The Effects of Linguistic Context on Word Recognition in Noise by Elderly Listeners Using Spanish Sentence Lists (SSL)

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Abstract This study evaluated the effects of the linguistic context on the recognition of words in noise in older listeners using the Spanish Sentence Lists. These sentences were developed based on the approach of the SPIN test for the English language, which contains high and low predictability (HP and LP) sentences. In addition, the relative contribution of peripheral hearing sensitivity, measured by pure-tone hearing thresholds (PTA), to the performance on both types of sentences was assessed in a regression analysis. The results showed that older listeners obtained benefits on word recognition from the linguistic context. PTA contributed significantly to explaining the variance in performance on both HP and LP sentences.

Keywords Word recognition · Noise · Linguistic context · Age effects

Introduction

Many older adults have difficulties understanding speech, especially in noise or cocktail-party conditions (Plomp 1978). The elevation of high-frequency hearing thresholds with age (Davis 1995; Divenji et al. 2005), along with individual differences in cognitive functioning (Gordon-Salant and Fitzgibbons 1997; Rönnberg et al. 2008; Wingfield and Stine-Morrow 2000; Wingfield and Tun 2007) seems to be the factor that most contributes to these difficulties (see Akeroyd 2008 for a review). By the age of 60, approximately 30% of individuals show age-related hearing loss, and by 80 years of age, nearly 50% of individuals are affected (Roth et al. 2011). Thus, the combined effects of increased pure-tone hearing thresholds (PTA) and noisy backgrounds, typical of everyday communication situations, cause these listeners to have considerable difficulties in understanding speech. The signal-to-noise ratio (SNR) is

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important in determining older listeners’ difficulty in listening to speech, with a positive relationship being found between SNR and speech perception (Helfer 2009).

However, older listeners may use the knowledge-based linguistic skills they have accumulated during their lifetime to compensate for age-related changes in hearing acuity (presbycusis). That is, in order to understand speech, older listeners can use top-down linguistic information to compensate for degraded acoustical (bottom-up) information when the listening conditions are difficult, for instance, in conditions of background noise. Listeners apply their knowledge of syntax, semantics and pragmatics to disambiguate phonemes, syllables or words. The ability to use contextual linguistic information is assumed to be part of the crystallized’ intelligence (Cattell 1971) and does not seem to decrease with age (Horn 1982). Therefore, this ability acts as a compensatory mechanism for the loss of hearing acuity in older listeners during language comprehension (Pichora-Fuller 2008).

The Ease of Language Understanding Model (ELU, Rönnberg et al. 2008) explains how perceptual bottom-up factors (such as loss of hearing sensitivity and noisy backgrounds) and top-down processing (such as linguistic knowledge) interact, especially in adverse listening situations. According to this model, for individuals without hearing problems and in optimal listening situations, understanding speech is easy and it is carried out implicitly or effortlessly. However, in the case of older individuals, speech perception is more demanding because aging is accompanied by a progressive decrease in hearing sensitivity to pure tones (higher PTA) especially in the high frequency range. Due to hearing loss, the transmission of the speech signal is deteriorated. If noise is present, the problem is exacerbated further. The combination of these two factors (hearing loss and noise background) produces poorer bottom-up processing, and additional top-down processing is required in order to understand speech. That is, the listener has to infer the meaning of the message by using additional linguistic information (semantic, syntactic and pragmatic information stored in long-term memory) such as the information provided by the sentence context (Stenfeld and Rönnberg 2009). The benefits of linguistic context also seem to be related to the degree of signal deterioration; lower or moderate noise levels enables the use of sentence context more than higher noise levels. Both behavioural studies (Mayo et al. 1997) and studies using functional magnetic resonance imaging (fMRI) (Golestani et al. 2013) suggest this interaction between SNR and linguistic context.

Thus, the assessment of the extent to which older listeners who experience difficulties in speech perception in noise can effectively use the linguistic context is an important research topic because it plays a key role in preserving communicative functioning in these listeners (Pichora-Fuller 2008).

