Types of Errors in a Memory Interference Task in Normal and Abnormal Aging

by

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Abstract

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The types of intrusion errors (Prior List, Semantically Related, and Unrelated) made on the LASSI-L verbal memory task were compared across three diagnostic groups (N = 160, 61 % female), Cognitively Normal (CN), amnestic Mild Cognitive Impairment (aMCI), and Alzheimer's disease (AD). Errors related to Proactive, Recovery from Proactive, and Retroactive Interference were also analyzed, as well as the relationship of errors to Amyloid load, a biomarker of AD. Results suggest that the types of error made indicated the level of cognitive decline. It appears that as deficits increase, impaired semantic networks result in the simultaneous activation of items that are semantically related to LASSI-L words. In the aMCI group, providing a semantic cue resulted in an increased production of Semantically Related intrusions. Unrelated intrusions occurred rarely, although, a small number occurred even in the CN group, warranting further investigation. Amyloid load correlated with all intrusion errors.

Dedication

I would like to express my gratitude to my husband and to my family for their patience, support, and endless love and encouragement.

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Introduction

Alzheimer's disease (AD) is a major neurocognitive disorder in which there is progression of impairment in one or more cognitive domains. The criteria for AD provided by the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association, 2013) includes behavioral and cognitive symptoms such as an impaired ability to learn and recall newly presented information, poor judgement, impaired visuospatial abilities, impaired language functions, and/or changes in personality or behavior. Probable AD dementia (McKhann et al., 2011) can present as amnestic or nonamnestic. The amnestic presentation occurs more often, and deficits are typically seen in learning and recall of new information, although deficits in another domain must be observed as well. The nonamnestic presentation of probable AD dementia is observed by deficits in either language, visuospatial skills, or executive function. There is a stage of transition, known as Mild Cognitive Impairment (MCI) in which memory functions are abnormal compared to normally aging individuals, but are not severe enough to meet the diagnostic criteria of AD. Subjects with MCI are likely to transition to clinically probable AD (Petersen et al., 2001). These individuals have a conversion rate to AD of 12% per year, compared to 1% to 2% observed in healthy control subjects (Petersen et al., 1999). One of the key distinctions between MCI and AD is a relative independence of function in daily life, although certain complex activities that were previously done with ease could become more difficult (Albert et al., 2011). When MCI is present with memory impairment, it is termed amnestic MCI (aMCI), whereas non-amnestic MCI (naMCI) includes impairment in domains other than memory (e.g., language, visuospatial skills). The current research focused on the most common type of MCI: aMCI (Petersen et al., 2001).

Individuals diagnosed with aMCI present with memory complaints which are also confirmed by an informant. Memory impairments are found upon neuropsychological evaluation after adjusting for age and education, although these patients are fairly normal in other cognitive areas (Petersen et al., 2001). It has been reported that MCI individuals with more severe memory deficits may have impairments that meet the criteria for mild dementia but do not meet the threshold for diagnosis (Morris et al., 2001). Therefore, early detection of MCI can be beneficial to the patient, because of the possibility of progressing to dementia. It is imperative that diagnoses are made as early as possible allowing those at risk to begin interventions early on. In addition, some risk factors are reversible (e.g., through exercise and participation in cognitively stimulating activities), and therefore an earlier diagnosis may reduce the risk of progression to dementia (Roberts & Knopman, 2013).

Semantic Interference

One of the features of aMCI appears to be an increased susceptibility to semantic interference effects in memory tasks. Retroactive interference (RI) effects, in which new learning interferes with old learning, and Proactive Interference (PI) effects, when old learning interferes with new learning, are found in subjects with suspected memory deficits (Loewenstein, et al., 2004). Researchers (Crocco, Curiel, Acevedo, Czaja, & Loewenstein, 2014; Borella et al., 2017) have suggested that an increased vulnerability to Proactive Interference (PI) for items related to a target list could aid in the differentiation between cognitively normal individuals from those with mild AD. PI effects have been studied by presenting words over the course of several trials and then evaluating the degree to which previous learning interferes with the learning of new words (Loewenstein et al., 2004). Borella et al. (2017) evaluated individuals using a memory test consisting of two sets of words, allowing for the buildup of PI. They reported that participants with MCI demonstrated the influence of increased PI. During recall, MCI participants recalled fewer correct words, compared to controls. They suggested that an increased demand in tasks with high semantic interference results in greater difficulty in inhibiting irrelevant information (Borella et al., 2017).

Besides using the number of correct items to characterize PI, Borella et al. (2017) also tested resistance to interference using the number of intrusion errors made on the same memory task. Intrusion errors were defined by Fuld (Fuld, Katzman, Davies, & Terry, 1982) as incorrect responses from a previous test or procedure. As expected, Borella et al. (2017) found a higher rate of intrusion errors in the MCI group compared to the controls. They speculate that these errors occurred from the MCI group's inability to inhibit words that were useful earlier on the test, but lost relevance as the task progressed.

Other research has used comparable paradigms to those used by Borella et al. (2017) to evaluate PI. Loewenstein et al. (2004) used the Semantic Interference Test (SIT), with common household objects in two separate bags, which participants had to identify and try to remember. This study found that participants with mild AD tended to show more PI effects, followed by the MCI group, followed by the controls. On the other hand, RI effects were similar for MCI and mild AD patients, although they showed more susceptibility to this interference than the cognitively normal controls. It was therefore concluded that PI may be more severe than RI in this population, and that the level of both effects corresponds to the severity of the disease (Loewenstein et al., 2004). The authors suggest that greater susceptibility to PI also interferes with encoding capabilities and recall. Other research has supported a hindrance in initial encoding as a reason behind increased PI (Rouleau, Imbault, Laframboise, & Bédard, 2001).

Ebert and Anderson (2009) challenged Loewenstein et al.'s (2004) results, as they did not find increased RI effects in aMCI patients relative to controls in a study using the AB-AC task, an interference paradigm in which participants learn two lists of word pairs. The first word of this pair is the same on both lists, while the second word varies. The discrepant results found in the Ebert and Anderson (2009) study could be attributed to numerous factors. First, their sample had not received an MCI diagnosis, whereas the patients in Loewenstein et al. (2004) were individuals diagnosed with MCI or mild AD. Based on this, it is possible that the participants in Ebert and Anderson's (2009) study were at early stages of MCI, and were therefore not as susceptible to interference effects. Secondly, these researchers eliminated group differences in encoding of words by requiring that all participants learn the lists of words with perfect accuracy, ensuring that all words from the first cycle of the AB-AC paradigm were memorized prior to continuing the remaining trials. The sample in the Loewenstein et al. (2004) study did not use this method to control for initial encoding differences across groups. Lastly, while the methodology behind the AB-AC and the SIT (Loewenstein et al., 2004) evaluated the same construct, the methodology behind these two measures is not very comparable, e.g., the AB-AC paradigm involves associated word pairs, whereas the SIT uses stimuli in the form of category exemplars. These differences highlight the need for future investigation.

In addition to PI and RI effects, researchers have described the utility of evaluating an individual's ability to recover from PI (RPI). Crocco et al. (2018) examined this concept in individuals with preMCI and found that this type of semantic interference related to reductions in AD prone brain regions. Normal controls can recover from PI effects significantly better than individuals diagnosed with preMCI or MCI. This suggests that the recovery from PI might be exhibited earlier in abnormal aging than other types of semantic interference. Other results by the same group have also identified RPI as a distinguishing factor between cognitively normal and aMCI elderly adults (Curiel et al., 2013; Crocco et al., 2014), as well as a relationship between deficits in RPI and amyloid load (Loewenstein et al., 2016)

Intrusion errors

Besides analyzing various aspects of inhibition to determine level of decline, another promising analysis comes from examining the qualitative nature of the intrusion errors made during testing paradigms, such as those described above. Research has examined the type of errors made in verbal memory tests, and reported differences across diagnostic groups. Measures that add a distractor trial between recall trials demonstrated that patients with mild AD have an increased susceptibility to intrusion errors, demonstrating an incomplete processing of words, such as remembering words that were not originally presented but belong to the same semantic category (Loewenstein et al., 2004). This suggests that intrusions could be due to a deficit in the inhibition of words that were not presented but which belong to the same semantic category.

Crocco et al. (2014) used the Loewenstein Acevedo Scales of Semantic Interference and Learning (LASSI-L) with a sample of normal elderly, aMCI, and probable AD participants. These researchers reported that most of the intrusion errors were words from the non-target list, followed by semantically related items not found on either word list. Furthermore, they found that aMCI and dementia subjects made more intrusions than controls, and that a greater number of errors occurred on cued recall, and this was attributed to an increased probability of making these errors resulting from the cue provided. The authors speculate that an inability to inhibit semantically related items during retrieval explains the larger number of intrusions made by the aMCI and probable AD individuals. In another study, Loewenstein et al. (1991) reported a greater number of unrelated intrusions in mild AD participants as compared to MCI participants using the FULD Object Memory Evaluation (Fuld, 1980). The authors speculated that the unrelated intrusions reflected difficulties in the realization that the words recalled were unrelated to the target items.

Similarly, Schram, Rubert, and Loewenstein (1995) found that unrelated intrusions were more prevalent during recall trials in mild AD patients as compared to vascular dementia. Rouleau et al. (2001) examined patients with AD, dementia with frontal lobe semiology (FD), and Parkinson’s disease (PD) in attempt to identify a type of intrusion unique to the AD patients. They found that the number of intrusion was not sufficient to differentiate among the three groups. However, their results demonstrated that patients with AD and FD made more unrelated errors than PD patients, and that intrusions from the non-target list were made more often by FD patients as compared to PD and AD. They posit that these errors could signify the inability to inhibit recalling irrelevant information.

Other research has failed to find differences in certain types of errors. Hart, Smith and Swash (1986) used a visual pictorial test and evaluated AD patients. Compared to controls, the AD patients made a greater number of errors, however, they did not find that this higher number of errors was composed of a majority of prior list intrusions.

These contradictory findings emphasize the importance of examining the types of errors made on memory tests to differentiate the underlying cognitive mechanism behind each of the intrusions. More importantly, the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987), which includes two lists belonging to four categories, along with free and cued recall trials, has been used to observe intrusion errors and explore their relationship with progression to AD (Bondi, Salmon, Galasko, Thomas, & Thal, 1999). These researchers found that intrusions on the CVLT were a significant predictor in the risk for conversion to AD. Recently, Thomas et al. (2018), reported that the quantity of intrusion errors on the Rey Auditory Verbal Learning Test (Rey, 1964) predicted progression from cognitively normal to MCI, and progression from cognitive normal to mild AD, even after controlling for demographic characteristics, depression, genetic susceptibility, and other factors. The authors concluded that the cognitive changes that lead to intrusion errors may appear before the deficits that can be observed in the total scores derived from other neuropsychological measures.

