presented in our results, this was not the case, with a much higher proportion of phonological errors, 33.2% (excluding telescoping and list inversion errors, which together accounted for 62.3%), compared to 4.5% semantic errors. These errors consisted in the pro- duction of phonological neighbours of the targets (some- times List B items even before being exposed to them), or phonological variations by adding a phoneme (e.g., *recourir* [to resort to] instead of *courir* [run]). Our results are consistent with previous studies that have shown that the context and instructions used may favour encod- ing based on phonological features of words at the expense of their meaning (Chan et al., 2005; Ciccone & Brelsford, 1975). Such induced phonological processing is consistent with both hierarchical theories, such as level- of-processing theory (Craik & Lockhart, 1972), and theories that suggest independent and parallel streams of verbatim (phonological) and gist (semantic) representations, such as the Fuzzy-trace theory (Brainerd et al., 2001; Brainerd & Reyna, 2002; Brainerd & Reyna, 2004, 2005; Reyna & Brai- nerd, 1995). According to the first theory, the results suggest that processing was maintained at the superficial level of phonological processing without reaching the deeper levels of semantic processing (serial model). According to the second theory, for the same item, the brain stored separate verbatim (phonological) and gist (semantic) records of experience simultaneously, and it is the construction of the test, the storing and retrieval cues, that favours the processing and retrieval of the ver- batim trace, although parallel storage of the gist (semantic aspect) occurs simultaneously. However, some of the results obtained might favour the second theoretical hypothesis. Indeed, 4.5% of semantic errors were made in the phonological task, whereas no frank phonological errors were made in the semantic task. According to hier- archical/serial theories, phonological processing precedes semantic processing, so it would be normal to observe a few phonological errors in the semantic task, and it is more difficult to explain that semantic errors were made in the phonological task if processing was kept to a more superficial level. According to the Fuzzy-trace theory, both types of processing are performed simultaneously, or the semantic processing (gist) would be even faster than the phonological one (verbatim) (Ahmad et al., 2017; Brainerd & Reyna, 2004; Draine & Greenwald, 1998; Greene & Naveh-Benjamin, 2022). This could explain the occurrence of semantic errors in the phonological task and the absence of the reverse. Finally, not only did the created task serve its purpose, but it also has more than satisfactory psychometric properties. The TIP-A has excellent internal consistency and adequate convergent validity (overall moderate) with the LASSI-L and other episodic memory tests. Indeed, considering the different type of material at this task (phonological), a higher convergence would not be expected.

When comparing the two tasks (TIP-A and the French adaptation of the LASSI-L), we find that, as expected, they are both similarly correlated with episodic memory tasks (moderate to strong associations overall). The LASSI-L is slightly more strongly associated with the episodic memory tasks than the TIP-A, which may be due to the semantic nature that this task shares with the conventional memory task (e.g., the possibility of forming a story or associations to facilitate memorising the material), which allows participants to perform better than on the TIP-A, where the "semantization" of the material has been voluntarily limited. In this regard, we observed a moderate association between free recall on the TIP-A and participants' short-term memory abilities (forward span), an association that was not present with the LASSI-L. These results suggest that learning in a phonological context mobilises short-term memory abilities more than learning in a semantic context. These results support the Levels of Processing theory (Craik & Lockhart, 1972), particularly with respect to the difference between *maintenance rehearsal* (dependent on the articulatory loop in Baddeley's model, see Baddeley (2012) for a comprehensive summary) and *elaboration rehearsal* (dependent on the episodic buffer in Baddeley's model). The latter involves processing stimuli more deeply by performing elaborated processing on them so that the memory trace is reinforced (e.g., creating a story for oneself), whereas the former involves maintaining stimuli at the same level of processing by simply paying uninterrupted attention to them (e.g., mentally repeating the information to oneself) (Giboin, 1979). The short-term memory test (digit span) assesses the capacity of the articulatory loop. The fact that performance on the TIP-A was associated with it suggests that participants relied more on this maintenance rehearsal process than they did on the LASSI-L, since semantic elaboration was deliberately hindered by orienting participants' attention to phonological features of the stimuli instead of their meaning, and by eliminating any semantic link between items. These results are also compatible with the idea that encoding the verbatim traces of an item (specific phonological and orthographic characteristics) is more resource-demanding and slower than encoding the gist of an item (its meaning, semantic association), which is done quickly and effortlessly (Fuzzy-trace theory, Brainerd & Reyna, 2001, 2004; Draine & Greenwald, 1998). Phonological processing should therefore be more dependent on short-term and working memory, and take place over a longer period, than semantic processing, which is rapidly carried out and encoded in episodic memory. Second, at the executive level, while we expected both the LASSI-L and the TIP-A to be correlated with executive tasks (given the involvement of interference management abilities), our results were rather equivocal. The few associations observed between the LASSI-L, the TIP-A and the executive tasks could be due to the choice of tasks. We would certainly have obtained better associations with tests specifically targeting interference management abilities in the context of information retention. However, both tasks are associated with verbal fluency. These associations can be explained by the fact that they all require items to be generated in a limited amount of time (efficient access and retrieval) according to a search by semantic or phonological criteria. The stronger correlations between the LASSI-L and categorical verbal fluency, and the association between phonological verbal fluency and free recall on the TIP-A (and not the LASSI-L), illustrate their respective natures. Finally, as expected, the LASSI-L is more strongly, and more frequently, associated with semantic tasks than the TIP-A. It should be noted, however, that these correlations are modest and non-systematic, since the LASSI-L and the other semantic tasks administered (e.g., naming logos, knowledge about public figures) are quite different.

