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Statistical learning of foreign language words in younger and older adults

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Abstract

Statistical learning, that is, our ability to track and learn from distributional information in the environment, plays a fundamental role in language acquisition, yet little research has investigated this process in older language learners. In the present study, we address this gap by comparing the cross-situational learning of foreign words in younger and older adults. We also tested whether learning was affected by previous experience with multiple languages. We found that both age groups successfully learned the novel words after a short exposure period, confirming that statistical learning ability is preserved in late adulthood. However, the two groups differed in their learning trajectories, with the younger group outperforming the older group during the later stages of learning. Previous language experience did not predict learning outcomes. Given that implicit language learning mechanisms are shown to be preserved over the lifespan, the present data provide crucial support for the assumptions underlying claims that language learning interventions in older age could be leveraged as a targeted intervention to help build or maintain resilience to age-related cognitive decline.

Highlights

- Statistical learning of non-native (L2) words is preserved in older adults.
- However, younger adults outperformed older adults during the later stages of the learning task.
- In contrast to previous research, prior language experience did not predict learning outcomes.
- Statistical learning could serve as an intervention to build resilience to age-related cognitive decline.

1. Introduction

Statistical learning, that is, our ability to track and learn from distributional information in the environment, plays a fundamental role in human cognition (Frost et al., 2019; Rebuschat, 2022). While statistical learning is clearly relevant in many domains of cognition, much, if not most, empirical research has focused on the contribution of statistical learning to language acquisition. Following close to three decades of research, it is well established that infants, children and young adults can rapidly learn sounds (e.g., Maye & Gerken, 2000; Maye et al., 2002), words (e.g., Saffran et al., 1996; Smith & Yu, 2008; Yu & Smith, 2007) and parts of the grammar (e.g., Monaghan et al., 2019; Rebuschat et al., 2021) of their native language(s) by statistically tracking linguistic properties in the input (see Isbilen & Christiansen, 2022; Siegelman, 2020; Williams & Rebuschat, 2023, for reviews). Recent research further confirms that statistical learning also plays a role in non-native (L2) language learning, for example, in the acquisition of non-native sounds and words (e.g., Escudero et al., 2022; Ge et al., in press; Tuninetti et al., 2020) as well as in heritage language bilingualism (Ge et al., 2024). While the systematic empirical exploration has greatly advanced our understanding of the role of statistical learning in language acquisition, there are still several important gaps in our knowledge (Rebuschat, 2022). These include our limited understanding of statistical learning over the lifespan, for example, in older populations, as most research has focused on children and young adults (see Bulgarelli et al., 2021, for an exception).

The above limitation is problematic on several levels. To begin, thanks to advances in health care, average lifespan is increasing and, given declining birth rates, many societies are witnessing significant increases in the proportion of older adults. In fact, in some countries, the elderly are already the largest (or only) expanding age demographic (World Health Organization [WHO], 2022). It is, thus, important to gain a much better understanding of age-related cognitive changes, which could include declines in statistical learning capacity in general and/or for language learning in particular. This is especially relevant given that language learning in late adulthood has been identified as one potential cognitively challenging task that, in isolation or combined with other engagements, could be leveraged as a targeted intervention to help build, maintain or foster resilience (cognitive reserve) to age-related cognitive decline and/or psychosocial rehabilitation in older age (e.g., Pikhart & Klimova, 2020; Pikhart et al., 2021; Nilsson et al., 2021; van der Ploeg, 2023; Qian et al., 2024; Yow et al., 2024). Although considerable research shows that statistical language learning is effective in children and young adults, it is worth investigating if and how the same mechanism functions in older populations. Doing so would enable us to (i) better understand how older adults acquire novel languages, (ii) provide a needed foundation for the claim that older-aged language learning has the potential to serve as a therapeutic intervention in the context of cognitive aging and, if needed, (iii) develop and inform bespoke pedagogical interventions to support language learning in late adulthood. The present study directly contributes to these important gaps by exploring how older adults, as compared to younger ones, learn novel foreign language vocabulary via cross-situational statistical learning (Yu & Smith, 2007; Ge et al., in press) and whether learners' prior language experience influences learning outcomes.

1.1. Statistical learning in older adults

Although research on statistical learning has focused predominantly on infants, children and young adults, a few studies have tested this ability in older populations with nonlinguistic tasks (e.g., Curran, 1997; Howard & Howard, 1997, 2013; Howard et al., 2004; Janacsek et al., 2012). For example, using the Alternating Serial Response Time (ASRT) task, Howard and Howard (1997) observed a preserved but gradually reduced ability to learn and respond to recurring sequences as age increases. This age deficit has also been observed in more language-like statistical learning tasks. In the case of visual statistical learning, when presented with picture sequences with embedded regularities, both younger and older adults were able to extract the regularities, but the younger learners tended to outperform the older ones (e.g., Campbell et al., 2012; Cox & Davis, 2022). Similarly, in auditory statistical learning, when streams of auditory sounds were played with embedded transitional probabilities (i.e., sound A was more probable to follow sound B than sound C), both younger and older adults could track the distributional information and extract probable words (i.e., sound sequences) from the pattern. However, the younger group tended to outperform the older group in distinguishing probable words from part-words (i.e., sound sequences that crossed word boundaries in the stream) (Palmer et al., 2018).