Research Aim and Hypotheses

Most studies concerning diagnostic criteria for MCI focus on total scores and number of errors on neuropsychological tests. This research proposes a qualitative analysis of the types of intrusions in a verbal cognitive task in participants presenting with memory complaints compared with normally aging participants, examining whether this analysis will aid in detecting subtle cognitive impairment in preclinical stages prior to the progression to aMCI. This could be useful in the development of early intervention strategies (Lezak, 2004). Despite the evidence that intrusions in tests of memory interference are early manifestations of AD (Thomas et al., 2018), there have not been any studies to our knowledge that have combined both quantitative and qualitative analyses of errors in patients with early neurodegenerative disorders and across two ethnic groups (European Americans and Hispanics). For the present study, the subjects were divided into the following groups: Cognitively normal (CN), aMCI, and Alzheimer's disease (AD). The intrusion errors made on the LASSI-L were divided into three categories: Prior List, Semantically Related, and Unrelated.

The types of intrusion errors made were expected to differ across groups. We predicted that the CN group would have the lowest number of all types of intrusions, followed by the aMCI group, and lastly, the AD group was expected to make the highest number of errors. In general, the aMCI and AD groups were anticipated to have a similar pattern in the type of errors, as results from previous studies support the idea that these two groups exhibit extra-list intrusion errors at a comparable rate (Libon et al., 2011). For

MCI participants, Semantically Related intrusions were hypothesized to occur more often than for the CN group, as the shared activation of semantically related items during the recall is thought to be greater in this group (Mulatti, Calia, Fara De Caro, & Della Sala, 2014). For AD participants, intrusion errors were expected to include a greater number of Unrelated and Semantically Related items, exhibiting a significantly higher number of Unrelated intrusions than the aMCI group, as suggested by previous research (Loewenstein et al., 1991). The CN participants were anticipated to exhibit mostly prior list intrusions, based on previous studies reporting that most intrusion errors in the LASSI-L come from the non-target list (Crocco et al., 2014).

It was predicted that patients with AD and MCI would show an increased susceptibility to Proactive Interference, Retroactive Interference, and Recovery from Proactive Interference effects, reflected by an increased number of errors on selected trials of the LASSI-L. Three trials of the LASSI-L that have previously shown to demonstrate these interference effects were used (Crocco et al., 2014; Loewenstein, Curiel, Duara, & Buschke, 2017). Specifically, differences in the participants' ability to recover from PI effects (as evaluated with the number of errors on Cued B2 compared to Cued B1) were expected, with the CN group demonstrating significantly fewer errors on Cued B2 compared to Cued B1. The aMCI and AD groups were not expected to recover from PI (i.e., the number of errors on Cued B1 and Cued B2 would be similar).

To test the diagnostic validity of intrusion errors, these were correlated with amyloid (Aβ) load accumulation, a valid biomarker of memory decline (Landau, Horng, & Jagust, 2018).

As the sample included Hispanics and non-Hispanics (European Americans), we conducted an exploratory analysis considering whether their ethnic background could be related to the type of intrusion errors made. This is particularly important considering that Hispanic elderly adults typically perform worse on cognitive tests (Uzzell, Pontón, & Ardila, 2007) and are reported to suffer from higher rates of AD when compared to non-Hispanics (Burke et al., 2018). Weissberger, Salmon, Bondi, and Gollan (2013) emphasized the necessity of examining differences across cultural groups on neuropsychological tests during cognitive examination, particularly on tests that are sensitive to the progression of AD, or those that can aid in the early diagnosis of AD.

Method

Participants

160 participants (97 females) were recruited from the Memory Disorders Center at the Wien Center for Alzheimer's Disease and Memory Disorders located at the Mount Sinai Medical Center in Miami Beach, Florida. Their mean age was 71.96 (*SD* = 7.76). The present project was part of the 1Florida Alzheimer's Disease Research Center (ADRC), an ongoing longitudinal study in which participants are tested with a comprehensive neuropsychological battery, accompanied by Magnetic Resonance Imaging (MRI) and amyloid Positron Emission Tomography (PET) scans, as well as a spinal tap. As part of the 1Florida ADRC, participants were evaluated once a year, over the course of five years. The current study used data obtained only during the first year of evaluation.

Participants showing motor or sensory deficits, low literacy levels, any psychiatric disorder, Major Depressive Disorder, those taking certain medications (acetylcholinesterase inhibitors), or those taking antipsychotics were excluded from the study. The sample in use excluded individuals born in countries besides the United States or those who were not immigrants from Latin American countries (individuals from Spain were excluded, as well).

Participants were subdivided into three groups: Cognitively Normal (CN), amnestic Mild Cognitive Impairment (aMCI) group, and Alzheimer's disease(AD). The sample consisted of 50 CN, 81 aMCI, and 29 AD participants. The CN group did not have informants reporting memory complaints and reported no impairment in daily function. The MCI group had memory complaints made by the participant and/or informant, memory or cognitive decline as observed by clinical evaluation, a Global Clinical Dementia Rating Scale of 0.5, no impairment in their daily life activities, and showed scores on the Hopkins Verbal Learning Test (Brandt, 1991) and NACC story passage recall of 1.5 SD or more below normal limits relative to age and education related norms. Other measures (such as the Trail Making Test A and Category Fluency) were normal for the aMCI group. Individuals with AD had scores of 2 SD or more below the mean, as well as impairment in daily life as assessed by the Functional Activities Questionnaire (Pfeffer, Kuroski, Harrah, Chance, & Filos, 1982).

Demographic variables were compared between groups using univariate general lineal models (GLM). Age, gender, and testing language did not vary significantly across the three groups, while MMSE scores differed across all groups (see Tables 1 and 2). Years of education differed significantly between the three diagnostic groups, $F(2,157) = 3.50$, $p = .033$, $\eta_p^2 = .04$. Post-hoc analyses did not reveal differences between the CN and aMCI group, or between the aMCI and AD group, $p > .05$. However, the CN and AD groups differed from each other, $p = .05$. The CN group reported the highest number of years of education (*M* = 15.76, *SD* = 3.12), followed by the aMCI group (*M* = 14.58, *SD* = 3.02), and lastly, the AD group (*M* = 13.90, *SD* = 3.98). Therefore, education was used a covariate in all subsequent analyses. In terms of ethnicity, one hundred and one participants reported being Hispanics, and fifty-nine reported being non-Hispanics of European origin.

Materials and Procedures

The following instruments were administered in Spanish or English to participants, according to the participants' preferred language.

Loewenstein-Acevedo Scales of Semantic Interference and Learning (LASSI-L).

Participants are tasked with remembering two lists of 15 words each, all of which are fruits, musical instruments, or articles of clothing (see Appendix A for administration procedure). The words are presented on cards and read by the patients, one at a time. Once all 15 words from the first list (List A) have been presented, there is a free recall, followed by cued recall of each of the 3 categories (i.e., fruits, musical instruments, or articles of clothing). List A is then presented again, and another section of cued recall for each category is conducted. A second list (List B), comprising semantically related items (also fruits, musical instruments, and articles of clothing) is subsequently presented in the same fashion. This is followed by a free recall, and cued recall of each category. Lastly, List B is presented for a second time, with another round of cued recall. At this point, the patient is asked to think back to List A, and a Free recall and Cued recall are done.

Previous analyses of the LASSI-L have demonstrated its sensitivity in differentiating between aMCI and cognitively normal participants (Loewenstein et al., 2016). In addition, this test is able to identify proactive and retroactive interference effects, and further emphasize these as one of the main characteristics of aMCI. In addition, aMCI as well as AD patients sometimes recalled more intrusions than correct responses. This test is considered a cognitive stress test, and is believed to be more sensitive to memory deficits. The LASSI-L has been found to have adequate test-retest reliabilities (*r* = .60 to *r* = .89) among aMCI and early dementia, in addition, high discriminative and concurrent validity were reported (Curiel et al., 2013). Noteworthy, the LASSI-L has shown cross-cultural sensitivity in the diagnosis of cognitively normal and aMCI Hispanic older adults (Curiel et al., 2017).

Procedure

Participants were administered a neuropsychological battery in one session consisting of 19 tasks evaluating cognitive flexibility, language, visuospatial skills, among others, in either English or Spanish. The test analyzed in the current study is a part of this neuropsychological battery, administered with other tests that will not be topic of analysis. In addition to this, blood tests, a short physical examination, and a clinician interview to corroborate the patients' memory complaints were conducted. The informants or study partners were also interviewed to corroborate patients' memory complaints and to assess any possible impairments in daily living activities. Participants received breaks throughout the evaluation, and were provided with a lunch hour halfway through the neuropsychological battery.

Intrusion errors in the LASSI-L, were divided into three categories: Prior List words, Semantically Related, and Unrelated (See Appendix B). For example, an intrusion which consists of words belonging to three categories (fruits, musical instruments, or articles of clothing), could be the word “blue”, which would be classified as an Unrelated intrusion. Words recalled belonging to the non-target list were classified as Prior List intrusions. This category differed across trials, however, as errors made at a time in which only List A had been presented were only categorized as Semantically Related or Unrelated. That is, if an error during the initial recall of List A was a word from List B, it was not considered a Prior List intrusion, as List B had yet to be presented. For the rest of the trials, words from the non-target list were counted as Prior List intrusions. Words related to the categories that appeared on the LASSI-L (i.e., a fruit, musical instrument, or clothing) were categorized as Semantically Related intrusions. These analyses were performed by two independent judges to ensure reliability of error categorization. The judges categorizing the intrusions were blind to the participants' diagnoses.

As the LASSI-L is a test shown to have sensitivity to the effects of semantic interference, we separated errors from List A and List B and categorized these as Proactive and Retroactive interference errors. When participants were asked to recall words from List A and words from List B were incorrectly recalled, these intrusion errors were considered as Retroactive Interference (new learning interfering with old learning; List B interfering with List A). Similarly, when asked to recall words from List B and List A words were mistakenly recalled, these were classified as intrusions related to Proactive Interference (old learning interfering with new learning; List A interfering with List B). These Prior List intrusions were considered errors of semantic interference since, at one point, they were relevant to the test, but during different trials and as the test progressed, they became irrelevant and needed to be inhibited (Borella et al., 2017).

Finally, the LASSI-L includes a unique trial that has shown increased sensitivity in distinguishing impaired individuals from controls even at the earliest levels of impairment; Cued B2. This trial reflects the ability to recover from Proactive Interference, as it is given after the second presentation of the List B words (see Figure 1 for administration procedure).

To quantify Aβ load from the PET scan images given to some participants, the FMRIB Software Library (FSL)[29] was employed to co-register the PET image to the aforementioned MRI T1 image. The Florbetaben PET scan, including the outline of the skull, were co-registered linearly (i.e., trilinear interpolation) with 12 degrees of freedom onto the T1 image from the MRI scan. Such a registration process ensured that the Florbetaben PET image had the same accurate segmentation and parcellation as in the MRI. Thus, mean uptake in counts for each of the FreeSurfer defined regions were calculated and global Standard Uptake Value Ratio (SUVR) was calculated by averaging cortical uptake in the frontal, parietal, lateral temporal, occipital, and anterior and posterior cingulate regions, normalized to mean gray matter counts in the cerebellum. The typical mean SUVR cut-off for amyloid positivity for Florbetaben is 1.4[23]. From our sample, 124 individuals had this data available, and within this subsample, mean SUVR ranged from 1.0470 to 2.2299, with 54 individuals at or above the threshold of 1.4.