The benefits of using the linguistic context can be assessed by comparing word recognition in a high-predictability (HP) sentence context and word recognition in a low-predictability (LP) sentence context. If the HP sentences have higher recognition scores than the LP sentences, it can be inferred that the listeners are using linguistic knowledge to recognize the word. At the same time, because older listeners are more affected by background noise than younger listeners (Dubno et al. 2000; Pichora-Fuller et al. 1995), the effects of sentence context are normally measured in noise conditions.

This strategy is used in the SPIN (speech perception in noise) test by Kalikow et al. 1977. When the SPIN test is administered, the listener has to repeat the sentence’s final word after each presentation. The test includes ten tape-recorded lists of 50 sentences mixed with babble noise. In each list, half of the sentences are highly predictable (HP), and the other half are low predictability (LP) sentences. The HP sentences contain contextual linguistic information that facilitates the identification of the key word (ex.: The candle flame melted the wax). In contrast, the LP sentences contain little contextual linguistic information (ex.: Paul can’t
discuss the wax). The contribution of the context to the recognition of the final word can be assessed by comparing the measured performance on the HP sentences with the performance on the LP sentences, following the assumption that increased contextual linguistic information contributes to a better understanding of the final word in HP sentences. Different equivalent lists are included in the SPIN test. The percent correct recognition scores of the final words in the sentence (or key words) at predetermined signal-to-noise ratios (SNRs) are recorded. Multi-talker babble is used as background noise.

Previous studies using the SPIN sentences in noise with elderly listeners (Dubno et al. 2000; Hutchinson 1989; Kalikow et al. 1977; Pichora-Fuller et al. 1995, 2007; Sheldom et al. 2008) showed that, although older listeners need higher signal-to-noise ratios (SNRs) to understand speech, they can effectively use contextual linguistic information, just as younger listeners do. Other studies using other types of sentences (Benichov et al. 2012) reached similar conclusions. Only the study by Schum and Matthews (1992) found less benefit from context in older listeners than expected.

The ability to effectively use the sentence context seems to be very important in language understanding in older listeners who experience speech perception difficulties. Thus, it seems necessary to develop sentence materials like the SPIN test for languages other than English, in order to evaluate individuals from other language communities. Spanish is the third most widely-spoken language in the world, according to the Instituto Cervantes (Moreno Fernández 2012) which means that the potential number of older listeners with speech perception difficulties is quite high, and there is a need to evaluate them. Moreover, different studies (Florentine 1985; Mayo et al. 1997) have shown that, when native speaking-Spanish listeners were evaluated with the SPIN test, their performance was significantly lower than the performance by native English speakers. These studies concluded that it is important to evaluate listeners in their native language.

To date, there are tests of sentence materials, like the Hearing in Noise Test (HINT) originally developed by Nilsson et al. (1994), that have been adapted to the Spanish language, both for the Castilian-Spanish (Huarte 2008) and Latin-American Spanish variants (Barón de Otero et al. 2008). The Matrix sentence test (Hagerman 1982), was recently adapted to the Spanish language as well (Hochmuth et al. 2012). However, these tests do not compare HP and LP sentences and they are not designed to measure the listener’s ability to use linguistic context.

The Spanish Sentence Lists (SSL) are not a translation of the sentences on the SPIN test by Kalikow et al. (1977), due to the differences in linguistic structure and vocabulary between the English and Spanish languages. These Spanish sentences were generated in such a way that the final or keywords were bisyllabic. All of them consisted of a stressed syllable followed by an unstressed syllable because this is the most frequent type of word in the Spanish language and the most frequent stress pattern. Moreover, monosyllabic nouns are much less frequent in Spanish than in English (McCullought and Wilson 2001). The Alameda and Cuetos (1995) word database was used to control the frequency of occurrence of the key word. All the key words in the SSL had a frequency of occurrence of between 16 and 41 per million. The SSL includes six lists of 50 sentences each (25 HP and 25 LP). The lists are equivalent in predictability, frequency of occurrence of the last word, length and phonetic content (Cervera and Gonzalez-Alvarez 2010). The procedure for recording and digitalizing these sentences has been described in Cervera and Gonzalez-Alvarez (2011). The lists were presented in three SNR conditions, 0, +5 and +10 dB, and they were selected because they cover the range above and below the hearing threshold. To create the masking condition, multi-talker noise was used. It was created by mixing 12 voices (six males and six females) reading a text in the Spanish language. These recordings were made in a sound-attenuated
room. The noise was mixed with each sentence, creating each of the three SNR conditions, by manipulating the overall root mean square (RMS) of both the signal and the noise. These manipulations were performed using Adobe Audition Pro software.