Memory performance and interference vulnerability in semantic and phonological contexts

The creation of this phonological task, following the procedure of the semantic task as closely as possible, allowed us to isolate the impact of the type of material on learning abilities and vulnerability to interference.

First, concerning learning (recall performance), our results mainly show that word memorisation is much more difficult in a phonological context (TIP-A) than in a semantic one (LASSI-L). Indeed, despite identical procedures, we observed drastically different performance: overall, 50% lower in a phonological context than in a semantic one during recall. These results were expected, although the effect was larger than anticipated, and are consistent with the depth-of-processing theory (Craik & Lockhart, 1972), which holds that information can be encoded along a continuum of hierarchical levels of processing, from superficial (based on structural and sensory features, e.g., phonological) to deeper and semantic. According to this theory, semantic encoding would promote a stronger and more durable memory trace, and therefore better performance. These results also show that the semantic aspect has been effectively reduced in the TIP-A, resulting in more superficial, more fragile memory traces, and therefore increased difficulty in memorising and retrieving the material. On this point, recognition accuracy was 12% lower in a phonological context than in a semantic one, the improvement in recognition performance, and then smaller phonological-semantic discrepancy, in recognition than in free recall suggest that the difficulties experienced in a phonological context are not only attributable to more superficial encoding, but also to increased difficulty in retrieving the information. Finally, no significant difference was observed regarding false recognition in phonological versus semantic contexts. Furthermore, in the TIP-A, a qualitative analysis of false recognition reveals that the more familiar an item from List B was (more frequent in the French language) the more likely it was to be falsely recognised as belonging to List A, which was not the case with a familiar verb that had never been presented. This suggests that false recognition of List B items may be associated with a double sense of familiarity, (1) the item was actually presented during the test, and (2) it is a familiar verb in the French language. Favouring the use of familiar items in an interference list may therefore be an optimal choice for tapping into source memory. Concerning the false recognition of unpresented items, our results suggest that the more phonologically similar a verb is to one of those presented, and the more concrete it is, the more likely it is to be falsely recognised. These results are consistent with previous studies on phonological DRM procedures (Ballou & Sommers, 2008; Sommers & Lewis, 1999; Watson et al., 2001; Watson et al., 2003) and support the idea of a phonological equivalent to the IAR (Implicit associative response theory), in which the activation of a lexical representation produced by repeated exposure to certain phonological features during the test may increase the salience of other non-presented items belonging to these same lexical categories, favouring false recognition. Regarding vulnerability to interference, our results do not show a significant difference in the average percentage of interference in phonological and semantic con- texts, but rather an opposite profile of interference according to the condition. Indeed, our results show a significant interaction between the condition (phonological or semantic) and the type of interference (proactive or retroactive). More specifically, we observed a significantly higher percentage of proactive interference in a semantic context than in a phonological one, and, conversely, a significantly higher percentage of retroactive interference in a phonological context than in a semantic one. Moreover, no difference was observed between the percentage of proactive and retroactive interference in a semantic context, whereas in a phonological one, we observed a significantly higher percentage of retroactive interference than that of proactive interference. To our knowledge, this is the first study to show a different pattern of interference (proactive vs. retroactive) depending on the type of material (phonological interference having been mainly studied by short-term build-up of interference and false recognition protocols). In accordance with the results presented previously, it is likely that, since the memory trace of phonological learning is weaker and more fragile than that of semantic learning, it interferes less strongly with subsequent learning (generating a lower proactive interference in a phonological context), and consequently, it would also be more difficult to recover after new learning (higher retroactive interference in phonological context). These results are in line with previous studies and theories suggesting that specific perceptual aspects of an episode are weaker and quickly forgotten (Craik & Lockhart, 1972; third principle of Fuzzy-trace theory concerning differential survival rate for verbatim and gist traces, Brainerd & Reyna, 2004; Sachs, 1967). The greater proactive interference in a semantic context may also be explained by the fact that the task encourages encoding of the meaning of items (e.g., semantic category belonging, gist) and the source of the interference introduced by the second list is precisely at the level of common semantics. Thus, to resolve the interference and recall the correct items, one would have to rely on the specific verbatim trace of the items, which is favoured in the phonological task but not in the semantic one, generating more interference in the second condition. Finally, concerning intrusion errors that occurred in both tasks, our results showed significantly higher percentages of intrusion errors in a phonological context than in a semantic one, which could be due to: (1) the fragility of memory traces in a phonological context, which makes intrusion more frequent due to target approximation (less distinctiveness, considering the more superficial treatment), and (2) a larger pool of possible items for the phonological task than for the semantic one (e.g., a larger pool of verbs sharing the same phonological characteristics as targets than is the case for musical instruments).