More recently, Bulgarelli et al. (2021) used a cross-situational word learning (CWSL) paradigm (e.g., Yu & Smith, 2007; Monaghan et al., 2019) to directly investigate statistical learning of language in older adults. In the training phase of their CSWL paradigm, participants were presented with novel words (e.g., *callute* and *pangle*) and unfamiliar objects (black-and-white shapes) under conditions of referential uncertainty. In each learning trial, participants would see two (or more) objects on the screen and hear two (or more) pseudowords, with no indication of which object each word referred to. The location of the object on the screen and the presentation sequence of the auditory pseudowords were unrelated, so it was not possible to figure out the mappings from one single trial. However, the mappings were learnable if learners were able to track statistics across learning trials. In the test phase, Bulgarelli and colleagues observed that older adults (mean age 72) could rapidly learn the word-referent mappings, even in highly ambiguous conditions when four words and four pictures were presented in each learning trial. However, their performance was significantly lower compared to that of younger adults (mean age 20 years). This study provided direct evidence that statistical language learning might be preserved in older adults, but it also suggests that there might be age-related declines in learning outcomes. However, the pseudowords used in Bulgarelli et al.'s (2021) study were based on the participants' native language (English) and, thus, the novel words contained phonemes that were familiar to the participants (in the sense that they existed in participants' L1) and phoneme combinations that followed the phonotactics of English. While this seemingly confirms that statistical learning remains operative over the lifespan (at least for the case of learning novel words from one's native language), it cannot be taken for granted from such evidence that statistical learning, and specifically cross-situational statistical learning, contributes to non-native language (L2) learning in older adulthood. And yet, (dis)confirming this is the case is particularly important in the context of claims identifying novel L2/L*n* as a powerful intervention tool for building and maintaining cognitive reserve (Pikhart & Klimova, 2020; Gallo & Abutalebi, 2023; van der Ploeg et al., 2023). In the current study, we will address this question by training older adults with non-native words by means of a CSWL paradigm.

1.2. The effect of language experience

In addition to investigating CSWL of a non-native language in younger and older adults, we will also explore how prior language experience interacts with statistical word learning. Previous research has reported positive effects of previous bilingualism in CSWL under certain conditions, such as learning minimal pair words (Escudero et al., 2016), accommodating exemplar and speaker variabilities (Crespo et al., 2023), and resolving 2-1 word-referent mappings (i.e., when each referent had two labels rather than one; Benitez et al., 2016; Poepsel & Weiss, 2016). However, it is unknown whether such a facilitative role of bi/multilingual language experience holds for older adults. Moreover, previous research treated language experience as a dichotomous variable, dividing participants into distinct groups of monolinguals and bi/multilinguals, based on participants' self-identification or report. This is problematic as participants often under- or overestimate their linguistic abilities and experiences (see Rothman et al., 2023a, for discussion). Such dichotomous categorization also goes against more recent discussions and practices in bilingualism research, problematizing the (default) use of monolingual comparisons and/or the unnuanced treatment of aggregated bilingual individuals monolithically (De Houwer, 2023; Rothman et al., 2023b). Indeed, individuals' linguistic engagement and diversity can vary significantly across dimensions and contexts. As a result, it is not at all a straightforward task to classify individuals as "monolingual" or "bilingual." Moreover, even when individuals can be meaningfully categorized as a type of "monolingual" or "bilingual," functionally ignoring individual differences in one's dynamic language exposure and usage patterns can obscure important patterns (e.g., DeLuca et al., 2019; Luk & Bialystok, 2013; Bice & Kroll, 2019; Titone & Tiv, 2023; Rothman et al., 2023a, 2023b). Simply put, language experience consists of multiple dimensions (e.g., quality and quantity of language use in a diversity of contexts) and should be considered continuously. Given that everyone's linguistic profile is unique and dynamic,

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depending on the research question, it is not always useful or meaningful to treat anyone's language performance as a presumed "baseline" (e.g., monolingual versus bilingual).

While there are multiple questionnaires that could be used (see Dass et al., 2024; Rothman et al., 2023a for review), here we employ Anderson et al.'s (2018) Language and Social Background Questionnaire (LSBQ) to measure participants' language experience in a more thorough fashion than previous statistical learning studies have done. The LSBQ records participants' language background and language use in different communicative contexts (e.g., at home, at work and in social settings), offering a series of composite scores (e.g., home score and social score) as well as an aggregated overall "bilingualism score" meant to reflect participants' bilingual language engagement. Thus, the LSBQ helps quantify individual degree of bilingualism, and the composite scores have been successfully used as a continuous variable or predictor in statistical analyses of bilingualism effects (e.g., DeLuca et al., 2019, 2020; Pliatsikas et al., 2021; Champoux- Larsson & Dylman, 2021; Mann & de Bruin, 2022; Tomić et al., 2023; see Anderson et al., 2020, for discussion about differences in factor relevance at distinct stages across the lifespan). This is a different, much more fine-grained measure of language experience as compared to previous work on the bilingualism effect in CSWL, where participants were divided into "bilingual" and "monolingual" groups based on their self-reported language experience (e.g., Escudero et al., 2016; Poepsel & Weiss, 2016).

1.3. Research questions and predictions

In the present study, we examined statistical learning of novel, non-native words across different age groups. The following research questions were addressed:

RQ1: Can older adults learn non-native (L2) words by keeping track of cross-situational statistics?

RQ2: Do older adults perform differently from younger adults in CSWL?

RQ3: Does previous language experience affect non-native word learning?

Based on previous research on statistical learning in older populations, including Bulgarelli et al. (2021), we predicted that both our younger and older participants (all native speakers of Mandarin) would be able to learn novel non-native words (Portuguese pseudowords) by keeping track of cross-situational statistics (RQ1), but that the performance of older learners would be lower than that of their younger counterparts because of age-related decline in statistical learning ability (RQ2). Additionally, in line with the argued additive effect of bilingualism on subsequent language learning (Cenoz, 2003) and evidence that prior bilingual experience can convey faciliatory effects in CSWL (e.g., Escudero et al., 2016; Poepsel & Weiss, 2016), we expected participants who were already bilingual to perform better in the word learning task. Given that the LSBQ data would allow for a regression of degree of bilingualism as a continuous variable, we pursued the idea that degree of bilingualism itself would calibrate to better performance as a function of increased experience/usage of multiple languages (RQ3).

2. Methods

2.1. Participants

Forty adult native speakers of Mandarin Chinese participated in this study (28 women and 12 men). Participants were divided into two groups, one with younger adults (n = 22, M_{age} = 23, range 20–34 years) and one with older adults (n = 18, M_{age} = 68.94, range 59–89 years).[1] The age groups were decided based on previous statistical learning studies with older learners (Bulgarelli et al., 2021; Campbell et al., 2012). All participants resided in China at the time of testing, and none had learned Portuguese before or had previously resided in a Portuguese-speaking country. We used the LSBQ (Anderson et al., 2018) to determine participants' linguistic backgrounds (e.g., language proficiency and language use at home and societal contexts) and to assess the degree to which they were actively bilingual.