These sentences were used in a perceptual task to assess their intelligibility in a sample of 474 young normal-hearing listeners (Cervera and Gonzalez-Alvarez 2011). The sentences were presented in multi-talker noise at different SNRs. The results showed that the HP sentences were better recognized than the LP sentences, and the percent correct scores were higher as the SNR increased, as expected. Thus, it was concluded that the SSL preserve the main characteristics of the SPIN sentences; that is, the recognition of the key word is sensitive to 1) the effects of the preceding linguistic context and 2) the level of background noise.

The next step was to evaluate the performance on the SSL by Spanish-speaking older listeners with age-related hearing loss, in order to assess the effects of sentence context on word recognition in noise in this type of listener. In order to accomplish this objective, the recognition scores for words presented in a preceding HP sentence context were compared to the scores for the words presented in LP sentences in different conditions of background noise (SNR). In each SNR, the HP–LP difference scores provided an estimation of the use of context in the recognition of the final word.

The ability to use linguistic context in word recognition is assumed to be independent from the language of the listener. Thus, the participants in the present study were expected to obtain similar benefits from the sentence context in word recognition to those obtained in previous studies with the SPIN sentences (Hutchinson 1989; Kalikow et al. 1977; Pichora-Fuller et al. 1995, 2007; Sheldom et al. 2008). That is, participants would show better recognition scores for the HP sentences than for the LP sentences.

However, participants in previous studies using the SPIN sentences were older listeners with near-normal hearing, while the participants in the present study showed mild-to-moderate hearing loss, especially at higher frequencies, which is typical of the hearing loss in old age (Demeester et al. 2009). In all the previous studies that measured speech perception in noise, as well as in the present one, pure-tone average thresholds (PTA) were used as a measure of listeners’ hearing acuity.

In the present study, older participants with mild-to-moderate hearing loss were selected because these types of listeners are representative of a large part of the older population (Roth et al. 2011). At the same time, one of the aims of the present study was to assess the predictive role of PTA in the performance on the SSL. The participants selected for the present study also had to have normal general cognitive functioning in order to reduce the potential effects of age-related cognitive impairment and focus only on the effects of hearing acuity.

To assess the predictive role of PTA in the recognition scores, two regression analyses were conducted, where PTA was used as the predictor variable and the HP and LP sentence scores were used as dependent variables in each analysis. In addition, as the group of older participants in the present study showed a wide range of ages (from 56 to 85 years of age), the possible relationships between age and performance on the HP and LP recognition scores, as well as the PTA, were also examined. Based on the previous literature in this research area (Akeroyd 2008 for a review), the listeners’ pure-tone average thresholds (PTA) were expected to be related to their performance on the recognition scores. On the other hand, the HP–LP difference scores, which express the effective use of linguistic context in the recognition of the final word (Kalikow et al. 1977), are assumed to consist of stored linguistic knowledge acquired through life-long experience with language (Cattell 1971). Therefore, HP–LP difference scores are not expected to be associated with the listener’s hearing acuity.
Fig. 1 Mean (and standard errors) for pure-tone air conduction hearing thresholds in both ears

Method

Participants

The listeners in the present study were 47 volunteers who were members of an association for older people. Their ages ranged from 56 to 85 years, with a mean age of 70.3 years (SD = 6.4). Of these participants, 29 were female, and 18 were male. All of them reported being in good health and not having neurological, speech or language problems or any chronic illnesses. All of them reported having some difficulties in understanding speech in noise or other adverse everyday listening situations. All of them gave their informed consent. The listeners were native Castilian-Spanish speakers. Their years of formal education ranged from 8 to 12 years. The pure-tone air conduction thresholds at 250, 500, 1,000, 2,000, and 4,000 were measured in each ear separately in all the participants (Fig. 1) using an Audiotest 330 audiometer in a sound-proof room. This frequency range is known to be a good predictor of performance on speech perception tasks (Humes 1996). The mean pure-tone average (PTA) for these frequencies (averaged in both ears) was calculated for each listener and used as a measure of the listener’s hearing acuity, with a mean value of 34 dB HL (SD = .96). This group of listeners presented mild-to-moderate hearing loss. This audiometric pattern, characterized by greater hearing loss at high frequencies than low, is one of the most frequent patterns in older individuals (Demeester et al. 2009). All of the participants presented bilateral symmetrical hearing loss. None of them used hearing aids.