Influence of individual characteristics on performance in semantic and phonological contexts

Our results show no impact of gender or education on memory performance and vulnerability to interference on either task. These results diverge from those reported by Matias-Guiu et al. (2017), who reported an impact of education on raw recall scores of the LASSI-L. This divergence could be explained by the fact that our sample is much more highly educated, with less variability in the number of years of education completed.

In terms of memory, our regression analyses suggest a significant impact of age on recall performance in semantic contexts (explained on average 16.1% of performance on 7 of the 10 scores), whereas performance in phonological contexts is very little influenced by age (on average 11.7% on only 2 of the 10 scores). Global cognitive functioning has relatively the same impact on performance regardless of the condition: 15.4% in semantic and 12.4% in phonological on 5 of the 10 scores for each. More specifically, these results suggest that the older we are, the worse our recall performance in semantic but not in phonological contexts, whereas poorer cognitive functioning influences recall performance in a similar way regard- less of the type of material. It is expected that memory performance decreases with age. Moreover, these associations between age and memory performance on the LASSI-L are comparable to those observed in a previous study (Matias-Guiu et al., 2017), although somewhat weaker, which could be explained by our smaller sample size. Consistent with the results presented above, it is possible that in phonological contexts, the impact of age on recall is less because, at the time of encoding, performance is more limited by short-term memory capacities than it is in semantic contexts. Several studies have shown that short-term memory ability, which is the acquisition of information requiring very little processing except retention, vary little in normal aging (Choi et al., 2014; Kumar & Priyadarshi, 2013; Ryan et al., 1996; Wingfield et al., 1988; Woods et al., 2011), hence less variability in performance that might be associated with age. Our results are therefore consistent with studies that have shown that the impact of aging on memory performance increases as a function of the level of manipulation or possible elaboration of the material presented (Belleville et al., 1998; Bopp & Verhaeghen, 2005; Wingfield et al., 1988), therefore a greater impact of age in the semantic than in the phono- logical condition.