To estimate the sample size needed for expected effects, we ran power analyses for the interaction effect of age group and block with Monte Carlo simulations of data. The expected power of an interaction effect reached above .80 with 20 participants per group. The study was approved by the ethics review panel of the *Anonymized for review*. Participants were not remunerated in this study.

2.2. Materials

2.2.1. Pseudowords and visual referents

Twelve consonants (/d, k, l, ʎ, m, n, ɲ, p, s, t/) and six vowels (/a, e, ɛ, i, u, o, ɔ/) from the Portuguese phonemic inventory were combined to create 12 pseudowords. Each pseudoword was disyllabic with CVCV structure and followed the phonotactics of Portuguese. The linguistic focus in our study was on four segments that are phonemic in Portuguese but not in Mandarin. Two of these target segments were consonants, namely, /ɲ/ (e.g., Portuguese *manha*, "ruse") and /ʀ/ (*carro*, "car"), and the other two were vowels, namely, /ɛ/ (*sede*, "head office") and /ĩ/ (*pinta*, "dot"). The pseudowords have no corresponding meaning in Mandarin or Portuguese. Table 1 presents the pseudowords created. The audio stimuli were recorded by a female native speaker of Portuguese, and the mean length of the audio stimuli was 500 ms. We did not use any written representation of the pseudowords.

We chose 12 novel and unusual objects from Horst and Hout's (2016) NOUN database as referents for our pseudowords. The pseudowords were randomly mapped to the objects, and we created three lists of word-referent mappings to minimize the influence of a

Table 1. The phonological segments and pseudowords used in this study

Categories	Target segments	Pseudowords		
Consonants	/ɲ/	/kiɲu/	/suɲu/	/toɲu/
	/ʀ/	/ʀifu/	/ʀebu/	/ʀogu/
Vowels	/ɛ/	/dɛtu/	/kɛpu/	/pɛmu/
	/ĩ/	/sĩdu/	/bĩzu/	/fĩgu/

[1]Our initial data collection targeted 20 younger adults and 20 older adults. However, when analyzing the data, we found that two participants who were 22 and 32 years old mistakenly entered the experiment link for the older group and completed the tasks. Since the tasks were identical for the two groups, we reassigned these two participants to the younger group in analyses. Hence, we had 22 participants in the younger group and 18 in the older group.

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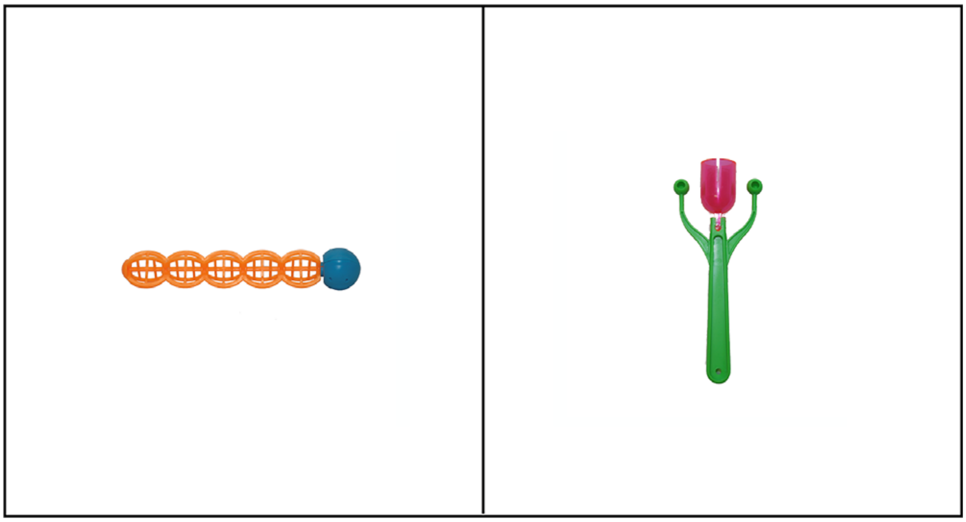

Figure 1. Example of a cross-situational word learning (CSWL) trial. Participants were presented with two novel objects and one spoken word (e.g., /ʀifu/). Participants had to decide, as quickly and accurately as possible, if the word referred to the object on the left or right of the screen. No feedback was provided on response accuracy.

particular mapping being more memorizable than other mappings. Each participant was randomly assigned to one of the mappings. All materials are available on our OSF project site: https://osf.io/mptd3/.

2.2.2. Language and Social Background Questionnaire

We used the LSBQ (Anderson et al., 2018) to gather information about participants' language background, to determine whether participants could be considered bilingual or not and, if the latter, their patterns of dual language usage. The questionnaire includes 22 items divided into three sections: (1) demographic information (i.e., age, education and years of living abroad), (2) language background (i.e., language proficiency of each linguistic skill) and (3) community language use (i.e., language use when interacting with friends, family and siblings in various social contexts, e.g., home, work and social gatherings). The second and the third sections in the questionnaire enable researchers to calculate a composite "bilingualism score," which represents the degree of engagement individuals have with their language(s). A higher score (above 1.23) indicates degree of bilingualism, and a lower score (−3.13) indicates monolingualism. Note, however, that we treat language experience as a continuous variable, in line with current practice (e.g., DeLuca et al., 2019, 2020; Pliatsikas et al., 2021) and as described above. The questionnaire takes around 10 minutes to complete.

2.3. Procedure

We used the Gorilla research platform (https://app.gorilla.sc/) to collect data. All tasks were administered in Mandarin. After successfully completing a sound check and providing informed consent, participants completed a CSWL task. The study concluded with the completion of the LSBQ.

In the CSWL task, participants were told that they would hear one word and see two objects on the screen. Their task was to decide, as quickly and accurately as possible, which object the word referred to. They were instructed to press "Q" on the keyboard if they thought the object on the left was the correct referent of the word and "P" for the object on the right. Since the task was very simple, no practice trials were administered.