Statistical Analyses

To explore differences in the number of errors across the three diagnostic groups, a 3-way ANOVA was conducted.

To examine differences between the diagnostic groups and the type of intrusion errors made, a 3X3 Repeated Measures ANOVA, was conducted. The between subjects factor was the diagnostic group, and the within subjects factor was the number of each of the three types of intrusions errors (i.e., Prior List, Semantically Related, and Unrelated).

To analyze the number of errors made in trials sensitive to the effects of semantic interference (Proactive Interference, Recovery from Proactive Interference, and Retroactive Interference), three 2X3 Repeated Measures ANOVA were conducted. The between subjects variable was the diagnostic group, and the within subjects variable was the number of Prior List intrusions made across the three LASSI-L trials evaluating the three types of interference. As a follow-up analysis, the specific types of errors on the selected trials were examined.

We also used a series of Pearson Product Moment correlation coefficients to study the associations between amyloid load and the type of intrusions errors within a subsample of our participants (*n* = 124) who had PET scans.

Lastly, due to the ethnic characteristics of the sample, differences in the number and type of errors made between European American and Hispanic individuals were examined. To analyze the number of errors a 3X2 GLM was conducted, with the between subjects factors as the 3 diagnostic groups (CN, aMCI, and AD) and the 2 ethnic groups (Hispanic and European American). A similar GLM was performed to evaluate differences in the types of errors, with the addition of the 3 types of intrusion errors (Prior List, Semantically Related, and Unrelated) as the within subjects factor. As some individuals of Hispanic origin chose to be tested in English, the variable of language of evaluation was also included. In this case, the total number of intrusions made in each language across the diagnostic groups were compared only within the Hispanic group, using a 3X2 GLM.

Post hoc analyses were performed using Tamhane's T2 statistic.

Results

Table 3 displays the means, standard deviations, and the percentage of intrusions of total responses within each recalled trial across diagnostic groups. A Univariate General Linear Model (GLM) demonstrated that for all types of intrusion errors, AD participants made the greatest number (M = 24.66, SD = 14.29), followed by the aMCI group (M = 22.16, SD = 16.28), and finally, the CN group (M = 11.78, SD = 8.66). Overall, the groups differed from each other, $F(2,157) = 11.09$, $p < .001$, $\eta_p^2 = .12$, with education as a non-significant covariate, $p = .67$. Post hoc analyses using Tamhane's T2 statistic revealed that these differences were significant between the CN and aMCI groups, $p < .001$, and between the CN and AD groups, $p < .001$. The comparison between the aMCI and AD groups was not significant, $p > .05$.

Types of Intrusion

The overall Repeated Measures GLM including the three diagnostic groups and the three types of intrusions revealed differences across the groups, with a significant diagnostic group main effect, $F(2,157) = 11.14$, $p < .001$, $\eta_p^2 = .12$, and type of intrusion main effect $F(2,156) = 148.43$, $p < .001$, $\eta_p^2 = .66$. The differences between the CN and aMCI group, and the CN and AD group were significant, according to Tamhane's T2 statistic, $p < .001$. The difference between the aMCI and AD group was not significant, $p > .05$. The most commonly occurring error was Prior List intrusions. The two-way interaction was also significant $F(4,314) = 6.10$, $p < .001$, $\eta_p^2 = .10$, showing that the highest number of intrusions were of words from the non-target list (Prior List), and were more frequently made by the aMCI and AD groups. Education did not show to be a significant covariate, $p = .62$.

To understand the significant interaction found, separate analyses were also conducted across each intrusion error type and the diagnostic group.

Prior list intrusions.

The number of Prior List intrusions (recalling List A during List B trials and List B words during List A trials) made by participants differed across diagnostic groups. Results indicated significant differences, $F(2,157) = 8.32$, $p < .001$, $\eta_p^2 = .10$, with education as a non-significant covariate, $p = .97$, and the Levene's statistic showing significance, $p = .04$. The CN group made fewer Prior List intrusions ($M = 9.16$, $SD = 7.56$) than the aMCI group ($M = 14.89$, $SD = 8.35$), and this difference was significantly different $p < .001$ according to Tamhane's T2 statistic. The CN group revealed a marginally significant difference from the AD group ($p = .057$), which had a mean number of Prior List intrusions of 13.07 ($SD = 6.62$), $p > .05$. The aMCI and AD groups did not differ, $p > .05$.

Semantically related intrusions.

The analysis examining the number of Semantically Related intrusions also revealed differences between the diagnostic groups. The model was significant, $F(2,157) = 9.50$, $p < .001$, $\eta_p^2 = .11$, with the covariate of education not reaching significance, $p = .43$. Tamhane's T2 statistic revealed that the CN group differed significantly from the aMCI group ($p = .001$), and with the AD group ($p < .001$). The CN group had the smallest number of Semantically Related intrusions ($M = 2.56$, $SD = 3.12$), followed by the aMCI group, (*M* = 6.67, *SD* = 9.27), and lastly, the AD group (*M* = 10.07, *SD* = 8.02). The aMCI and AD groups did not differ from each other, p >.05.

Unrelated intrusions.

Lastly, for the Unrelated intrusions, the model indicated a significant group effect, $F(2,157) = 4.45$, $p = .01$, $\eta_p^2 = .05$, with the covariate of education as non-significant, $p = .99$. Differences emerged between the CN and aMCI groups, $p = .01$, with the aMCI group (*M* = .60, *SD* = 1.51) making a greater number of these intrusions compared to the CN group (*M* = .06, *SD* = .24). The AD group had the greatest number of these intrusions, (*M* = 1.55, *SD* = 4.38). The frequency of these intrusions did not differ between the CN and AD group, $p > .05$, or the aMCI and AD group, $p > .05$.

Semantic Interference Errors

The number of words from the non-target list (i.e., Prior List intrusions) were examined on trials that have previously shown sensitivity to the effects of semantic interference, i.e., Free B1, Cued B1, Cued B2, Free A2, and Cued A3.

Proactive interference (PI) errors.

The semantic interference analyses with the number of Prior List intrusions made on trials sensitive to the effects of PI (Free B1 and Cued B1) failed to reveal a significant interaction between diagnostic group and number of intrusions, $F(2,157) = 2.47$, $p = .09$, $\eta_p^2 = .03$

Recovery from proactive interference (RPI) errors.

Cued B2, sensitive to effects of RPI, had significant differences across the three diagnostic groups, $F(2,157) = 12.34$, $p < .001$, $\eta_p^2 = .14$, with education as a non-significant covariate, $p = .80$. The CN group evidenced the fewest number of Prior List intrusions (words from List A recalled) on this trial (*M* = 1.46, *SD* = 1.47), followed by the aMCI group (*M* = 3.11, *SD* = 2.35), and the AD group (*M* = 3.45, *SD* = 2.14). Tamhane's T2 statistic revealed that differences between the CN and aMCI groups were significant, $p < .001$, and differences between CN and AD were significant as well, $p < .001$. The aMCI and AD groups did not differ significantly from each other, $p > .05$.

Recovery from PI; Cued B1 and Cued B2.

The overall analysis did not reveal a significant interaction between the number of Prior List intrusions on Cued B1 compared to Cued B2 and diagnostic group, $F(2,157) = 2.55$ $p = .08$, $\eta_p^2 = .03$. As a follow-up analysis, the number and types of errors on Cued B2, sensitive to the effects of recovery from PI, were compared to the types of errors on Cued B1 (sensitive to PI) within each diagnostic group.

The number of total errors occurring on Cued B1 compared to Cued B2 were examined within diagnostic group (see Table 6). Within the CN group, fewer total errors were made on Cued B2 (*M* = 1.60, *SD* = 1.67) than on Cued B1 (*M* = 2.64, *SD* = 2.18), $F(1,49) = 19.79$, $p < .001$, $\eta_p^2 = .29$. The aMCI group had similar results, with fewer overall errors on Cued B2 (*M* = 3.64, *SD* = 2.74) compared to Cued B1 (*M* = 4.59, *SD* = 3.17), $F(1,80) = 14.57$, $p < .001$, $\eta_p^2 = .15$. The AD also made fewer errors on Cued B2 than on Cued B1, but this difference was not statistically significant, $p > .05$.

More specifically, we explored differences in the types of errors being made on Cued B1 (PI) as opposed to Cued B2 (recovery from PI) within diagnostic groups. The CN group evidenced fewer Prior List intrusions on Cued B2 (*M* = 1.46, *SD* = 1.47) than on Cued B1 (*M* = 2.44, *SD* = 2.15), $F(1,49) = 19.45$, $p < .001$, $\eta_p^2 = .28$. Differences were not significant regarding the number of Semantically Related intrusions, $F(1,49) = .47$, $p = .50$, $\eta_p^2 = .01$. The CN group did not make Unrelated intrusions on either trial.

The aMCI group also differed in the number of Prior List intrusions on Cued B1 and Cued B2, $F(1,80) = 12.72$, $p = .001$, $\eta_p^2 = .14$, with fewer occurring on Cued B2 ($M = 3.11$, $SD = 2.35$) than on Cued B1 ($M = 3.93$, $SD = 2.62$). Semantically Related intrusions did not significantly change across Free B1 and Cued B1, $F(1,80) = 1.14$, $p = .29$, $\eta_p^2 = .01$, and Unrelated intrusions also did not differ significantly, $F(1,80) = .20$, $p = .66$, $\eta_p^2 = .002$.

The AD group, contrary to the results from the CN and aMCI group, did not show significant decreases on the number of Prior List intrusions, $F(1,28) = .08$, $p = .77$, $\eta_p^2 = .003$. However, this group evidenced marginally significant decreases in Cued B2 compared to Cued B1 regarding Semantically Related intrusions, $F(1,28) = 3.80$, $p = .06$, $\eta_p^2 = .12$. The AD group did not have any Unrelated intrusions on either trial.

Retroactive interference (RI) errors.

Retroactive Interference (RI) effects were explored with the number of Prior List intrusions (the erroneous recall of List B words) on Free A2 and Cued A3. The model revealed a significant interaction between the diagnostic groups and the number of Prior List intrusions on these trials, $F(2,157) = 6.55$, $p = .002$, $\eta_p^2 = .08$, and education was a non-significant covariate, $p = .28$. A different trend was found with the number of errors on these trials, in which the CN group averaged fewer intrusions on these trials ($M = 2.14$, $SE = .29$), followed by the AD group ($M = 2.21$, $SE = .38$), and finally, the aMCI group ($M = 3.09$, $SE = .23$). Tamhane's T2 revealed significant differences between the

CN and aMCI groups (p = .05), and between the aMCI and AD group, p = .04. The differences between CN and AD were not significantly different, p > .05.

A trend observed in the semantic interference results was the higher number of errors on the selected cued trials compared to the selected free recall trials (Cued B1 and Free B1, and Free A2 and Cued A3) across all diagnostic groups. Therefore, additional analyses were conducted to determine if specific types of errors were increasingly prone to occur on cued recall trials as opposed to free recall trials.

