Comprehension cueing strategies in elderly: a window into cognitive decline?

Abstract

Language abilities gradually decline as we age, but the mechanisms of this decline are not well understood. The present study investigated comprehension of subject vs. object *who* and *which* direct questions (DQs), embedded questions (EQs) and relative clauses (RCs) in 39 cognitively healthy native speakers of Spanish. The elderly participants (n = 21) were further classified according to their scores on a general cognitive test, Montreal Cognitive Assessment (MoCA), into a group with low MoCA scores, LM (n = 10), and a group with normal MoCA scores, NM (n = 11). A mixed-model, repeated-measures analysis of variance (ANOVA) showed that the elderly participants achieved significantly worse accuracy and speed than the young participants (Y) in all tasks. Accuracy was significantly lower and reaction times significantly longer in the LM group compared to the NM group in DQs and RCs. Accuracy in comprehension of EQs was also worse in LM compared to NM, with no significant difference in RTs between the two groups. The results are explained within the competition model and reliance on a language-specific cueing strategy. Reliance on cueing strategies in sentence comprehension may be an effective indicator of cognitive decline associated with aging.

Keywords: comprehension; wh-dependencies; aging.

Introduction

Cognitive aging is typically associated with a decline in speed of processing and deterioration of memory and attention (Salthouse, 2009). Language abilities also gradually decline as we age, which is reflected in decreased vocabulary, smaller mean number of clauses per utterance, simplified syntactic structure of produced sentences, reliance on optimization strategies when choosing referring expressions as well as difficulty in comprehension of complex sentences (Kemper, Thompson & Marquis, 2001; Grossman, Cooke, De Vita, Chen, Moore et al., 2002; Hendriks, Englert, Wubs & Hoeks, 2008). Older adults' language comprehension decline appears to be due not to sensory, but cognitive demands of spoken language, with complex syntax slowing down the comprehension even when sentence understanding is accurate (Tun, Benichov & Wingfield, 2010). Research on English has shown that comprehension of structures that require a syntactic operation of movement and involve a longer gap between a moved element and its trace (*t*), such as object relative clauses (e.g., The cat$_i$ that the dog chased t_i is black), is impaired in elderly adults, while comprehension of subject relative clauses, in which this gap is smaller (e.g., The cat$_i$ that t_i chased the dog is black), is spared (e.g., Zurif, Swinney, Prather, Wingfield & Brownell, 1995; Stine-Morrow, Ryan & Leonard, 2000). One explanation of this finding is that the object relative clauses require allocation of more working memory (WM) resources than subject relative clauses, and WM limitation is one of key features of cognitive aging (Zurif et al., 1995; Caplan & Waters, 1999; Stine-Morrow et al., 2000; Grossman, Cooke, De Vita, Alsop, Detre et al., 2002).

Furthermore, neuroimaging research has shown that when processing complex sentences, healthy seniors compared to young participants show reduced activation in the core language areas (e.g., inferior frontal regions), while showing additional activation of some areas that are not considered the "core" sentence processing network as well as difference in the coherence of connectivity of the involved brain areas (Peelle, Troiani, Wingfield, & Grossman, 2010; Tyler, Shafto, Randall, Wright, Marslen-Wilson et al., 2010). Activation of the brain regions that are not typically involved in language processing has been interpreted as an indicator of compensatory processes (Grossman et al., 2002; Wingfield & Grossman, 2006; Tyler et al., 2010).

Better understanding of the earliest changes in typical cognitive aging is also an important step towards better understanding of the Alzheimer's disease (AD) continuum. Structural and metabolic changes in AD brain occur long before cognitive symptoms become apparent (Dubois et al., 2007, 2010; Sperling et al., 2011). Crucially, even small metabolic and structural alterations in the brain may affect the dynamics enabling cognitive function (Buckner, Snyder, Shannon, LaRossa, Sachs, et al., 2005). Thus, it is important to understand the brain's ability to engage alternate networks and rely on cognitive strategies compensating for a deteriorating cognitive function.

One goal of the present study was to determine whether elderly native speakers of Spanish rely on compensatory strategies in sentence comprehension. We chose to study comprehension of *wh*-structures (i.e., structures formed by *wh*-words, such as *what*, *who*, *which*, etc.): direct and embedded questions introduced by interrogative pronouns *qué* ("what, which") and *quién* ("who") and relative clauses introduced by *que*. Like in English, the distance between a moved element and its gap is longer in object than in subject *wh*-structures, as shown in (1-2):

(1) ¿Quién$_i$ t_i comió una naranja?
(2) ¿A quién$_i$ mordió$_j$ el perrito t_j t_i ?

However, in Spanish preposition *a* marks object *wh*-questions and therefore it could serve as a processing cue. Since it appears before the moved *wh*-word, it signals an object structure, allowing the parser to assign a temporary thematic role before encountering the gap. Thus, reliance on this cue would facilitate comprehension of object structures, resulting in their good comprehension, even though they are syntactically more difficult than subject structures and require more WM resources.

2. Present Study

2.1 Participants

We tested 39 neurologically healthy native speakers of Spanish, of which 21 were older and 18 were young persons. There was a statistically significant difference in age between the groups (t (27) = 28.457, $p < 0.05$) and years of education (t (30) = 6.76, $p < 0.05$), but not in gender distribution ($\chi^2(1) = 1.857$, $p = 0.17$).