Regarding the vulnerability to interference assessed by the percentage of interference on trials as well as by the number of intrusions and false recognition errors, our results suggest no impact of age regardless of the condition (semantic or phonological). These results are consistent with those of Matias-Guiu and colleagues (2017), who also observed an impact of age on memory performance on the Spanish version of the LASSI-L, but not on interference vulnerability scores. Most interestingly, the percentage of intrusion and false recognition errors that occur in recall are instead influenced by overall cognitive functioning regardless of age, and this effect is particularly notable in a semantic context. Indeed, in the semantic context, the total number of intrusions associated with source memory (inversion of the two lists), as well as the percentage of intrusions that occur with proactive interference (recall of List B) are the scores most influenced by cognitive functioning, regardless of age. Similarly, in the phonological context, the number of false recognitions attributable to source memory (List B items recognised as being part of List A), as well as the percentage of intrusions that occur with retroactive interference (short-term recall of List A), are the most influenced by cognitive functioning, regardless of age. It is important to note that these intrusion and source memory errors occur on the trials that generate the most interference according to type of material, i.e., during proactive interference in the semantic context and retroactive interference in the phonological context. These results are very interesting because they suggest that the tendency to intrusions and source memory errors is particularly indicative of poorer overall cognitive efficiency, independently of age, and more markedly in a semantic context. This type of error could there- fore be a valuable marker of poorer cognitive functioning unrelated to age. These results are part of a line of studies (Bondi et al., 1999; Cahn-Weiner et al., 1997; Davis et al., 2002; Libon et al., 2011; Loewenstein et al., 2004; Loewen- stein et al., 2018b; Thomas et al., 2018; Torres et al., 2019) that suggest that analysis of errors made on learning tests is more sensitive in identifying cognitive difficulties than quantitative performance per se (recall rates). Further- more, Thomas and colleagues (2018) demonstrated that intrusive errors made on recall reflect subtle cognitive changes predictive of the later development of mild cognitive impairment, and did so with greater precision than standard neuropsychological scores. Finally, in general, our results showed no impact of age or global cognitive functioning on the percentage of interference (i.e., on the quantitative difference in correct words recalled between lists A and B). It would thus seem that the errors made (intrusion, false recognition) are more eloquent indicators of cognitive efficiency than the percentage of interference, at least in normally aging individuals.

Limitations

With respect to the limitations of the present study, reducing semantic processing of the material in the phonological task as much as possible inevitably made this task more difficult than the semantic one, especially by limiting the amount of encoded information. A slight floor effect was also observed in short-term recall. This aspect may contribute to decreasing the comparability of performance under both conditions. To overcome this problem, we calculated interference as a percentage rather than as an absolute number of words recalled between trials. Future studies aiming to compare phonological and semantic interference effects in learning paradigm should consider various ways of enhancing encoding in phonological con- texts, such as reducing list size and increasing the number of learning trials. Second, the data collected remain pre- liminary, since the task was only administered to a somewhat small sample of individuals aged 61 years and older, which limits the interpretation of certain results, including the impact of age on performance.

Conclusion

To our knowledge, this is the first study to assess phonological interference in a concurrent word list learning task using the same procedure as a semantic homologous test to further explore the impact of the type of material on all learning processes as well as the vulnerability to interference. Among our main results, the study demonstrated that it was possible to induce a phonological interference effect, and thus that this type of interference is not limited to an immediate or working memory build-up effect. or to false recognition as with DRM paradigm. It was consequently possible to show a phonological interference pattern opposite to that observed in a semantic context, with a greater proportion of retroactive than proactive interference. This profile probably illustrates the fragility of the initial memory trace, which interferes less with subsequent learning, but is logically more difficult to recover later. Moreover, our results show a significant association between short-term memory abilities and learning in a phonological context and, as expected, overall weaker memory performance than in a semantic context. Our results also suggest that qualitative aspects of performance, such as the number of intrusions and source memory errors, may be specific markers of poorer cognitive efficiency regardless of age, especially in the semantic context. Despite the aforementioned limitations, the main objective of the present study was to test the feasibility and applicability of a phonological interference paradigm, which ultimately proved promising. Administering a similar phonological task in conjunction with a homologous semantic task to a larger sample of individuals of varying age and education may contribute to learning more about vulnerability to interference in normal and pathological aging. To this end, there is a growing interest in studying vulnerability to semantic interference in pathological aging, as it would be an early marker of cognitive impairment, especially in populations with semantic impairments such as Alzheimer's disease and aMCI. In the future, it may be relevant to administer the present phono-logical and semantic interference comparison paradigm to these clinical populations to better characterise the source of their greater vulnerability to interference. Indeed, using conditions of two different type that can mutually act as a control condition for each other, it would be possible to distinguish a more generalised vulnerability to interference from a vulnerability specifically associated with certain types of material, e.g., a vulnerability to semantic interference in the case of semantic memory impairment. Furthermore, the administration of these two tasks could allow for better identification and characterisation of semantic and phonological disorders associated with various pathologies of aging, as well as their respective impacts on learning abilities. For example, having demonstrated in the present study the significant involvement of short-term memory capacities on learning in a phonological context, we could expect that individuals suffering from logopenic primary progressive aphasia (LPA) would present particular difficulties on the TIP-A, or any future similar task, given the early impairment of the phonological loop in this pathology (Gorno-Tempini et al., 2008).