Types of Errors on Free versus Cued recall

To explore the types of errors made on Free B1 compared to Cued B1, and on Free A2 compared to Cued A3, one-way repeated measures GLM were conducted (Table 5). As the trial sensitive to the effects of RPI only consists of one cued trial (Cued B2), this comparison was not possible.

Cognitively normal.

On the two trials evaluating PI, Free B1 and Cued B1, significant differences were found in the number of Prior List intrusions made by the CN group, $F(1,49)$ = 45.64, p < .001, η_p^2 = .48. A greater number of Prior List intrusion errors were made on Cued B1 (M = 2.44, SD = 2.15) compared to Free B1 (M = .98, SD = 1.29). Differences were not found on the number of Semantically Related intrusions made by the CN group on Free B1 and Cued B1, $F(1,49)$ = 1.15, p = .29, η_p^2 = .2. The analysis of Unrelated Intrusions was not conducted as the CN group did not make these types of errors on these trials.

On the trials evaluating RI, i.e., Free A2 and Cued A3, the comparison of the types of error revealed a similar pattern. In the CN group, the analysis of number of Prior

List intrusions on Free A2 and Cued A3 was significant, $F(1,49) = 17.38$, $p < .001$, $\eta_p^2 = .26$, with a greater number of these errors on Cued A3 ($M = 2.62$, $SD = 2.63$) than on Free A2 ($M = 1.66$, $SD = 1.93$). Like the results from the errors on the trials sensitive to PI, differences were not found across number of Semantically Related, $F(1,49) = .11$, $p = .74$, $\eta_p^2 = .002$, or Unrelated intrusions, $F(1,49) = 1$, $p = .32$, $\eta_p^2 = .02$ in the CN group.

Amnestic MCI.

In the aMCI group, the selected trials showing sensitivity to PI and RI also showed differences in the types of intrusion errors. On the trials evaluating PI, more Prior List intrusions occurred on Cued B1 ($M = 3.93$, $SD = 2.62$) than on Free B1 ($M = 1.68$, $SD = 1.79$), $F(1,80) = 88.17$, $p < .001$, $\eta_p^2 = .52$. Additionally, the number of Semantically Related intrusions also differed between Free B1 and Cued B1, with a greater number made on Cued B1 ($M = .64$, $SD = 1.14$) than on Free B1 ($M = .31$, $SD = .58$), $F(1,80) = 9.73$, $p = .003$, $\eta_p^2 = .11$. No significant differences were found in the number of Unrelated Intrusions across Free B1 and Cued B1, $F(1,80) = .11$, $p = .74$, $\eta_p^2 = .001$.

The LASSI-L trials sensitive to RI effects (Free A2 and Cued A3) also evidenced a similar pattern of increased errors on the cued recall trial. The aMCI group made a greater number of Prior List intrusions on Cued A3 ($M = 4.04$, $SD = 2.85$) than on Free A2 ($M = 2.14$, $SD = 1.95$), $F(1,80) = 56.69$, $p < .001$, $\eta_p^2 = .42$. The aMCI group, contrary to the CN group, evidenced differences in Semantically Related intrusions, with a greater number found on Cued A3 ($M = .88$, $SD = 1.68$) compared to Free A2 ($M = .53$, $SD = 1.13$), $F(1,80) = 6.89$, $p = .01$, $\eta_p^2 = .08$. Differences were not significant regarding the Unrelated intrusions on Free A2 and Cued A3, $F(1,80) = 1$, $p = .32$, $\eta_p^2 = .01$.

Alzheimer's disease.

Lastly, within trials evaluating PI (Free B1 and Cued B1), the AD group made more Prior List intrusions on Cued B1 (*M* = 3.52, *SD* = 2.41) than on Free B1 (*M* = 1.69, *SD* = 1.49), $F(1,28) = 20.22$, $p < .001$, $\eta_p^2 = .42$. Additionally, a greater number of Semantically Related intrusions was also found on Cued B1 (*M* = 1.52, *SD* = 1.82) than on Free B1 (*M* = .24, *SD* = .43), $F(1,28) = 16.16$, $p < .001$, $\eta_p^2 = .37$. Unrelated intrusions did not differ on these trials sensitive to PI, $F(1,28) = 1.50$, $p = .23$, $\eta_p^2 = .05$.

Within the trials of RI (Free A2 and Cued A3), the frequency of Prior List intrusions made on Cued A3 (*M* = 3.48, *SD* = 1.88) were higher than on Free A2 (*M* = .93, *SD* = 1.22), $F(1,28) = 70.33$, $p < .001$, $\eta_p^2 = .72$. No significant differences were found on these trials when considering the number of Semantically Related, $F(1,28) = 2.9$, $p = .10$, $\eta_p^2 = .09$, or Unrelated intrusions, $F(1,28) = 2.07$, $p = .16$, $\eta_p^2 = .07$.

Amyloid Load and Intrusion Errors

The subsample of individuals with available amyloid load data was composed of 39 CN, 59 aMCI, and 26 AD participants. Amyloid levels differed significantly across the three diagnostic groups, $F(2,121) = 22.66$, $p < .001$, $\eta_p^2 = .27$. The CN group had the lowest mean SUVR (*M* = 1.2254, *SD* = .1622), followed the aMCI group (*M* = 1.4250, *SD* = .2757), and the AD group (*M* = 1.6456, *SD* = .2846).

The analyses exploring the relationship between SUVR in the grey cerebellum revealed significant correlations (Table 7). Prior List, Semantically Related and Unrelated intrusions showed significant positive correlation to SUVR values, $r(124) = .30$, $p = .001$., $r(124) = .40$, $p < .001$, $r(124) = .23$, $p = .01$, respectively. Lastly, the total number of errors on the LASSI-L also correlated positively to amyloid levels, $r(124) = .42$, $p < .001$.

Ethnic Group

The main effect of ethnic group was not significant $F(1,154) = .72$, $p = .40$, $\eta_p^2 = .005$. Similarly, the interaction of ethnic group with diagnostic group did not reveal any differences in the total number of errors, $F(1,154) = .16$, $p = .86$, $\eta_p^2 = .002$, where education was not a significant covariate, $p = .87$. The interaction of the type of error with ethnic and diagnostic group was not significant; Prior List intrusions, $F(2,154) = .39$, $p = .68$, $\eta_p^2 = .005$, Semantically Related, $F(2,154) = .60$, $p = .55$, $\eta_p^2 = .008$, or Unrelated intrusions, $F(2,154) = 1.86$, $p = .16$, $\eta_p^2 = .02$. Education was not a significant covariate in this analysis, $p = .98$.

Some Hispanic individuals ($n = 28$) preferred to be evaluated in English, therefore this variable was included in the analysis. The main effect of language did not reach significance, $F(1,95) = .11$, $p = .74$, $\eta_p^2 = .001$. The interaction of testing language and diagnostic group did not reach significance, either, $F(2,95) = .29$, $p = .75$, $\eta_p^2 = .006$, with education as a non-significant covariate, $p = .90$.

Discussion

The present study examined intrusion errors on a verbal cognitive test, the LASSI-L, to determine whether these could yield additional information about cognitive status in Cognitively Normal and in individuals suffering from memory decline due to abnormal aging. We used the total number of errors and classified these into three types: Prior List, Semantically Related, and Unrelated intrusions. These variables were compared across three diagnostic groups (Cognitively Normal, amnestic aMCI, and Alzheimer's disease). The number of Prior List intrusion errors on specific LASSI-L trials that are susceptible to Proactive Interference (PI), Recovery from Proactive Interference (RPI), and Retroactive Interference (RI) were also examined across the diagnostic groups. As a subsequent analysis, the types of errors made on two cued recall trials were compared to the types of errors present on two comparable free recall trials. Contrasts were also performed regarding the number and types of errors made on a trial evaluating PI related to those made on another trial sensitive to RPI. Additionally, the errors produced by a subsample of individuals from the three diagnostic groups were correlated to a measure of amyloid load to determine the clinical validity of intrusion errors. Finally, since the sample was comprised of European American and Hispanics, we conducted analyses exploring whether the number and type of intrusion errors would vary across these ethnic groups and their preferred language of evaluation.

Total Correct and Intrusions

As expected, the total number of correctly recalled items was highest in the CN group, followed by the aMCI, and lastly, the AD group. Furthermore, the pattern of number of errors evidenced the opposite trend, in which the AD group exhibited the highest number of errors, followed by the aMCI group, and lastly, the CN group. The overall model indicated that the CN and aMCI groups, and the CN and AD groups, differed significantly in the types of errors made. These results are consistent with previous research showing that intrusion errors in memory association tasks may distinguish normal from abnormal aging (Libon et al., 2011)

Types of Intrusion Errors

Upon comparison of the total number of the three categories of intrusion errors, we found that Prior List intrusions occurred most often, followed by the Semantically Related intrusions, and lastly, the Unrelated intrusions.

Prior list intrusions.

As expected, the CN group had the lowest number of Prior List intrusions, although an unexpected result was that the aMCI group made more of these types of intrusions than the AD group. It is possible that the deficits in the semantic networks of the LASSI-L categories in the AD group hindered their ability to memorize words from either list, so upon recall, they resorted to other types of intrusions, (i.e., words not found on either list; Semantically Related and Unrelated), consistent with previous research (Schram et al., 1995) indicating that Unrelated intrusions occur in AD. Possibly, as the aMCI group may retain their ability to encode and remember words, their mistakes seem to occur more often from the inability to maintain List A and List B separately during recall.

Semantically related intrusions.

The results from the analysis of Semantically Related intrusions revealed a different trend from the Prior List intrusions, in which the CN group made a smaller number, followed by the aMCI group, and lastly, the AD group. This finding suggests that semantic errors are associated with the severity of cognitive decline in AD, and supports the idea that the pattern of verbal recall by AD patients is a demonstration of deficits in semantic knowledge and lexical access (Davis, Price, Kaplan, & Libon, 2002). It seems that individuals with AD are impaired at successfully storing words from either of the LASSI-L lists. Semantically Related intrusion errors can occur from the inability to inhibit words that are part of the semantic categories used on the LASSI-L (i.e., fruits, musical instruments, and articles of clothing). It seems that upon recall, the impaired groups, in particular, the AD group, were unable to inhibit the retrieval of words belonging to the same semantic category as the LASSI-L words.

Unrelated intrusions.

The Unrelated intrusions only differed between the CN and aMCI group. The number of Unrelated intrusions made by the CN and aMCI groups was extremely low (.06 and .60, respectively), but it is important to note that these errors still occurred, and notably, showed statistical differences. Future research should explore whether individuals who make any Unrelated intrusions might have an underlying deficit and might progress to aMCI or AD at an accelerated rate.