All participants passed The Mini-Mental State Examination (MMSE) (Folstein et al. 1975), adapted to the Spanish population by Lobo et al. (1999). This test was used to screen potential cognitive disorders. The scores obtained by the participants ranged from 24 to 30 (M=26.45, SD=2.6). There was no indication of cognitive impairment in any of the participants.

Procedure

The participants were tested individually in two sessions. In the first session, the pure-tone air conduction thresholds were measured in each participant. Next, the participants completed the Mini-Mental State Examination (MMSE). Both the audiological testing and the MMSE examination are described in the preceding section. Participants were also asked about their
health and self-perception of their hearing problems in everyday situations. The first session lasted approximately 30 min. The measures with the SSL sentences were conducted during the second session, which lasted approximately 30 min. The speech materials consisted of lists 1, 2 and 3 from the SSL. Each list had 25 HP sentences and 25 LP sentences. The listeners performed the perceptual task individually in a sound-proof room. Each individual was presented with the three lists, each list under a different SNR condition. Of the 47 participants, 16 participants were administered list 1 at 0 dB SNR, list 2 at +5 dB SNR, and list 3 at +10 dB SNR; 16 participants were administered list 1 at +5 dB SNR, list 2 at +10 dB SNR, and list 3 at 0 dB SNR; and 15 participants were administered list 1 at +10 dB SNR, list 2 at 0 dB SNR, and list 3 at 5 dB SNR. The order of presentation of the three lists was randomized across individuals.

The stimuli were presented individually from a Pentium PC with Sennheiser HD 265 supra-aural cushion headphones. The participants listened to the stimuli diotically. The stimuli were presented at 80 dB SPL. This listening level was chosen to maximize audibility for each listener with hearing loss, without exceeding the loudness discomfort level and it was determined in a pre-test using similar sentence material for all participants. The listeners were instructed to listen to the sentence and repeat the last word they heard. They were encouraged to guess, if necessary, in order to provide a response to each item. Then, the experimenter registered the response by typing it, using the computer keyboard. He/she typed exactly what was reported by the listener, including incomplete or nonsense words. The administration of the stimuli and the registration of the listeners’ responses were performed by a Java program developed specifically for this task. The scoring method was the same one used in the SPIN test by Kalikow et al. (1977); that is, when the listener correctly repeated the key word (the final word of the sentence), a point was scored. The total correct recognition scores (expressed in percentages) of the key words in the HP and LP sentences were computed separately for each listener. Next, the difference between the HP–LP scores (expressed in percentages) was also scored as another dependent variable.

**Results**

Perceptual Scores on HP and LP Sentences

As presented in Fig. 2, the percentage of correct scores was higher for the HP sentences than for the LP sentences in the three SNR conditions: 0, +5, and +10 dB SNR. For the HP sentences, the mean percentage of final words correctly identified was about 11 % (SE = .13) in the 0 dB SNR condition, 46 % (SE = .25) in the +5 dB SNR condition, and 77 % (SE = .18) in the +10 dB SNR condition. For the LP sentences, the mean percentages of final words correctly identified were much lower: about 2 % (SE = .3) in the 0 dB SNR condition, 12 % (SE = .10) in the +5 dB SNR condition and 37 % (SE = .19) in the 10 dB SNR condition.

As Fig. 2 shows, the HP sentences present higher perceptual scores than the LP sentences. At the same time, the perceptual scores increase as the SNR increases. To examine whether the differences between the LP and HP sentence scores in the different SNR conditions were significant, we submitted the data to a two-way ANOVA, with the percent correct scores obtained on the perceptual task as a dependent measure, and context (HP and LP sentences) and SNR (0, +5, and +10 dB) as within-subject factors.