In each trial, participants first saw a fixation cross at the center of the screen for 500 ms. They were then shown two objects on the screen (one on the left side and one on the right) and were played a single pseudoword. After the pseudoword was played, participants were prompted to enter their response on the keyboard (Q or P). The objects remained on the screen during the entire trial, but the pseudoword was only played once. The next trial only started after participants made a choice for the current one. No feedback was provided after each response. We recorded the keyboard responses in each trial to calculate accuracy and response times. Figure 1 provides an example of a CSWL trial.

Each participant completed six cross-situational learning blocks, with each pseudoword-object mapping occurring twice per block. There were thus 24 trials per block, and 144 trials in total. The order of trials within each block was randomized for each participant as was the sequence in which the six blocks occurred.

2.4. Data analysis

We excluded participants who failed to successfully complete the initial sound check or failed to complete the CSWL task within one hour. We also excluded individual responses that lasted over 30 seconds. This was because these participants failed to follow the instruction to respond as quickly and accurately as possible. After excluding these data points, we visualized the data using R for general descriptive patterns. We then used generalized linear mixed effects modeling for statistical data analysis. Mixed effects models were constructed from a null model (containing only random effects of item and participant) to models containing fixed effects. We tested if each of the fixed effects of age group and block improved model fit using log-likelihood comparisons between models. A quadratic effect of block was also tested for its contribution to model fit, as block may exert a quadratic rather than linear effect. This allows us to determine if learning is linear or not over training – a linear block effect indicates that participants' performance (accuracy) increases over the training blocks constantly, whereas a quadratic block effect indicates that performance increases more rapidly during the middle part of training and is asymptotic toward the end of training.

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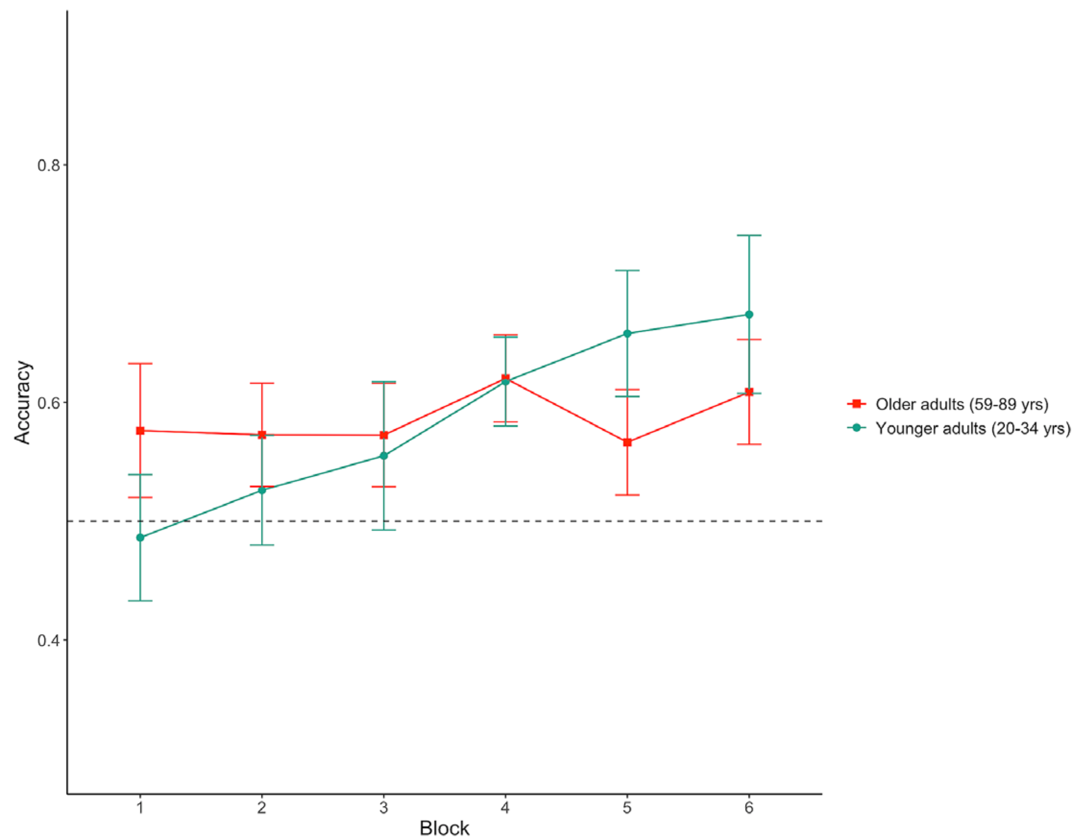

Figure 2. Mean proportion of correct pictures selected in each block of the CSWL task.