Within our sample, it appears that all types of intrusion errors included in this study (Prior List, Semantically Related, and Unrelated) can successfully distinguish between CN and aMCI samples, with the aMCI group having a higher frequency of these types of errors compared to the CN group. Our results support previous findings indicating that as deficits in semantic network organization are observed in AD and aMCI (Mascali et al., 2018; Vogel, Johannsen, Stokholm, & Jørgensen, 2014). These are manifested with different types of intrusions. Impaired semantic networks may result not only in Unrelated intrusions, but also in the occurrence of Semantically Related intrusions. For instance, during testing, when the cue 'fruits' is provided, this category may extend in weakened semantic networks and cover other food-related words (e.g., vegetables).

As discussed above, the finding that some CN and aMCI participants made Unrelated intrusions could serve as an early warning sign of certain inhibition failures, particularly from our findings indicating significant differences between these diagnostic groups. For the most part, Unrelated intrusions have been reported only in impaired patients; therefore, these types of errors before or early during the onset of aMCI or AD deserve further investigation.

Semantic Interference Errors

As it was hypothesized that certain trials of the LASSI-L evaluating semantic interference could be more sensitive to the detrimental effects of cognitive decline, particularly in the early stages of neurodegenerative disease, Free B1 and Cued B1, Cued B2, and Free A2 and Cued A3 were further analyzed. Intrusion errors from the non-target list (Prior List intrusions) were divided into 3 types: 1) Proactive Interference errors (recalling words from List A when asked about List B; observed on Free B1 and Cued B1), 2) Recovery from Proactive Interference errors (recalling List A words when asked about List B for a second time; Cued B2, and 3) Retroactive Interference errors (recalling words from List B when asked about List A; observed on trials Free A2 and Cued A3).

Proactive interference errors.

Our results showed that in trials evaluating PI (Free B1 and Cued B1), the average number of Prior List intrusions on these two trials did not differ across any of the diagnostic groups. It is possible that, as this is early during the test, sufficient PI has yet to build up in order to be able to differentiate across groups.

Recovery from proactive interference errors.

On Cued B2, evaluating the participant's ability to recover from the effects of PI through the inhibition of List A words, differences in the number of Prior List intrusions emerged. Cued B2 is conducted after the presentation of List B words for a second time, and therefore, it is expected that the effects of PI (observed on the previous B recall trials) would be lessened, as reflected by more words recalled correctly, and fewer errors made. As we only included the number of intrusion errors in our analysis, we found fewer errors were made on Cued B2 by the CN group, followed by the aMCI, and lastly, the AD group. Our analyses suggest that the recovery from semantic interference is more challenging and sensitive than other LASSI-L trials. Cognitively unimpaired individuals typically do not make intrusion errors here, as supported by previous findings (Loewenstein et al., 2016).

From our results, it appears that on the trial sensitive to RPI, the CN group demonstrates an increased ability to inhibit words from List A, compared to the other diagnostic groups.

Recovery from PI: Cued B1 and Cued B2

A separate analysis evaluating the participants' ability to recover from PI was examined using the total number of errors made on Cued B1 compared to Cued B2. Results showed that the CN group evidenced fewer errors on Cued B2 than on Cued B1. Unexpectedly, our results showed that the aMCI group also demonstrated this pattern; within this diagnostic group, significantly fewer errors occurred on Cued B2 than on Cued B1. The AD group did not have significant decreases in the number of errors across these trials.

While these results differ from previous findings indicating that ability to recover from PI is impaired in aMCI, the methodology is different and possibly accounts for these discrepancies. Other research using the LASSI-L has focused on the number of items correct on Cued B1 versus Cued B2, while the present research measured the ability to recover from PI with the number of intrusion errors.

Perhaps the optimal way to evaluate failure or ability to recover from PI is to use percentages of recalled items to intrusion errors, as has been previously done with the LASSI-L (Loewenstein et al., 1991; Crocco et al., 2014). This can be particularly beneficial on Cued B2, which may have greater sensitivity during the diagnosis process.

The types of errors on Cued B1 and Cued B2 showed differences, as well. The CN and aMCI group showed a tendency of making fewer Prior List intrusions on Cued B2 than on Cued B1, but did not evidence significant decreases in Semantically Related intrusions. It seems that Cued B2, as it is directly preceded by the second presentation of List B words, is further strengthening the separation of the two lists (decreasing Prior List intrusions) and the encoding of the List B words (decreasing Semantically Related intrusions) for both CN and aMCI groups.

The AD group did not show significant decreases of Prior List or Semantically Related intrusions on Cued B2 as compared to Cued B1. This could imply that they are not able to benefit from the semantic cue provided during Cued B2 recall in order to reduce the number of errors.

Across the three groups, Unrelated intrusions did not differ significantly between Cued B1 and Cued B2; these types of errors were virtually non-existent on these trials.

Retroactive interference errors.

The mean number of Prior List intrusion errors on Free A2 and Cued A3 exhibited an unexpected pattern, with the CN group making the lowest number, followed by the AD group and the aMCI. It is worth noting, however, that the aMCI group correctly recalled more items than the AD group on both trials.

From the analyses semantic interference analyses we observed that a greater number of Prior List intrusion errors were made on the cued recall trials (Cued B1 and Cued A3) compared to the free recall trials (Free B1 and Free A2). This was true among all diagnostic groups. As the cueing is intended to aid in the recall, it seems that while the number of correct words recalled on cued trials was greater, so were the number of errors. As these results only included one type of intrusion error (Prior List), further analyses were conducted to determine if differences emerged with the inclusion of Semantically Related and Unrelated intrusions made during free versus cued recall.

Types of Errors on Free versus Cued Recall

More specific analyses were subsequently conducted to examine variations in the types of intrusion errors that occurred within groups on cued versus free recall trials on the LASSI-L.

In the CN group, the trials sensitive to PI (Free B1 and Cued B1) demonstrated differences only in the number of Prior List intrusions, with a greater number seen Cued B1 than on Free B1. Semantically Related intrusion errors did not differ, and the CN group did not make any Unrelated intrusions on these trials. On Free A2 and Cued A3, sensitive to RI, the CN group only differed in the number of Prior List intrusions, as well, with a greater frequency of these occurring on Cued A3 compared to Free A2.

In the aMCI group, Prior List intrusions also differed between the Free B1 and Cued B1, and between Free A2 and Cued A3. On both comparisons, more Prior List intrusions were found on the cued trials compared to the free trials. Diverging from the CN group, the aMCI group differed in the number of Semantically Related intrusions made across cued and free recall trials. A higher frequency of Semantically Related intrusions was found on Cued B1 compared to Free B1, and on Cued A3 compared to Free A2. Finally, no differences were found between these trials and the amount of Unrelated intrusion errors.

Lastly, Prior List intrusions also differed between Free B1 and Cued B1, and Free A2 and Cued A3 within the AD group, with a greater number on the cued recall trials. Differences were also found regarding Semantically Related Intrusions only on Free B1 and Cued B1. Free A2 and Cued A3 had a similar trend, with fewer Semantically Related on Free B1, but this number was not significantly different. Unrelated intrusions failed to show any difference between free and cued recall trials within the AD sample.

In summary, across all three diagnostic groups, the number of Prior List intrusions increased on the cued recall compared to the free recall trials. It appears that the cueing on Cued B1 and Cued A3 is leading to an increase in intrusions from the non-target list, even among the CN group. This finding can suggest that the ability to keep the lists separate is hindered by semantic cues. The cueing on tests of verbal memory is expected to aid in the correct recall of words, however, it seems that when participants are asked to activate a semantic category (i.e., all the fruits from List B) they are simultaneously recalling fruits from List A. Similar results indicating more errors on cued than on free trials on the LASSI-L have been found (Crocco et al., 2014).

From these results, it can be concluded that the distinguishing factor between CN and aMCI in terms of the types of errors made on cued versus free trials is the increase of Semantically Related intrusions by the aMCI group. While both groups increased their frequency of errors in general, only the aMCI group added words not found on either list of the LASSI-L. It is evident that the deterioration of the semantic networks may begin in aMCI, and upon cueing, the impaired network is activated and results in the increased occurrence of Semantically Related intrusions. Semantically Related intrusions did not differ significantly between Free A2 and Cued A3 in the AD group, however, the number was higher in the cued trial than on the free trial. It is possible that this difference was not observed due to the small sample size of the AD group.

Perhaps unsurprisingly, Unrelated intrusions decreased across all groups on cued trials. Even for the AD group, the cueing provided during Cued B1 and Cued A3 appeared to be successful in lessening the influence of semantic interference effects thus resulting in fewer unrelated words recalled. Subsequent research using Unrelated intrusions as a potential indicator of level of cognitive decline should consider these types of errors separately before and after a semantic cue is provided.

Amyloid load and Intrusion Errors

Significant positive correlations emerged between the total number of intrusions and amyloid load, as well as between each of the three types of intrusion errors and amyloid load. The strongest positive correlations were found between amyloid load with the total number of errors on the LASSI-L, and with the total number of Semantically Related intrusions. These correlations suggest that deficits in the semantic networks typically associated with more advanced stages of neurodegenerative disease and which tend to lead to the production of Semantically Related intrusions are related to mean SUVR.

Ethnic Group

As the current data are being collected in South Florida, the sample is culturally diverse, including both European Americans and individuals from multiple Spanish-speaking countries. This provided us with the unique opportunity to investigate whether the number and type of error differed as a function of an individual's self-reported ethnic background. The analyses did not reveal any differences when comparing the number or type of error between European Americans and Hispanics across diagnostic groups. Furthermore, as some Hispanics preferred to be evaluated in English, testing language was additionally added to the model. Differences also failed to emerge in this analysis. Considering the LASSI-L is validated for use with Hispanic elderly (Curiel et al., 2017), these findings are not surprising. However, they successfully demonstrated the strength of this paradigm when used in a culturally heterogeneous sample of Hispanics and non-Hispanics, which is of particular importance in the South Florida area.

Conclusion

Overall, the three types of errors used in these analyses showed differences between the CN and aMCI group, with the aMCI group evidencing a higher rate of these intrusions errors compared to the CN group. This supports previous literature about the LASSI-L's sensitivity at the earliest stages of abnormal aging, and which have been supported by imaging results (Crocco et al., 2014, 2018).

On the trials evaluating the ability to recover from PI, the CN and aMCI group successfully decreased the number of errors on Cued B2 when compared to Cued B1, signifying an improved ability to inhibit words from the non-target list across trials.

Differences in the types of intrusion were found between cued and free recall trials. Prior List intrusions and Semantically Related intrusions occurred more often during cued recall trials than free recall trials. On the other hand, Unrelated intrusions decreased in the cued trials; while this was not significant, all groups showed decrements in the number of Unrelated intrusions, even the AD group. This suggests that while the cueing procedure is not as beneficial to the AD group when compared to the less impaired groups, the AD group is still able to better inhibit Unrelated words because of the cue.

Furthermore, amyloid load was positively correlated to all the types of intrusion errors, particularly to Semantically Related intrusions.

Our results are consistent with previous analyses using the LASSI-L with a sample of Hispanic individuals, suggesting that this test is valid with Spanish speaking individuals, regardless of the chosen language of evaluation.