Significant main effects were found for context (F(1, 48) = 418.71, p < .01 η² = .90), and SNR (F(2, 96) = 288.56, p < .01, η² = .86). Thus, the recognition of the final words was better when they were presented in a high-predictability context than when they were
presented in a low-predictability context. A posteriori comparisons of the levels of the SNR factor, by means of the Bonferroni test, showed significant differences between 0 and +5 dB ($p < .01$), 0 and +10 dB ($p < .01$), and between +5 and +10 dB ($p < .01$). The context X SNR interaction was also significant ($F(2, 96) = 74.02, p < .01 \eta^2 = .61$) suggesting a differential effect of context at different SNRs. Specifically, the effects of context are more evident at lower noise levels such as +10 and +5 dB SNR than at higher noise levels such as 0 dB SNR (see Fig. 2). Thus, it seems that very difficult listening conditions hinders the use of linguistic context. At 0 dB SNR, the bottom-up information is very poor limiting the listener’s ability to compensate for it with top-down linguistic strategies.

**Correlation and Regression Analysis**

Table 1 shows the product-moment Pearson correlations for the percent correct scores on the HP sentences, the percent correct scores on the LP sentences, and the HP–LP difference scores, along with the values for PTA and the age of the listeners.

**Table 1** Pearson product-moment correlations among low-predictability (LP) sentence scores, high-predictability (HP) sentence scores, the HP–LP difference scores, pure-tone average hearing thresholds (PTA), and age

<table>
<thead>
<tr>
<th></th>
<th>HP</th>
<th>LP</th>
<th>HP–LP</th>
<th>PTA</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP</td>
<td>–</td>
<td>.83(**)</td>
<td>.82(**)</td>
<td>−.52(**)</td>
<td>−.33(*)</td>
</tr>
<tr>
<td>LP</td>
<td>−</td>
<td>.36(*)</td>
<td>−.58(**)</td>
<td>−.32(*)</td>
<td></td>
</tr>
<tr>
<td>HP–LP</td>
<td>−</td>
<td>−</td>
<td>−.25</td>
<td>−.23</td>
<td></td>
</tr>
<tr>
<td>PTA</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>.47(**)</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05, **p < .01*
Table 2  Linear regression with low-predictability (LP), high-predictability (HP) sentence scores, and HP–LP scores as dependent variables, and pure-tone average hearing thresholds (PTA) as a predictor variable

<table>
<thead>
<tr>
<th>Predictor</th>
<th>β</th>
<th>t</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP PTA</td>
<td>−.52</td>
<td>11.47(**)</td>
<td>.27</td>
</tr>
<tr>
<td>LP PTA</td>
<td>−.58</td>
<td>−4.75(**)</td>
<td>.33</td>
</tr>
</tbody>
</table>

*p < .05, **p < .01

A strong positive relationship between the HP and LP sentence scores was observed \((r = .83, p < .01)\), indicating that the listeners’ performance on the two types of sentences was related. The scores on the HP sentences and the scores on the LP sentences showed a negative relationship with hearing acuity \((r = −.52, p < .01, \text{ and } r = −.58, p < .01, \text{ respectively})\). That is, higher hearing thresholds were associated with poorer word recognition in noise, whether the word was presented in a predictable context or in a non-predictable context. The HP–LP difference scores showed a strong positive relationship with the scores on both the HP and LP sentences \((r = .82, p < .01, \text{ and } r = .36, p < .05, \text{ respectively})\), but not with PTA. Finally, age showed a negative relationship with the scores on both the HP sentences \((r = −.33, p < .05)\) and the LP sentences \((r = −.32, p < .05)\), but not with the HP–LP difference scores. Age also showed a positive moderate relationship with PTA \((r = .47, p < .01)\), as expected.