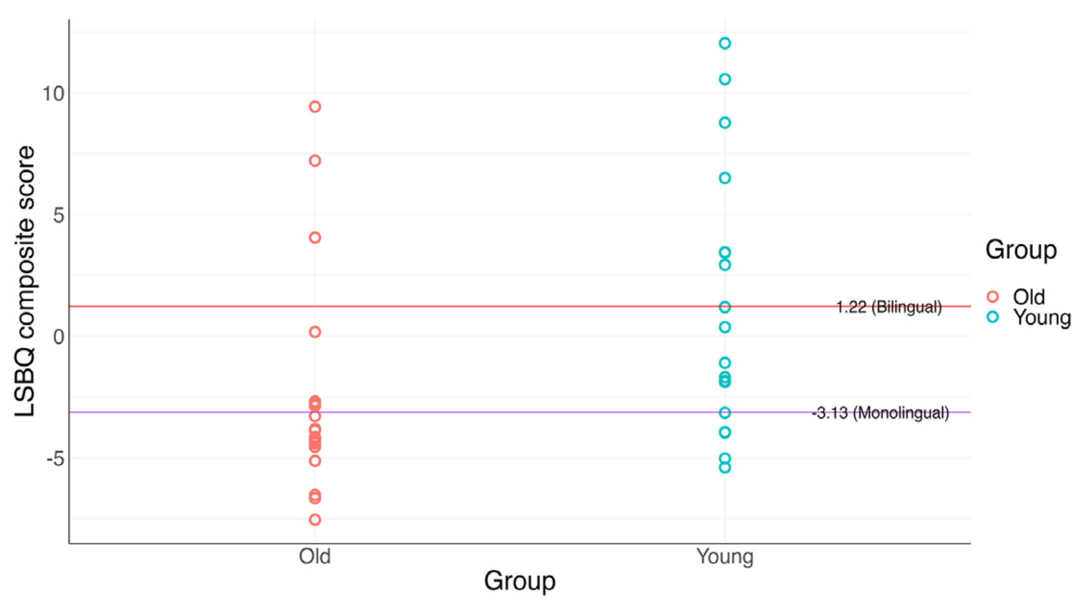

Figure 3. The degree of dual language engagement for each participant based on LSBQ composite score. Following Anderson et al. (2018), a higher LSBQ score of 1.22 or above would indicate bilingualism and a score of −3.13 or below monolingualism.

3. Results

3.1. Performance on the CSWL task

Both the younger and older adult groups showed clear learning effects, with the younger adults performing above chance from Block 4 (i.e., after 96 trials) and the older adults from Block 1 (after only 24 trials). This confirms previous findings that older adults preserved the ability to learn words from cross-situational statistics (Bulgarelli et al., 2021), but it demonstrates, for the first time, that this ability applies to non-native (L2) learning as well. Figure 2 presents the overall percentage of correct responses of the younger

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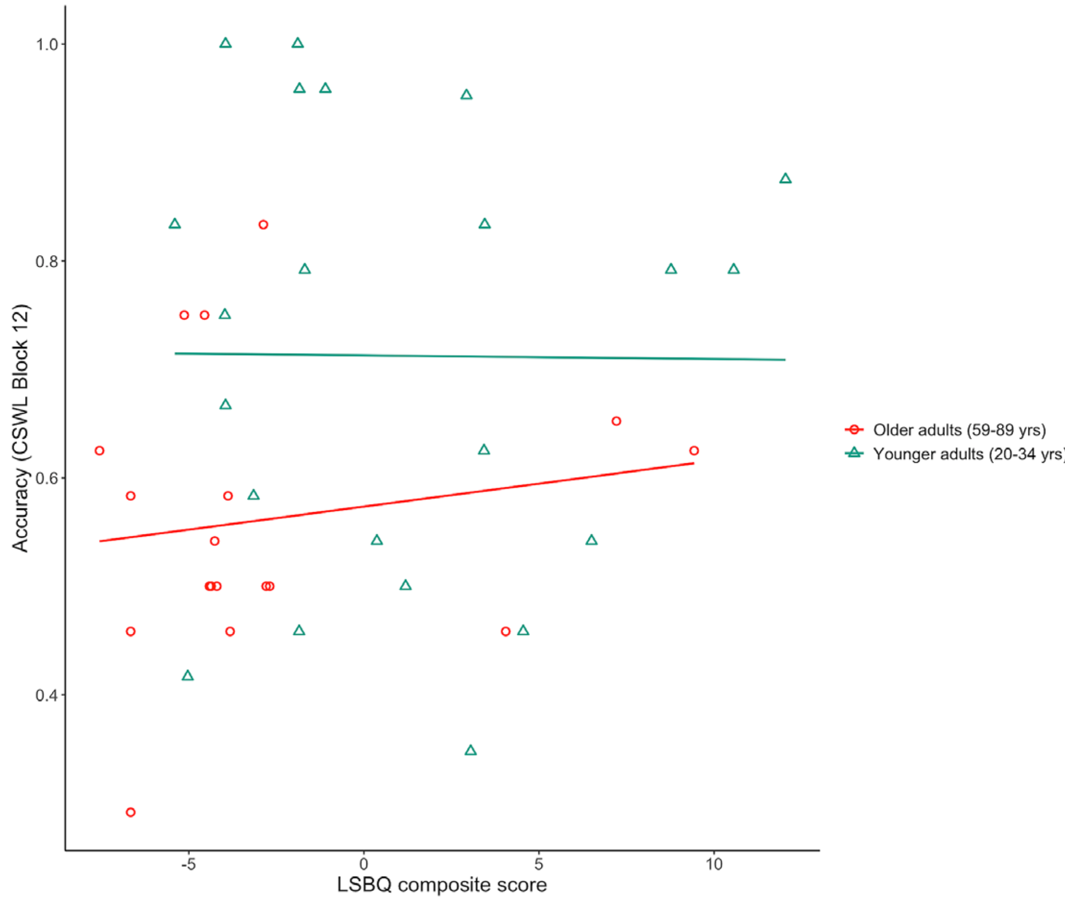

Figure 4. Correlation of CSWL accuracy and LSBQ composite score.

Table 2. Mean accuracy (overall) and standard deviations across the six blocks of the CSWL task

Group		Block 1	2	3	4	5	6
Younger	M	0.49	0.53	0.55 *	0.62 ***	0.66 ***	0.67 ***
	SD	0.12	0.10	0.14	0.08	0.12	0.15
Older	M	0.58 **	0.57 **	0.57 **	0.62 ***	0.57 **	0.61 ***
	SD	0.11	0.09	0.09	0.07	0.09	0.09

Note:
*$p < 0.05$
**$p < 0.01$
***$p < 0.001$ (against chance level 0.5)

Table 3 Estimates of best-fitting model for accuracy in CSWL

Fixed effects	Estimate	SD error	z value	*p* value
(Intercept)	0.068	0.103	0.660	0.509
Block	0.029	0.042	0.683	0.495
Younger group	−0.206	0.143	−1.437	0.151
Block: younger group	0.173	0.060	2.871	0.004 **

Number of observations: 5707, participants: 40, item, 12. AIC = 7514.8, BIC = 7627.8, log-likelihood = −3740.4.
R syntax: glmer(acc ~ block + agegroup + block:agegroup + (1 + block*agegroup | Pseudoword) + (1 + block | subjectID), family = binomial)

and older adult groups. Table 2 summarizes overall response accuracy across the six blocks of the CSWL task.