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Figure Captions

Figure 1: LASSI-L and TIP-A procedure

Figure 2. Memory performance. Mean (SD); FR = free recall; CR = cued recall; STF = short-term free recall; STC = short-term cued recall; DR = delayed recall

Figure 3. Interference performance. Mean (SD); FRPI = free recall proactive interference; CRPI = cued recall proactive interference; PImean = mean proactive interference; FRRI = free recall retroactive interference; CRRI = cued recall retroactive interference; RImean = mean retroactive interference; Imean = mean interference.

Table 1. Data from the French adaptation of the LASSI-L compared to the original data from the English version.

	LASSI-L original[a] (N = 47)	LASSI-L French adaptation (N = 43)	Cohen's d (*p*)
Age	78.0 (4.7)	75.8 (7.02)	0.37 (p=0.08, ns.)
Education	14.0 (3.7)	14.3(2.70)	0.09 (p=0.66, ns.)
Cued recall 1A	11.36 (2.2)	10.88(2.6)	0.20 (p=0.35, ns.)
Cued recall 2A	13.83(1.2)	13.74(1.4)	0.07 (p=0.74, ns.)
Free recall B	7.09(2.5)	7.07(2.2)	0.01 (p=0.97, ns.)
Cued recall 1B	8.09(2.3)	7.44(2.8)	0.25 (p=0.23, ns.)
Cued recall 2B	11.47(2.0)	11.35(2.3)	0.06 (p=0.79, ns.)
Short-term free A	6.53(3.1)	6.44(2.6)	0.03 (p=0.88, ns.)
Short-term cued A	8.57(2.9)	8.32(2.3)	0.10 (p=0.65, ns.)

a. Data from Crocco et al., 2014.

ns. = not significant

Table 2. Performance correlations (r) with age and MoCA

	AGE		MoCA	
	LASSI-L	TIP-A	LASSI-L	TIP-A
FRA	-.266	-.076	.432**	.314*
CR1A	-.357*	-.149	.477**	.337*
CR2A	-.261	-.118	.138	.341*
FRB	-.431**	-.365*	.372*	.472**
CR1B	-.291	-.189	.369*	.001
CR2B	-.391**	-.081	.486**	.105
STFA	-.406**	-.018	.481**	.261
STCA	-.411**	-.067	.568**	.156
DR	-.450**	-.318*	.219	.400**
REC.ac	-.354*	-.221	.118	.351*
%FR	.192	.144	.020	-.341*
FRPI (%)	.158	.270	.048	-.220
CRPI	.092	.058	-.138	.310*
FRRI	.188	-.120	-.189	-.171
CRRI	.039	-.101	-.187	.147
PEI.pro	.082	.167	-.395**	-.110
PEI.retro	.251	.028	-.421**	-.331*
PEI.total	.177	.231	-.382*	-.302*