Limitations

Differences in the number of individuals belonging to each diagnostic group, particularly within the AD group, are a limitation to the generalizability of these results. The sample included fewer cases of AD than any other diagnostic group. This could be the result of the level of impairment impeding the participant to be evaluated with the entire neuropsychological battery, including the LASSI-L. Therefore, the results of the AD group should be interpreted with caution and should be confirmed with a larger sample.

While the categories of intrusion errors used were sufficient in categorizing all errors on the LASSI-L, there is a certain level of ambiguity, in that certain words could be interpreted as phonemically related (they sound like words from the test; e.g., lemon), or as belonging to a superordinate category (e.g., recalling the word ‘fruits’). Future research may benefit by adding additional categories for greater detail of the types of intrusions.

The LASSI-L is a new test that has been validated and shows high sensitivity in detecting early cognitive changes (Curiel et al., 2013; Crocco et al., 2014). Nonetheless, results should be compared to other verbal memory tests that have been administered to larger samples.

While the LASSI-L was translated to Spanish by proficient Spanish speakers and has been validated for use in the diagnosing of aMCI with a sample of Hispanic individuals, certain items have more than one translation, and this varies across and within countries. For example, the word ‘banana’ was translated to ‘banano’, however, Spanish speakers from several Latin American countries refer to this as ‘guineo’, ‘cambur’, or ‘plátano’. This issue occurs with other words such as ‘medias’, ‘fresa’, and ‘cinturón’, which were at times referred by participants as ‘calcetines’, ‘frutilla’, and ‘correa’ or ‘cinto’, respectively. Ideally, a test designed for Spanish speakers would include words that are more consistent across regions and countries.

Lastly, during administration of the LASSI-L, participants were not corrected when intrusion errors were made, therefore, the same errors were often repeated across trials, even after the second presentation of the words. These perseverations may reflect a different mechanism than deficits in inhibitory process. Davis et al. (2002) analyzed these perseverative errors and concluded that, compared to patients with Ischaemic Vascular Dementia, AD patients made repeated intrusion errors across trials more often. The researchers suggest that these perseverations might be unique to the amnestic presentation of AD. Future research should quantify perseverations occurring within and between each recall trial to explore this specific type of error.

Future directions

One possible way to further investigate the role of intrusion errors is to analyze responses using a ratio to account for the increase in errors in cued recall trials. Additionally, Unrelated intrusions occurring in CN and aMCI groups might be early indications of deteriorating semantic networks. These data are part of a longitudinal study, therefore allowing the possibility to closely monitor the trajectories of change in the number of intrusion errors as well as the transition in the type of errors made (e.g., from Prior List to Unrelated intrusions) with disease progression.

Our sample included European Americans and Hispanics, however, specific linguistic variables, such as proficiency, age of acquisition, and levels of bilingualism were not examined. It is possible that the interaction of these factors could play a role in mediating the number and type of intrusions, and therefore this should be further explored.

Despite the limitations, the present study had a strong methodology with the inclusion of detailed analyses and classification of all intrusion errors made on the LASSI-L. the sample in use was culturally homogenous; including only individuals born in the United States or Latin American immigrants, allowing for the exploration differences in performance across ethnic groups with a greater degree of generalizability.

Appendices

Appendix A: Tables

Table 1

Sample Characteristics: Age, years of education, and MMSE scores

	Diagnostic Group								
	Normal *N*=50			aMCI *N*=81			AD *N*=29		
	Min.	Max.	Mean (SD)	Min.	Max.	Mean (SD)	Min.	Max.	Mean (SD)
Age	54.00	84.00	70.54 (5.96)	56.00	93.00	72.84 (7.60)	45.00	90.00	71.97 (10.42)
Education	8.00	20.00	15.76 (3.12)	6.00	21.00	14.58 (3.02)	5.00	20.00	13.90 (3.98)
MMSE	25.00	30.00	29.10 (1.11)	19.00	30.00	26.90 (2.56)	5.00	29.00	21.97 (5.10)

Table 2

Sample characteristics: ethnic group, testing language, and gender

		DX Groups Valeria					
		Normal		aMCI		AD	
		Count	%	Count	%	Count	%
Ethnic Group	European American	20	40.00%	30	37.04%	9	31.03%
	Hispanic	30	60.00%	51	62.96%	20	68.97%
Testing Language	English	29	58.00%	43	53.09%	15	51.72%
	Spanish	21	42.00%	38	46.91%	14	48.28%
Gender	Male	17	34.00%	38	46.91%	8	27.59%
	Female	33	66.00%	43	53.09%	21	72.41%

Table 3

Total correct, intrusions, and percentage of intrusions to total recalled per trial

	Diagnostic Group								
	Normal			aMCI			AD		
	Mean	SD	%	Mean	SD	%	Mean	SD	%
Free A1	9.50	2.72		6.48	2.69		3.93	2.42	
Intrusions Free A1	0.32	0.89	3.26%	0.53	1.01	7.57%	0.62	1.42	13.64%
Cued A1	10.48	2.30		7.84	2.58		5.03	2.49	
Intrusions Cued A1	0.64	0.88	5.76%	1.40	1.92	15.11%	1.93	2.02	27.72%
Cued A2	13.58	1.42		11.05	2.36		7.38	3.13	
Intrusions Cued A2	0.34	0.69	2.44%	1.22	1.96	9.96%	2.14	1.92	22.46%
Free B1	7.46	2.31		5.12	2.29		3.28	2.17	
Intrusions Free B1	1.10	1.36	12.85%	2.02	2.08	28.32%	2.10	1.78	39.10%
Cued B1	8.36	2.24		5.88	2.32		3.17	2.35	
Intrusions Cued B1	2.64	2.18	24.00%	4.59	3.17	43.87%	5.03	3.28	61.34%
Cued B2	11.62	1.89		8.91	2.84		5.17	3.00	
Intrusions Cued B2	1.60	1.67	12.10%	3.64	2.75	29.01%	4.45	2.68	46.24%
Free A2	6.32	2.87		3.77	2.51		1.62	1.99	
Intrusions Free A2	1.84	2.17	22.55%	2.70	2.47	41.79%	1.93	2.33	54.37%
Total Cued A3	8.38	2.71		6.33	2.55		4.86	2.36	
Intrusions Cued A3	2.80	2.78	25.04%	4.93	3.68	43.75%	5.03	2.72	50.87%
Delay Total	20.24	3.20		12.51	6.34		5.28	5.99	
Intrusions Delay	0.50	0.65	2.41%	1.12	1.95	8.24%	1.45	2.37	21.54%

Table 4

Amount and type of intrusion errors across groups

	Diagnostic Group								
	Normal		aMCI		AD				
	Mean	SD	Mean	SD	Mean	SD	*F*	*p*	*pη2*
Prior List	9.16	7.56	14.89	8.35	13.07	6.62	8.32	.00	.10
Semantically Related	2.56	3.12	6.67	9.27	10.07	8.02	9.50	.00	.11
Unrelated	.06	.24	.60	1.51	1.55	4.38	4.45	.01	.05

Note. *pη2* = partial eta squared

Table 5

Type of error across trials sensitive to PI and RI

	Diagnostic Group					
	Normal		aMCI		AD	
	Mean	SD	Mean	SD	Mean	SD
Prior List Intrusions Free B1	$.98_{a}$	1.29	1.68_{b}	1.79	$1.69_{a,b}$	1.49
Prior List Intrusions Cued B1	2.44_{a}	2.15	3.93_{b}	2.62	$3.52_{a,b}$	2.41
Semantically Related Intrusions Free B1	$.12_{a}$	.39	$.31_{a}$	.58	$.24_{a}$	.44
Semantically Related Cued B1	$.20_{a}$	.53	$.64_{a}$	1.14	1.52_{b}	1.82
Unrelated Intrusions Free B1	$.00_{a}$	.00	$.04_{a}$	.25	$.17_{a}$	.76
Unrelated Intrusions Cued B1	$.00_{a}$	.00	$.02_{a}$	.22	$.00_{a}$	.00
Prior List Intrusions Free A2	$1.66_{a,b}$	1.93	2.14_{a}	1.95	$.93_{b}$	1.22
Prior List Intrusions Cued A3	2.62_{a}	2.63	4.04_{b}	2.85	$3.48_{a,b}$	1.88
Semantically Related Intrusions Free A2	$.16_{a}$	.37	$.53_{a,b}$	1.13	$.86_{b}$	1.48
Semantically Related Intrusions Cued A3	$.18_{a}$	.44	$.88_{b}$	1.68	1.55_{b}	1.78
Unrelated Intrusions Free A2	$.02_{a}$	.14	$.04_{a}$	.19	$.14_{a}$	.52
Unrelated Intrusions Cued A3	$.00_{a}$	.00	$.01_{a}$	.11	$.00_{a}$	.00

Note. Values in the same row and subtable not sharing the same subscript are significantly different at p < .05 in the two-sided test of equality for column means. Cells with no subscript are not included in the test. Tests assume equal variances.[1]
1. Tests are adjusted for all pairwise comparisons within a row of each innermost subtable using the Bonferroni correction.

Table 6

Types of errors in trials sensitive to PI and recovery from PI

	Diagnostic Group					
	Normal		aMCI		AD	
	Mean	SD	Mean	SD	Mean	SD
Prior List Intrusions Cued B1	2.44_{a}	2.15	3.93_{b}	2.62	$3.52_{a,b}$	2.41
Prior List Intrusions Cued B2	1.46_{a}	1.47	3.11_{b}	2.35	3.45_{b}	2.15
Semantically Related Cued B1	$.20_{a}$	.53	$.64_{a}$	1.14	1.52_{b}	1.82
Semantically Related Cued B2	$.14_{a}$	.40	$.52_{a}$	.94	1.00_{b}	1.22
Unrelated Intrusions Cued B1	$.00_{a}$	.00	$.02_{a}$	.22	$.00_{a}$	.00
Unrelated Intrusions Cued B2	$.00_{a}$	.00	$.01_{a}$	.11	$.00_{a}$	.00

Note. Values in the same row and subtable not sharing the same subscript are significantly different at p< .05 in the two-sided test of equality for column means. Cells with no subscript are not included in the test. Tests assume equal variances.[1]

1. Tests are adjusted for all pairwise comparisons within a row of each innermost subtable using the Bonferroni correction.

Table 7

Correlation Matrix: Correlations between intrusion errors and mean SUVR

	SUV Grey Cerebellum	Number of Errors	Prior List	Semantically Related	Unrelated
SUV Grey Cerebellum					
Number of Errors	.42**				
Prior List	.30**	.83**			
Semantically Related	.40**	.88**	.49**		
Unrelated	.23**	.46**	.12	.44**	

Note. **. Correlation is significant at the 0.01 level (2-tailed).