We ran generalized linear mixed effects models to investigate whether learning performance was different between younger and older adults. We started from a model with the maximal random effects that converge, which included item slope for the interaction between learning block and participant group, and participant slope for learning block. Then we added fixed effects of learning block, group and the block*group interaction in order to test if they improved model fit. We also tested for a quadratic effect for block.

Compared to the empty model, adding the fixed effect of learning block (χ^2 (1) = 9.3301, p = 0.002) improved model fit, but the main effect of age group (younger vs. older adults) did not (χ^2 (1) = 1.0505, p = 0.305). The block*group interaction improved model fit (χ^2 (1) = 7.3756, p = 0.007). Adding the quadratic effect for block did not result in a significant difference (χ^2(2) = 0.171, p = 0.918). The best-fitting model is reported in Table 3. This suggests that the older and younger groups had significantly different learning trajectories across blocks. The older group reached an above-chance performance earlier but remained at a stable accuracy afterward, while the younger group showed steady improvement throughout the blocks and outperformed the older group in the second half of the learning task.

3.2. Language and Social Background Questionnaire

Our analyses showed that the LSBQ composite score for the younger adults was 0.77 (SD = 5.25) and for the older adults –

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2.89 (SD = 4.31). This suggests that older learners tended to be more functionally monolingual than the younger learners and that most participants had diverse language backgrounds across a considerable spectrum, even for a majority of functional monolinguals not meeting the threshold for what one would consider truly bilingual. Following the classification proposed by Anderson and colleagues, in the younger adult group, six participants were unambiguously monolingual, seven displayed significant degrees of linguistic diversity albeit still falling under a classification of functional monolingualism and seven were unambiguously bilingual. In the older adult group, following the same order as described for the younger group, the numbers were 15, 5 and 3, respectively. For further discussion of the LSBQ and of the interpretation of individual and composite factor scores, see Anderson et al. (2018). The descriptive statistics for the LSBQ items can be found in Table 4 in the Appendix. Figure 3 visualizes the distribution of the LSBQ scores in the two groups, demonstrating that participants' degree of dual language engagement and use within our sample hits the entire spectral array. It is thus inappropriate to simply divide them into "monolingual" versus "bilingual" groups.

3.3. The relationship between language background, age and cross-situational learning

Figure 4 represents the relationship between the LSBQ composite scores and the accuracy in the final block of the CSWL task, which represents learning outcomes. For both groups, we failed to observe significant correlations, younger adults, rho = −0.065, $p = 0.773$, and older adults, rho = 0.058, $p = 0.820$. Additionally, to better understand whether and how LSBQ scores interact with the learning trajectory and different age groups, we ran generalized linear mixed effects models with LSBQ composite score as a fixed effect, as well as the block*LSBQ interaction, the age group*LSBQ interaction and the 3-way interaction between block, age group and LSBQ. However, the addition of none of these fixed effects led to significant improvement in mixed effects model fit (LSBQ: χ^2 (1) = 0.9069, $p = 0.341$; block*LSBQ: χ^2 (1) = 1.0117, $p = 0.315$; age group*LSBQ: χ^2 (2) = 1.2279, $p = 0.541$; 3-way interaction: χ^2 (2) = 1.3951, $p = 0.498$). These findings indicate that the degree of mono/bilingualism was not associated with variations in individuals' word learning performance.

4. Discussion

In the present study, we investigated non-native word learning in younger and older adults by means of a cross-situational statistical learning paradigm. Our results suggest that a short exposure of around ten minutes is powerful enough for older adults to learn novel words by tracking cross-situational statistics. Moreover, we collected information on participants' bi/multilingual experience. Although we found no direct association between bi/multilingual experience and performance in the word learning task, the use of the LSBQ composite score as a continuous measure of language experience allowed us to better understand participants' language profiles and differences.

RQ1: *Can older adults learn non-native words from cross-situational statistical learning?*

As predicted, the older participants successfully learned the non-native Portuguese pseudowords from cross-situational statistics, and their learning was rapid: performance was above chance from the first block. This means that the ability to quickly pick up statistical regularities from the input is preserved in late adulthood, consistent with Bulgarelli et al.'s (2021) findings. Moreover, the inclusion of non-native speech sounds and phonotactics did not pose substantial difficulty in learning. As such, these findings are particularly insightful for questions related to the potential utility of cognitive training interventions for older adults targeting or including foreign language learning as an intervention.

Obviously, for foreign language learning to be a viable cognitive training intervention several things need to be true. The present study provides much needed evidence for one dimension of the fundamentals that must be true, showing that older adults retain sufficient statistical learning abilities to learn new languages. To date, this has surprisingly not been well documented, but rather functionally assumed. While limited previous work with older adults has shown that statistical learning needed for language learning is preserved in older age (Bulgarelli et al., 2021), it was not at all clear previously how such evidence would actually translate into insights for foreign language intervention. This is the case because, as discussed above, existing work had targeted pseudoword learning following the phonotactics of the participants' L1. As such, what was previously shown was that older adults have the statical learning ability needed under a CSWL paradigm to learn new words in their L1. On this basis, would one be justified *a priori* to assume that sufficiently preserved statistical learning ability needed for foreign language learning is intact? In other words, is this equally true for foreign language learning when, among other variables, language-specific differences in how words are formed must be considered (e.g., when words in foreign languages present novel phonological contrast such as phonemes absent in the L1 inventory and distinct syllable structure)? Simply put, while previous research has offered some promise that older adults could have sufficiently preserved statistical learning abilities needed for foreign language learning (e.g., if they did not for pseudoword learning with the phonotactics of the L1 that would likely preclude it outright for novel language learning), CSWL work like the present was needed to resolve the latent question of applicability to novel language learning in older adults. As such, by confirming that indeed older adults have sufficiently preserved statistical learning ability to meaningfully engage in such an intervention itself, the present results provide needed, yet lacking evidence of what would have needed to be true to support the functionality/appropriateness of utilizing foreign language learning in the older age as a viable, testable cognitive intervention. Of course, research like the present has nothing to contribute to discussions on the actual effectiveness of foreign language learning as a cognitive training intervenor *per se*, but rather serves the growing body of literature looking into foreign language intervention in the older age as a potential means to affect preserved (or gain newly acquired) cognitive resilience by showing that an underlying, critical assumption inherent to adopting novel language as a potential intervention in older adults is on the right track in the first place. Moreover, the present research goes beyond this important confirmatory offering by highlighting how foreign language learning in late adulthood can benefit from implicit exposure to linguistic input, even when instructions and feedback are not provided.