*$p < .05$
**$p < .01$

Table 3. Regression analyses data for memory scores

	LASSI-L					TIP-A				
Scores	R^2	ΔR^2	ΔF	p	β (effect)	R^2	ΔR^2	ΔF	p	β (effect)
FRA										
Bloc 1: Age	.071	.071	3.11	.085	-.27	.006	.006	0.24	.626	-.076
Bloc 2: MoCA	.204	.134	6.73	**.013**	.39	.099	.093	4.14	**.049**	.32
CR1A										
Bloc 1: Age	.127	.127	5.99	**.019**	-.36	.022	.022	0.94	.339	-.149
Bloc 2: MoCA	.273	.146	8.03	**.007**	-.23	.115	.093	4.20	**.047**	.32
CR2A										
Bloc 1: Age	.068	.068	2.99	.091	-.26	.014	.014	0.57	.452	-.12
Bloc 2: MoCA	.071	.003	0.14	.715	.06	.116	.102	4.64	**.037**	.34
FRB										
Bloc 1: Age	.186	.186	9.35	**.004**	-.43	.133	.133	6.29	**.016**	-.37
Bloc 2: MoCA	.246	.060	3.20	.081	.26	.273	.236	7.69	**.008**	.40
CR1B										
Bloc 1: Age	.085	.085	3.79	.059	-.29	.036	.036	1.51	.226	-.19
Bloc 2: MoCA	.169	.084	4.06	.051	.31	.040	.004	0.18	.673	-.07
CR2B										
Bloc 1: Age	.153	.153	7.38	**.010**	-.39	.007	.007	.271	.606	-.08
Bloc 2: MoCA	.297	.144	8.22	**.007**	.40	.013	.007	.280	.599	.09
STFA										
Bloc 1: Age	.165	.165	8.08	**.007**	-.41	.000	.000	0.01	.907	.02
Bloc 2: MoCA	.301	.136	7.80	**.008**	.39	.080	.079	3.45	.071	.30
STCA										
Bloc 1: Age	.169	.169	8.33	**.006**	-.41	.004	.004	0.19	.670	-.07
Bloc 2: MoCA	.380	.211	13.6	**.001**	.49	.025	.020	0.82	.370	.15
DR										
Bloc 1: Age	.203	.203	10.41	**.002**	-.45	.101	.101	4.62	**.038**	-.32
Bloc 2: MoCA	.208	.006	0.29	.588	.08	.200	.098	4.92	**.032**	.33
REC accuracy										
Bloc 1: Age	.126	.126	5.89	**.020**	-.35	.037	.037	1.57	.218	-.19
Bloc 2: MoCA	.126	.000	.000	.983	.003	.121	.084	3.83	.057	.31

Table 4. Regression analyses data for interference, intrusion and false recognition scores

	LASSI-L					TIP-A				
Scores	R^2	ΔR^2	ΔF	*p*	β (effect)	R^2	ΔR^2	ΔF	*p*	β (effect)
FRPI										
Bloc 1: Age	.025	.025	1.05	.312	.16	.073	.073	3.22	.080	.27
Bloc 2: MoCA	.036	.011	0.45	.505	.11	.093	.020	0.87	.357	-.15
CRPI										
Bloc 1: Age	.009	.009	0.35	.557	.09	.003	.003	0.14	.714	.06
Bloc 2: MoCA	.022	.013	0.54	.467	-.12	.124	.121	5.50	**.024**	.38
FRRI										
Bloc 1: Age	.036	.036	1.51	.226	.19	.014	.014	0.60	.442	-.12
Bloc 2: MoCA	.054	.018	0.77	.386	-.14	.064	.049	2.10	.155	-.23
CRRI										
Bloc 1: Age	.002	.002	0.06	.805	.04	.010	.010	0.42	.520	-.10
Bloc 2: MoCA	.035	.034	1.41	.243	-.20	.025	.015	0.60	.442	.13
PEI Pro										
Bloc 1: Age	.007	.007	0.28	.601	.08	.028	.028	1.17	.285	.17
Bloc 2: MoCA	.158	.152	7.20	**.011**	-.41	.031	.003	0.14	.706	-.06
PEI Retro										
Bloc 1: Age	.063	.063	2.75	.105	.25	.001	.001	0.03	.860	.03
Bloc 2: MoCA	.192	.129	6.40	**.015**	-.38	.117	.116	5.26	**.027**	-.36
PEI Total										
Bloc 1: Age	.031	.031	1.33	.256	.18	.053	.053	2.31	.136	.23
Bloc 2: MoCA	.149	.118	5.55	**.023**	-.36	.111	.058	2.60	.115	-.25
Intrus A-B										
Bloc 1: Age	.009	.009	0.390	.536	.10	.005	.005	0.19	.666	.07
Bloc 2: MoCA	.177	.168	8.15	**.007**	-.43	.044	.039	1.64	.207	-.21
FR A-B										
Bloc 1: Age	.017	.017	0.69	.410	.13	.004	.004	0.16	.690	-.06
Bloc 2: MoCA	.035	.018	0.76	.388	-.14	.219	.215	11.03	**.002**	-.49

Intru A-B = intrusions due to a source memory failure between List A and List B, **FR A-B =** false recognition due to source memory failure between lists A and B