Appendix B: Figures

Figure 1

LASSI-L Administration Procedure

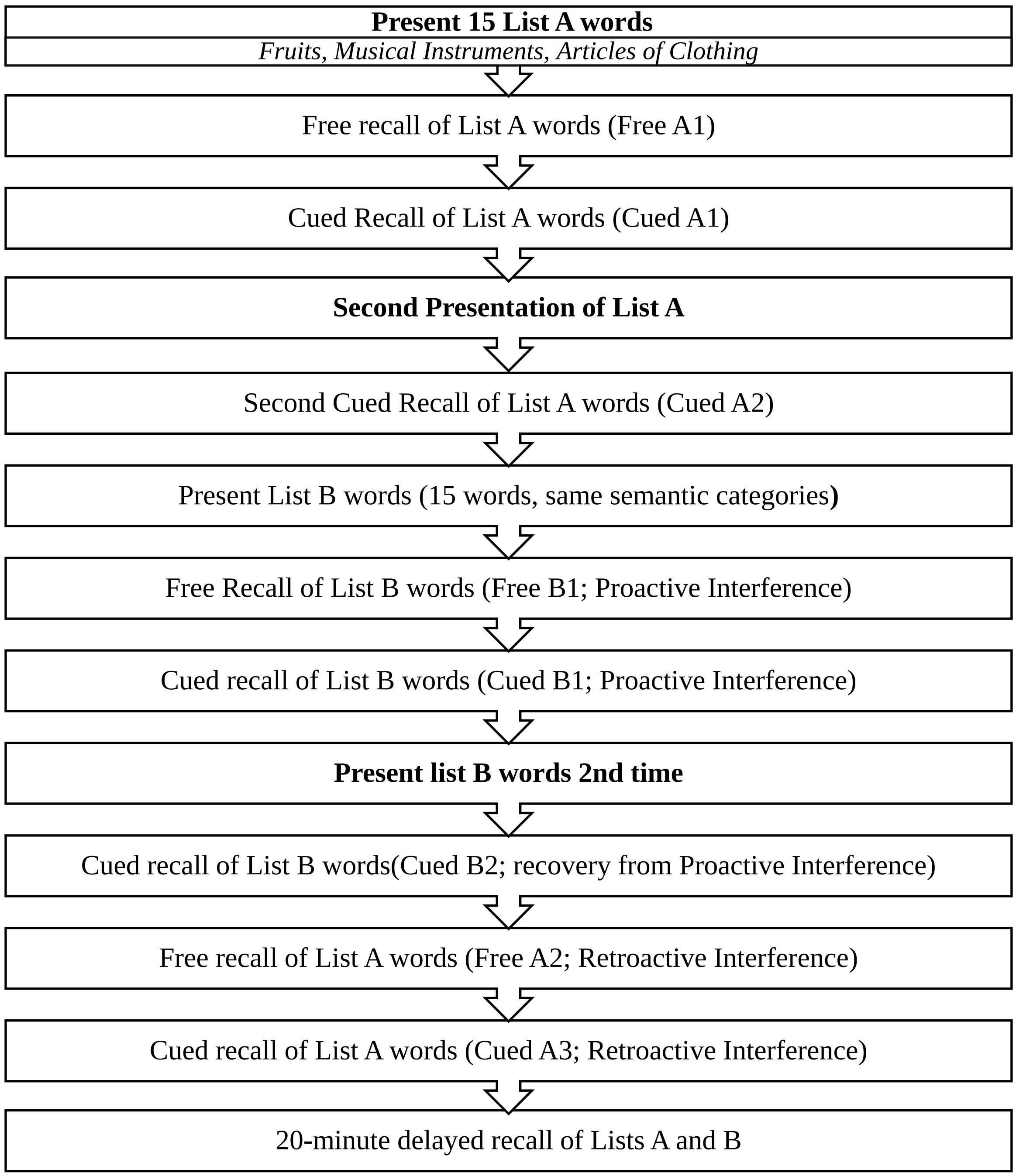
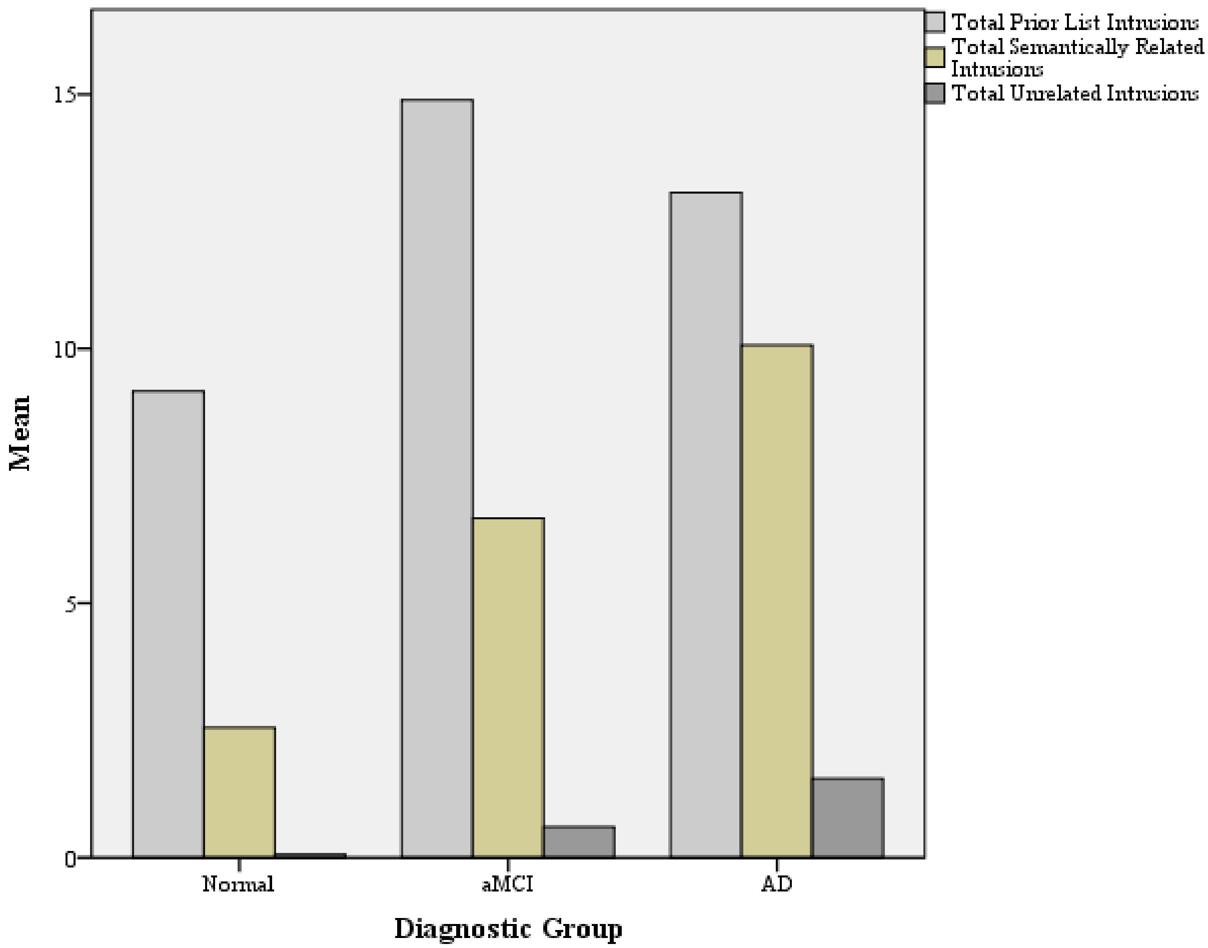


Figure 2

Quantity of types of errors across diagnostic group



Appendix C: LASSI-L Words in English, Spanish

List A	List B
Pear, pera	Pineapple, piña
Banana, banana	Orange, naranja
Strawberry, fresa	Peach, melocotón
Mango, mango	Grapes, uvas
Lime, limón	Coconut, coco
Flute, flauta	Trumpet, trompeta
Harmonica, armónica	Accordion, acordeón
Violin, violín	Saxophone, saxofón
Piano, piano	Harp, arpa
Guitar, guitarra	Clarinet, clarinete
Sock, media	Shoe, zapato
Shirt, camisa	Pants, pantalón
Tie, corbata	Belt, cinturón
Jacket, chaqueta	Sweater, suéter
Hat, sombrero	Gloves, guantes

Appendix D: Semantically Related and Unrelated intrusion errors in English and Spanish on the LASSI-L

Semantically Related-English	Unrelated-English	Semantically Related-Spanish	Unrelated-Spanish
apple	ball	abrigo	animales
apricot	banana chips	aguacate	armario
bagpipes	bat	albaricoque	cama
blackberry	beach	anillo	camello
blouse	bear	anón	casa
blueberry	bicycle	bloomer	conejo
bongo	birds	blusa	cosas de cocina
boots	candy	brazalete	esparrago
bugle	cars	bufanda	flor
cantaloupe	cat	calcetines	gallos
carrots	chains	camiseta	gato
cello	chocolate	cereza	jirafa
cherry	clock	chaleco	lápiz
clothing	dog	chirimoya	libro
coat	elephant	cinto	llama
cymbals	fence	corneta	mariposa
dress	fire station	correa	maza
drum	flower	durazno	medida
fig	giraffe	esparrago	memoria
fruit	harmony	faja	mesa
grapefruit	home	falda	pantalla
guava	horse	filarmónica	pavo real
harpsichord	house	frambuesa	pavos
horn	ice cream	frutas	peine
jeans	labels	guanábana	perro
kiwi	lion	guayaba	pescado
leggings	peanuts	jean	pirámide
lemon	pearl	kiwi	puerta
loquat	pretzel	lira	reloj
mandarin	red	mamey	rinosauro
mandolin	sheep	mandarina	sonrisa
maracas	signs	mandolina	tornillos
melon	tables	manzana	toro
mittens	tarp	manzano	vaca
neckties	taxi	maraca	ventana
nectarine		marimba	vidrio
organ		melón	

Semantically Related-English	Unrelated-English	Semantically Related-Spanish	Unrelated-Spanish
pajamas		mora	
panties		nectarinas	
papaya		órgano	
philharmonic		pantalones largos	
plums		pañuelo	
potato		plátano	
prune		reloj	
raincoat		ropa	
raspberry		ropón	
ring		saco	
robe		sandia	
sandals		saya	
scarf		tambor	
shorts		timbales	
skirt		toronja	
slacks		traje	
sneakers		trombón	
strawberry		vestido	
swim trunks			
tangerine			
tank tops			
tomato			
top			
trombone			
trousers			
t-shirt			
tuba			
ukulele			
umbrella			
underwear			
viola			
watch			
watermelon			
xylophone			

References

Albert, M. S., DeKosky, S. T., Dickson, D., Dubois, B., Feldman, H. H., Fox, N. C., … & Phelps, C. H. (2011). The diagnosis of mild cognitive impairment due to Alzheimer's disease: recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia: The Journal of the Alzheimer's Association*, *7*(3), 270–279. doi.org/10.1016/j.jalz.2011.03.008

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th ed.). Arlington, VA: American Psychiatric Publishing.