RQ2: *Do older adults perform differently from younger adults in CSWL?*

The older and the younger participants showed interesting differences in learning trajectories throughout the CSWL task. First, like

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Bulgarelli et al. (2021), we observed that the younger learners demonstrated better learning outcomes at the final CSWL block than the older learners. However, since we also recorded participant responses across blocks (in contrast to Bulgarelli et al., 2021), our task design allowed us to plot the learning trajectories of participants. We found that the older learners started to improve and show above-chance performance earlier in the learning process compared to the younger learners, but their performance stayed relatively stable and did not further increase across blocks. The younger learners, on the other hand, exhibited steady improvement throughout the task and outperformed the older learners only in the second half of the task. It is worth noting that the overall average performance between the two groups did not differ significantly, indicating that the statistical learning ability may not vary greatly with age. Instead, the divergence in learning trajectories might result from age-related decline in the memory systems and strategic differences in learning. It has been documented that in late adulthood, declarative memory of semantic information (e.g., vocabulary and facts) faces a smaller degree of decline (Rönnlund et al., 2005), whereas implicit, procedural memory seems to be more affected by aging (Xie et al., 2023). Therefore, it is possible that older learners rely more on the explicit, declarative memory system and attempt to consciously retrieve words in learning. This strategy might allow them to selectively attend to the occurrence of a few objects and words, hence figuring out a few word-referent mappings quickly at the beginning. However, this strategy could be problematic when they try to associate more words with referents. First, it is more cognitively demanding to attend to and temporarily hold all the co-occurrence encounters until all word-referent mappings are resolved. Second, our task involved unusual referent objects for which participants were unlikely to have a verbalizable label. This would make the explicit retrieval of the semantic meanings more difficult. There is evidence that when unverbalizable objects are used as referents in CSWL, the learning process is supported by implicit rather than explicit memory (Wang, 2020). These might explain why the older learners did not continue to improve throughout CSWL, as their implicit memory system is subject to greater age-related decline, and they depended more on explicit memory. For the younger learners, however, this could be different, as they might be more flexible in retrieving explicit and implicit memory in the learning process. The initial switches between strategies might explain why they started to show above-chance performance later, but their better implicit memory allowed them to improve steadily throughout the task. All of this speaks to types of qualitative differences between younger and older participants that in principle accord neatly with insights from the aging and cognition literature more broadly.

However, there is yet another possibility to consider related to what would be more of a quantitative distinction between the two groups, namely, task fatigue, either as the main/sole driver of the differences we observed or in addition to/combination with the above qualitative ones. Such a combination would also accord with the general aging and cognition literature as many approaches assume/predict a combination of qualitative and quantitative source differences, for example, as under posterior-anterior shift in aging (PASA; Davis et al., 2008). Given the pattern of differences between the groups showing up in the second half of the experiment, we cannot preclude the possibility that the observed differences are in whole or in part due to fatigue effects. In this sense, it is useful to keep in mind the specifics of the differences between the groups: the older participants did well overall, but simply did not continue to improve after Block 4, whereas the younger group did so. However, the older participants' performance did not fall off *per se* either at that point; they simply maintained *status quo* and did not continue along an improvement trajectory as the younger group did. In general, good, something even enhanced (which we see in the present data), initial learning rates being accompanied by subsequent (anticipated) exhaustion of cognitive resources with increasing task difficulty is a pattern widely predicted for seniors by models of cognitive aging. And so, it could be the case that the trajectory differences we see in the present data relate more to such a fatigue effect than anything else or combine with other underlying qualitative reasons.

Future targeted work to determine if any of these insights are on the right is warranted. However, assuming for the moment that they are it is worth noting how some implications would make further links between research of the present type and the foreign language learning as a cognitive training intervention literature. While it might be the case that older adults rely more on explicit, declarative memory making it more cognitively challenging for them to learn a foreign language as the lexicon/language grows than for younger adults, this fact and/or explicitly testing it might prove particularly useful in the domain of intervention as opposed to the domain of language learning ease/success itself. Indeed, if on the right track it means that older adults are somewhat disadvantaged for the language learning task itself relative to younger adults, evidence for which the present study already brings to bear. But if, as a result, there is a trade-off in exercising cognition more as a result of the increased cognitive complexity inherent to incremental language learning in older adulthood then it is reasonable to hypothesize that the timing of foreign language learning as a cognitive intervention would have the greatest effect in the older age itself, precisely when it is needed most and being target in the relevant literature as a potential cognitive trainer. After all, the functional task of learning a foreign language does not change by how old a given learner is at onset, but if the same objective task (i.e., the language learning) becomes cognitively more challenging than it should be the case that same task increases its exercising capacity.

RQ3: *Does previous language experience facilitate non-native word learning?*

The analyses of the LSBQ responses and CSWL performance revealed that the language experience (degree of bilingual engagement) was not directly associated with non-native word learning. To quantify the degree of bilingual engagement, we computed a composite score based on participants' language(s) usage in different contexts and language proficiency (Anderson et al., 2018). The distribution of the composite scores indicated that participants' language experience and bilingualism status lie on a continuum and cannot be easily classified into monolingual versus bilingual groups. For our participants, it would be inaccurate to assign them to either a monolingual or bilingual group based on simple self-identification. This leaves an important message for future CSWL studies to explore potential bilingualism effects using a more reliable measure such as the LSBQ.