The predictive value of PTA in the percent correct scores for the HP and LP sentences was tested in two different regression analyses (one for each dependent variable). The HP–LP scores were not tested in a regression analysis because this dependent variable did not show any significant relationship with PTA. On the other hand, as age showed a significant relationship with PTA, it was not included as an independent variable in the regression model, in order to avoid collinearity effects. The results are shown in Table 2. The first regression analysis, with the HP sentence scores as dependent variable and PTA as an independent variable, showed that PTA accounted for a significant \((p < .01) 27\% \text{ of the total variance in the HP sentence scores.} \)

PTA was also used as a predictor variable in a second regression analysis, in which the scores on the LP sentences were the dependent variable. The results showed that PTA accounted significantly \((p < .01) 33\% \text{ of the total variance (Table 2).} \)

Discussion

The present study examined the recognition of words in noise in two types of sentence contexts, HP and LP, in Spanish-speaking older adults in different SNR conditions. As expected, the recognition scores on the HP sentences were higher than those on the LP sentences in the three SNR conditions, suggesting that the participants benefited from the linguistic context. In other words, in order to accomplish speech understanding, the older listeners used their stored knowledge about the phonology, semantics, syntax, and pragmatics of their language. This result, also obtained with Spanish-speaking listeners, in general, confirms results from previous studies with English-speaking participants that also measured the percent correct scores on the SPIN sentences in fixed SNR conditions (Kalikow et al. 1977; Hutchinson 1989).
However, although the benefits of context (the HP–LP difference scores) are similar in previous studies and the present one, the participants in the present study needed higher SNR to obtain the maximum benefits from context, compared to the listeners in the previous studies. The SNR at which the listeners in the present study obtained the maximum benefit was the +10 dB SNR condition (with a benefit of 42%). By contrast, in the study by Kalikow et al. (1977), the older listeners obtained the maximum benefit from the context at 0 and +5 dB SNRs (with a benefit of about 45 and 38%, respectively, according to the estimations derived from the figures presented in that study). In the study by Hutchinson (1989), the maximum benefit obtained from the context by the older listeners was at 0 dB SNR (with a benefit of 31%). However, in the present study, the minimum benefit of context was produced at the 0 dB SNR, where the individual perceptual scores corresponding to the HP and LP sentences were very low (near “floor” level performance), similar to what was found in the study by Kalikow et al. (1977) in a lower—5 SNR condition (in the Hutchinson study, the—5 SNR condition was not used).

Thus, it seems that listeners in the previous studies and in the present one obtained context facilitation at intermediate levels of speech intelligibility, but not at floor levels, where intelligibility is very low. It seems clear that poor perception of the sentence context reduces its potential beneficial effect. A minimal amount of sensory information from the speech signal would be necessary to induce top-down linguistic processes. In the case of the listeners in the present study, the elevation of hearing thresholds (compared to the normal hearing thresholds of the listeners in the previous studies) increased the SNR necessary for speech reception and therefore, for using the sentence context.

In the present study, the role of hearing acuity (measured by PTA) in the recognition scores was examined in a regression analysis. The results showed that PTA accounted for a significant amount of the variance in the performance on both the HP and LP sentences. This result agrees with previous literature on speech perception in noise in older listeners (see Akeroyd 2008). The age of the elderly participants in the present study (from 56 to 85 years) also showed a relationship with PTA, as expected, based on the data on the prevalence of hearing loss in the older population (Demeester et al. 2009).

On the other hand, PTA (and age) did not show a relationship with the HP–LP difference scores, which reflect the use of linguistic context in sentence perception. This result is consistent with the fact that, while hearing acuity decreases with age, linguistic knowledge is thought to be preserved in normal aging. Moreover, some authors (Pichora-Fuller et al. 1995; Wingfield et al. 2005) have suggested that older listeners may even develop expertise in the ability to use context to compensate for their hearing difficulties in understanding speech in noise backgrounds, as these are the most frequent everyday communication situations.

The aim of the present study was to assess the extent to which older Spanish-speaking listeners with mild-to-moderate hearing loss can benefit from the linguistic context in word recognition in noise, by using speech materials specifically developed for the evaluation of Spanish native speakers. In general, the results agree with findings from previous studies using the SPIN sentences, showing beneficial effects of sentence context on word recognition. However, it seems that when listeners have age-related hearing loss (as in the case of the listeners in the present study), they need higher SNR than older listeners with normal hearing, in order to be able to use the sentence context.

Thus, the data from the present study extend the results found with English-speaking listeners, and they may also provide clinically relevant information for the evaluation of speech comprehension difficulties in older native Spanish-speaking listeners with age-related hearing loss. However, it would be necessary to obtain normative data for the older population.
using a larger number of participants, in order to use the SSL as a clinical tool, and this could be an objective for future research.

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