Beekly, D. L., Ramos, E. M., Lee, W. W., Deitrich, W. D., Jacka, M. E., Wu, J., … Raskind, M. (2007). The National Alzheimer's Coordinating Center (NACC) database: The uniform data set. *Alzheimer Disease and Associated Disorders*, *21*(3), 249–258. doi: 10.1097/WAD.0b013e318142774eBondi, M. W., Salmon, D. P., Galasko, D., Thomas, R. G., & Thal, L. J. (1999). Neuropsychological function and apolipoprotein E genotype in the preclinical detection of Alzheimer's disease. *Psychology and Aging, 14*(2), 295-303. doi.org.ezproxy.fau.edu/10.1037/0882-7974.14.2.295

Borella, E., Carretti, B., Mitolo, M., Zavagnin, M., Caffarra, P., Mammarella, N., … Piras, F. (2017). Characterizing cognitive inhibitory deficits in mild cognitive impairment. *Psychiatry Research*, *251*, 342–348. doi.org/10.1016/j.psychres.2016.12.037

Brandt, J. (1991). The Hopkins Verbal Learning test: Development of a new memory test with six equivalent forms. *Clinical Neuropsychologist*, *5*(2), 125–142. doi.org/10.1080/13854049108403297

Burke, S. L., Rodriguez, M. J., Barker, W., Greig-Custo, M. T., Rosselli, M., Loewenstein, D. A., & Duara, R. (2018). Relationship between Cognitive Performance and Measures of Neurodegeneration among Hispanic and White Non-Hispanic Individuals with Normal Cognition, Mild Cognitive Impairment, and Dementia. *Journal of the International Neuropsychological Society*, *24*(2), 176–187. doi.org/10.1017/S1355617717000820

Crocco, E., Curiel, R. E., Acevedo, A., Czaja, S. J., & Loewenstein, D. A. (2014). An evaluation of deficits in semantic cueing and proactive and retroactive interference as early features of Alzheimer's disease. *The American Journal of Geriatric Psychiatry: Official Journal of the American Association for Geriatric Psychiatry*, *22*(9), 889–897. doi.org/10.1016/j.jagp.2013.01.066

Crocco, E. A., Loewenstein, D. A., Curiel, R. E., Alperin, N., Czaja, S. J., Harvey, P. D., … Cardenas, K. (2018). A novel cognitive assessment paradigm to detect Pre-mild cognitive impairment (PreMCI) and the relationship to biological markers of Alzheimer's disease. Journal of Psychiatric Research, 96, 33–38. doi.org/10.1016/j.jpsychires.2017.08.015

Curiel, R., Crocco, E., Czaja, S., Levin, B., Wahlestedt, C., Wright, C., & Loewenstein, D. (2013). Deficits in semantic cuing, proactive and retroactive interference as early features of Alzheimer's disease. *Alzheimer's & Dementia*, *9*(4, Supplement), P456. doi.org/10.1016/j.jalz.2013.05.915

Curiel, R., Loewenstein, D., Chan, A., Crocco, E., Raffo, A., Penate, A., & Melo, J. (2017). Culturally Sensitive Cognitive Stress Test is Related to Alzheimer's Disease (AD) Signature Regions on MRI. *Biological Psychiatry*, *81*(10, Supplement), S128–S129. doi.org/10.1016/j.biopsych.2017.02.327

Davis, K. L., Price, C. C., Kaplan, E., & Libon, D. J. (2002). Error Analysis of the Nine-Word California Verbal Learning Test (CVLT-9) Among Older Adults With and Without Dementia. The Clinical Neuropsychologist, 16(1), 81–89. doi.org/10.1076/clin.16.1.81.8330

Delis, D. C., Kramer, J. H., Kaplan, E., & Ober, B. A. (1987). California Verbal Learning Test, Research Edition, Adult Version. *CVLT*.

Ebert, P. L., & Anderson, N. D. (2009). Proactive and retroactive interference in young adults, healthy older adults, and older adults with amnestic mild cognitive impairment. *Journal of the International Neuropsychological Society: JINS*, *15*(1), 83–93. doi.org/10.1017/S1355617708090115

Fuld, P. A. (1980). Guaranteed stimulus-processing in the evaluation of memory and learning. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *16*(2), 255–271.

Fuld, P. A., Katzman, R., Davies, P., & Terry, R. D. (1982). Intrusions as a sign of Alzheimer dementia chemical and pathological verification. *Annals of Neurology*, *11*(2), 155–159. doi.org/10.1002/ana.410110208

Hart, S., Smith, C. M., & Swash, M. (1986). Intrusion errors in Alzheimer's disease. *British Journal of Clinical Psychology*, *25*(2), 149–150. doi.org/10.1111/j.2044-8260.1986.tb00686.x

Landau, S. M., Horng, A., Jagust, W. J. & Alzheimer's Disease Neuroimaging Initiative (2018). Memory decline accompanies subthreshold amyloid accumulation. Neurology. Mar 23. doi: 10.1212/WNL.0000000000005354.

Libon, D. J., Bondi, M. W., Price, C. C., Lamar, M., Eppig, J., Wambach, D. M., … Penney, D. L. (2011). Verbal Serial List Learning in Mild Cognitive Impairment: A Profile Analysis of Interference, Forgetting, and Errors. *Journal of the International Neuropsychological Society, 17*(5), 905–914. doi.org/10.1017/S1355617711000944

Lezak, M. D. (2004). *Neuropsychological assessment*. Oxford University Press, USA.

Loewenstein, D. A., Acevedo, A., Luis, C., Crum, T., Barker, W. W., & Duara, R. (2004). Semantic interference deficits and the detection of mild Alzheimer's disease and mild cognitive impairment without dementia. *Journal of the International Neuropsychological Society: JINS*, *10*(1), 91–100. doi.org/10.1017/S1355617704101112

Loewenstein, DA.; Acevedo, A. Loewenstein Acevedo Scale for Semantic Interference and Learning: Manual of Procedures and Interpretation. Miami Beach, Florida: 2005.

Loewenstein, D. A., D'Elia, L., Guterman, A., Eisdorfer, C., Wilkie, F., LaRue, A., … & Duara, R. (1991). The occurrence of different intrusive errors in patients with Alzheimer's disease, multiple cerebral infarctions, and major depression. *Brain and Cognition*, *16*(1), 104–117. doi.org/10.1016/0278-2626(91)90088-P

Loewenstein, D. A., Curiel, R. E., Duara, R., & Buschke, H. (2017). Novel cognitive paradigms for the detection of memory impairment in preclinical Alzheimer's disease. Assessment, 1-12. doi.org/10.1177/1073191117691608

Loewenstein, D. A., Curiel, R. E., Greig, M. T., Bauer, R. M., Rosado, M., Bowers, D., … & Duara, R. (2016). A Novel Cognitive Stress Test for the Detection of Preclinical Alzheimer Disease: Discriminative Properties and Relation to Amyloid Load. *The American Journal of Geriatric Psychiatry: Official Journal of the American Association for Geriatric Psychiatry*, *24*(10), 804–813. doi.org/10.1016/j.jagp.2016.02.056

Mascali, D., DiNuzzo, M., Serra, L., Mangia, S., Maraviglia, B., Bozzali, M., & Giove, F. (2018). Disruption of Semantic Network in Mild Alzheimer's Disease Revealed by Resting-State fMRI. *Neuroscience*, *371*, 38-48.

McKhann, G. M., Knopman, D. S., Chertkow, H., Hyman, B. T., Jack, C. R., Kawas, C. H., … Phelps, C. H. (2011). The diagnosis of dementia due to Alzheimer's disease: recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia: The Journal of the Alzheimer's Association*, *7*(3), 263–269. doi.org/10.1016/j.jalz.2011.03.005

Morris, J. C., Storandt, M., Miller, J. P., McKeel, D. W., Price, J. L., Rubin, E. H., & Berg, L. (2001). Mild cognitive impairment represents early-stage Alzheimer disease. *Archives of Neurology*, *58*(3), 397–405.

Mulatti, C., Calia, C., De Caro, M. F., & Della Sala, S. (2014). The cumulative semantic interference effect in normal and pathological ageing. *Neuropsychologia*, *65*, 125–130. doi.org/10.1016/j.neuropsychologia.2014.10.007

Petersen, R. C., Doody, R., Kurz, A., Mohs, R. C., Morris, J. C., Rabins, P. V., … Winblad, B. (2001). Current Concepts in Mild Cognitive Impairment. *Archives of Neurology*, *58*(12), 1985–1992. doi.org/10.1001/archneur.58.12.1985

Petersen, R. C., Smith, G. E., Waring, S. C., Ivnik, R. J., Tangalos, E. G., & Kokmen, E. (1999). Mild cognitive impairment: clinical characterization and outcome. Archives of neurology, 56(3), 303-308.

Pfeffer, R. T., Kuroski, C., Harrah, J., Chance, J. M., & Filos, S. (1982). Measurement of functional activities of older adults in community. Journal of Gerontology, 37(3), 323–329.

Rey, A. (1964). L'examen clinique en psychologie [The clinical psychological examination]. Paris, France: Presses Universitaires de France

Roberts, R., & Knopman, D. S. (2013). Classification and Epidemiology of MCI. *Clinics in Geriatric Medicine*, *29*(4), 753–772. doi.org/10.1016/j.cger.2013.07.003

Rosselli, M., Loewenstein, D. A., Curiel, R. E., Peñate, A., Torres, V. L., Lang, M., Greig, M.T., Baker, W.W., Duara, R. (submitted). The Effects of Bilingualism on Verbal and Nonverbal Memory Measures in Mild Cognitive Impairment (MCI). *Journal of the International Neuropsychological Society.*

Rouleau, I., Imbault, H., Laframboise, M., & Bédard, M. A. (2001). Pattern of intrusions in verbal recall: Comparison of Alzheimer's disease, Parkinson's disease, and frontal lobe dementia. *Brain and Cognition*, *46*(1–2), 244–249. doi.org/10.1016/S0278-2626(01)80076-2

Schram, L. L., Rubert, M., & Loewenstein, D. A. (1995). A qualitative analysis of semantic intrusive errors in Alzheimer's disease. Archives of Clinical Neuropsychology, 10(3), 255–263. doi.org/10.1016/0887-6177(94)00044-Q

Thomas, K. R., Eppig, J., Edmonds, E. C., Jacobs, D. M., Libon, D. J., Au, R., . . . The Alzheimer's Disease Neuroimaging Initiative. (2018). Word-list intrusion errors predict progression to mild cognitive impairment. Neuropsychology, 32(2), 235-245. doi.org.ezproxy.fau.edu/10.1037/neu0000413

Uzzell, B. P., Pontón, M. O., & Ardila, A. (2007). International Handbook of Cross-Cultural Neuropsychology. Mahwah, NJ: Lawrence Erlbaum Associates

Vogel, A., Johannsen, P., Stokholm, J., & Jørgensen, K. (2014). Frequency and severity of semantic deficits in a consecutive memory clinic cohort. *Dementia and geriatric cognitive disorders*, *38*(3-4), 214-223.

Weissberger, G. H., Salmon, D. P., Bondi, M. W., & Gollan, T. H. (2013). Which neuropsychological tests predict progression to Alzheimer's disease in Hispanics? *Neuropsychology, 27*(3), 343-355. doi.org.ezproxy.fau.edu/10.1037/a0032399