The lack of any effect correlated to LSBQ scores in this study could be due to the task design and complexity. Previous CSWL studies, which divided participants into "monolingual" and "bilingual" groups, usually observed a bilingual advantage in cross-situational learning. For example, in Poepsel and Weiss (2016), monolingual and bilingual participants performed similarly when the word-object mapping was one-to-one, but bilinguals outperformed monolinguals when the mapping was two-to-one, that is, when each word was associated with two referents. In this situation, participants with experience in multiple languages might be less constrained by mutual exclusivity (Byers-Heinlein & Werker, 2009; Houston-Price et al., 2010) and more willing to accept multiple-to-one word-meaning associations. Such an advantage was also found when fine details of word phonology were manipulated (i.e., manipulation of phonological overlap between words) (Escudero et al., 2016). In our study, we employed the basic CSWL paradigm with one-to-one mappings and no phonological overlaps between stimuli, which makes the task rely primarily on the fundamental statistical tracking ability. It is possible that this ability is not generally affected by previous language experience. Even in late adulthood, the statistical learning ability might be largely preserved (yet subject to decline) regardless of the degree of bilingualism. Language experience might only make a difference in learning conditions where potentially advantageous bilingual cognitive adaptations (e.g., phonological short-term memory and inhibitory control) play a role, for instance, when learners need to suppress certain irrelevant visual/auditory cues in novel word learning.

Another possibility is that our sample of older adults overall lies toward the monolingual side of the bilingualism spectrum, with a few being more bilingual. This might hinder any potential effect of bilingualism. Further studies could attempt to target older populations with more diverse language profiles and perform more like functional bilinguals.

5. Conclusion

In this paper, we reported findings on statistical word learning among the older population. Evidence supported previous results that statistical learning ability is preserved but declines in late adulthood and further confirms that older learners can also track statistical information to learn novel words from a foreign language. Our analyses of the language experience measure revealed no significant relationship between bilingual experience and statistical word learning performance among both the younger and older learners. These findings have implications for second/foreign language learning practice targeting the older population, suggesting that implicit exposure to the input is effective for older learners, too.

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Appendix

Table 4. Descriptive statistics for language and social background items from the LSBQ

Add here	Variables	Younger adults M	Younger adults SD	Older adults M	Older adults SD
	Parents' education	1.98	1.23	1.44	0.8
Non-Chinese home use and proficiency	Language used with grandparents	0.50	1.19	0.25	0.61
	Language used in infancy	0.32	0.72	0.08	0.28
	Code switching with family	0.91	1.02	0.79	1.06
	Non-Chinese understanding proficiency	63.64	29.04	49.54	41.27
	Non-Chinese language-speaking proficiency	55.45	30.19	44.08	40.28
	Language used with other relatives	0.41	1.05	0.29	0.62
	Language used in preschool	0.27	0.55	0.13	0.34
	Language used with parents	0.41	1.05	0.25	0.61
	Non-Chinese language-listening frequency	2.27	1.12	2	1.44
	Non-Chinese language-speaking frequency	2.05	1.09	2	1.5
	Language used at home	0.45	1.06	0.17	0.38
	Language used in primary school	0.41	0.59	0.25	0.61
	Language used for religious activities	0.55	1.21	0.36	0.5
	Language used with siblings	0.5	1.06	0.25	0.53
	Chinese listening frequency	3.41	0.96	3.79	0.51
	Language used for praying	0.08	0.28	0.4	0.52
	Language used in high school	0.45	0.6	0.29	0.62
	Chinese speaking frequency	3.41	0.96	3.79	0.51
Non-Chinese social use	Language used at work	0.37	0.68	0.3	0.63
	Language used at school	0.91	1.02	0.26	0.62
	Language used for health care, banks and government services	0.55	1.18	0.21	0.51
	Language used for shopping, restaurants and commercial services	0.64	1	0.25	0.61
	Language used for social activities	0.82	0.96	0.29	0.62
	Language used for e-mailing	0.82	1.3	0.27	0.46
	Language used with friends	0.41	0.59	0.38	0.71
	Language used for extracurricular activities	0.5	0.6	0.25	0.61
	Language used with roommates	0.27	0.46	0.25	0.61
	Language used for texting	0.82	1.3	0.2	0.41
	Language used on social media	0.86	0.99	0.4	0.74
	Language used for watching movies	1.09	1.06	0.25	0.53
	Language used for browsing the internet	0.64	0.85	0.32	0.58
	Code switching on social media	1.41	1.05	0.42	0.97
	Language used with neighbors	0.59	1.3	0.21	0.51
	Language used for watching TV/listening to radio	0.73	0.94	0.25	0.53
	Language used for writing lists	0.41	0.67	0.22	0.52
	Language used for reading	0.73	0.88	0.22	0.42
	Language used with partner	0.18	0.39	0.29	0.62
	Code switching with friends	1.55	0.96	0.92	1.1

(*Continued*)

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Table 4. (*Continued*)

Add here	Variables	Younger adults M	Younger adults SD	Older adults M	Older adults SD
Chinese proficiency	Chinese language understanding proficiency	94.55	9.12	94.58	11.03
	Chinese reading proficiency	94.09	9.08	90	22.46
	Chinese writing proficiency	94.55	8	87.5	22.89
	Chinese speaking proficiency	94.55	8	95	9.78
	Chinese writing frequency	3.41	1.01	2.96	0.86
	Composite scores	1.04	5.08	−**2.89**	**4.31**

Note: The items in the second and the third sections of LSBQ contribute to each participant's overall language use at home (marked as A. Non-Chinese home use and proficiency in the table), language use in social context (marked as B. Non-Chinese social use in the table) and language proficiency (marked as C. Chinese Proficiency in the table). The overall bilingualism scores at the bottom (i.e., composite scores) are calculated based on each item in the table. From sections A to C in the table above, lower scores refer to less exposure to second language (i.e., more exposure to native language). Participant who scores below −3.13 are considered "monolingual," while those who score above 1.23 are considered "bilingual" (scoring between −3.12 and 1.22 are neither monolingual nor bilingual).

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