Figure 1

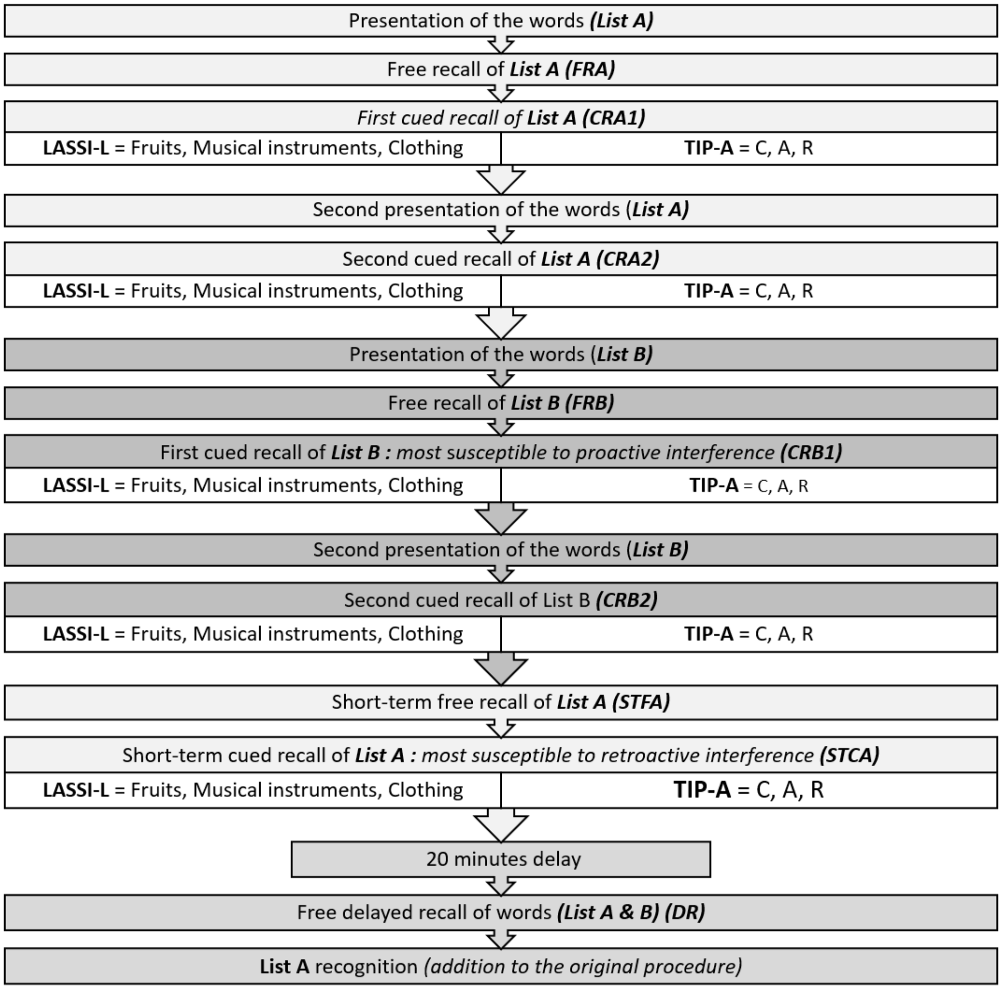
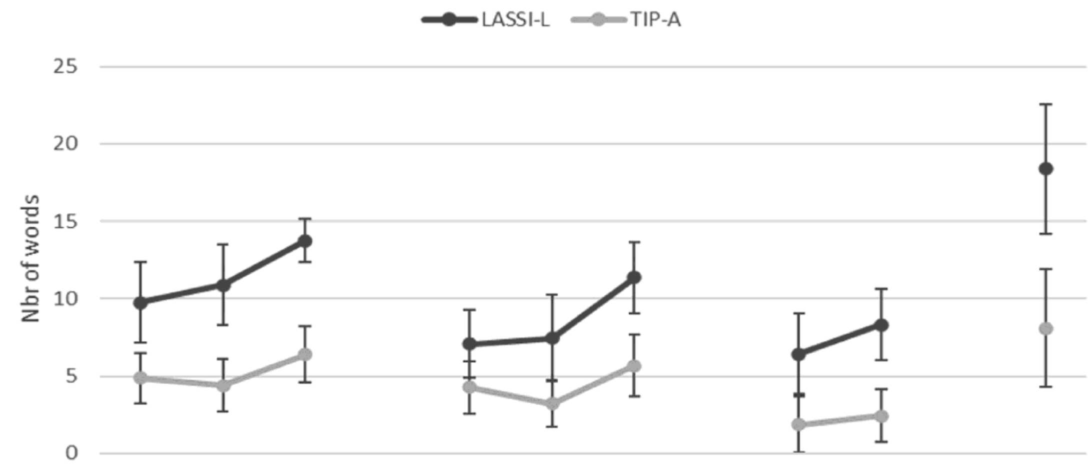


Figure 1. LASSI-L and TIP-A procedure. Adapted from Crocco et al. (2014).

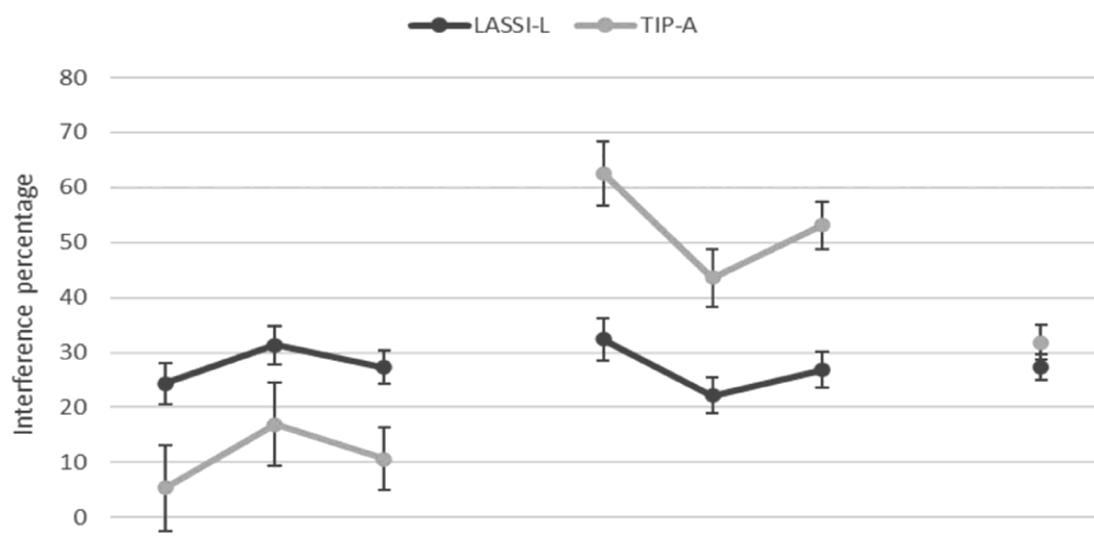
Figure 2



	FRA	CRA1	CRA2		FRB	CRB1	CRB2		STFA	STCA		DR
LASSI-L	9.74(2.6)	10.88(2.6)	13.74(1.4)		7.07(2.2)	7.44(2.8)	11.35(2.3)		6.44(2.6)	8.32(2.3)		18.4(4.2)
TIP-A	4.86(1.6)	4.37(1.7)	6.40(1.8)		4.28(1.7)	3.21(1.5)	5.67(2.0)		1.86(1.8)	2.44(1.7)		8.09(3.8)

Figure 2. Memory performance. Mean (*SD*); Error bars represent *SD*; FR = free recall; CR = cued recall; STF = short-term free recall; STC = short-term cued recall; DR = delayed recall.

Figure 3



	FRPI	CRPI	PImean		FRRI	CRRI	RImean		Imean
LASSI-L	24.33(24.7)	31.3(23.1)	27.31(20.4)		32.35(25.7)	22.12(21.6)	26.8(21.5)		27.31(15.5)
TIP-A	5.35(41.5)	16.86(49.8)	10.63(37.4)		62.59(32.4)	43.58(34.4)	53.09(27.9)		31.86(21.2)

Figure 3. Interference performance. Mean (*SD*); Error bars represent standard error of the mean; FRPI = free recall proactive interference; CRPI = cued recall proactive interference; PImean = mean proactive interference; FRRI = free recall retroactive interference; CRRI = cued recall retroactive interference; RImean = mean retroactive interference; Imean = mean interference.