The group of elderly was divided into two subgroups, based on their MoCA scores: since the scores lower than 26 indicate mild cognitive impairment (MCI) (Chertkow, Massoud, Nasreddine, Belleville, Joanette, et al., 2008), we used a cut-off score of 26 to dichotomize the elderly participants into a Normal MoCA scores group (NM) (≥ 26) and a Low MoCA group (LM) (< 26). Comparing the age means of the latter two groups revealed that the LM group (73.8 ±6.25) was significantly older than the NM group (66.45 ±5.14): t (19) = 2.95, $p = 0.008$). The two groups did not differ significantly in years of education (t (19) = 6.14, $p = 0.54$) or in gender distribution ($\chi^2(1) = 0.064$, $p = 0.8$).

All participants were healthy, with no history of stroke, neurological disorders, alcohol/drug abuse, or other conditions that could affect cognition. They all reported normal hearing, and normal/ corrected to normal vision. All participants were recruited through the Ingema Foundation. Participants' characteristics are summarized in Table 1.

2.2 Evaluative measures

In addition to a test of global cognition (MoCA), we administered the Month Ordering Test to assess verbal WM (VWM). This test assesses storage and manipulation of material with semantic content, i.e., names of the months in calendar, which makes it highly relevant for studies of sentence comprehension (Almor et al., 2001; Goral, Clark-Cotton, Spiro, Obler, Verkuilen et al., 2011). The months are given in a non-canonical order and participants' task is to repeat them canonically. There are 20 strings of months in total, distributed across 5 levels, with 4 strings at each level, containing a different number of months to order. Each correctly ordered string is scored as one point. Thus, the total possible score is 20. Participants' scores on evaluative measures are summarized together with their demographic characteristics in Table 1.

Table 1: Participants characteristics.

	Elderly		**Young**
	LM (n=10)	**NM (n=11)**	**Y (n=18)**
Age	73.8 ±6.2	66.45 ±5.1	24.6 ±2.6
Age range	65-85	60-78	20-30
Gender (m/f)	4/6	5/6	4/14
Education (y)	10.56 ±5	11.25 ±3	17.44 ±1.9
MoCA	21.9 ±3.0	27.42 ±2	28.83 ±1.2
VWM	10.78 ±2.4	14.67 ±1.8	15.17 ±2.1

2.3 Experimental measures

There were three experiments in the study. Experiment 1 tested comprehension of *who* and *which NP* direct questions (DQs) extracted from a subject vs. object position in a sentence. It contained 40 sentences: 20 *who* DQ (ten subject and ten object questions) and 20 *which NP* DQs (ten subject and ten objects questions). Each question was preceded by a declarative sentence describing a situation from everyday life, such as: *Pablo is eating apples and Juan is eating oranges.* Thus, for a subject position, a *who* question would be: *Who is eating oranges*? And a *which-NP* question would be: *Which boy is eating oranges?* The sentences were presented auditorily, and possible answers—*Pablo*, *Juan*—appeared in a written form, on the left and right side of the computer screen, respectively. The participants indicated their responses by pressing the left or right arrow on the keyboard, depending on whether the correct answer was on the left or on the right side of the screen.

Experiment 2 tested comprehension of embedded questions (EQs). There were 80 EQs: 40 *who* and 40 *which NP* questions, with 20 subject and 20 object questions within each group. Half of the questions (n=40) contained one prepositional phrase (PP) and the other half contained two PPs. EQs were tested in a verification paradigm: participants were required to listen to a sentence, followed by a verification statement, and decide whether the statement was correct or incorrect relative to the sentence. The participants indicated their answers by pressing the left vs. right arrow on the keyboard, depending on whether "Correct" and "Incorrect" appeared on the left or right side of the computer screen.

In Experiment 3, we tested comprehension of relative clauses (RCs). There were 10 subject and 10 object RCs introduced by *que*. The tested structure was preceded by a simple sentence providing a context. As in Experiments 1 and 2, participants were required to indicate their answers by pressing the left or right keyboard arrow.

Sentence stimuli for each experiment were first randomized in Excel and then recorded in Audacity (http://audacity.sourceforge.net/). Prerecorded sentences were imported in the DMDX (www. http://www.u.arizona.edu/~kforster/dmdx) and presented auditorily over a PC computer and a set of speakerphones.

2.4 Procedures

Participants were instructed to respond to a question as fast and as accurately as possible. The next sentence was initiated by the subject's response. The left and right arrow responses for correct answers were counter-balanced across conditions in each experiment. There was a time window of 5,000 msec for answers. If the participant did not respond within that time, the answer options disappeared from the screen, and a fixation cross appeared, indicating that a new auditory stimuli was about to appear. A failure to respond within 5,000 msec was scored as an error. There was a 30-second break after every 20 sentences. Feedback showing whether the answers were correct or incorrect was given on the computer screen only during the practice trials. There was no feedback during the actual testing.

Each session began with the experimenter describing the study, and the participant reading and signing the informed consent. After that, demographic details were collected and precise instructions on how to execute the experimental tasks were given. This was followed by the participant's taking 8 practice trials. After a satisfactory performance on the practice trials, the participants were tested on the experimental measures. Finally, MoCA and the Month Ordering Test to assess verbal WM (the VWM test henceforth) were administered.

All the materials were administered in the same order to each participant, except for the experimental stimuli, which were administered as two different randomizations, which were introduced to allow controlling for the effects of stimulus ordering. Testing was carried out in a quiet room at Ingema laboratory facilities in San Sebastián. It was conducted individually with each participant and completed in a single session, which lasted approximately 1 hour and 10 minutes. The study was conducted in accordance with the Declaration of Helsinki and was approved by the local Ethics' Committee.

3. Results

3.1 Evaluative Measures

There were statistically significant differences between the elderly group overall and the young participants on MoCA (t (25) = 4.431, $p < 0.0005$) and VWM test (t (36.5) = 2.714, $p = 0.01$), indicating better performance of the younger compared to the older participants. Within the group of elderly participants, the NM group outperformed the LM group on both tests – MoCA: t (19) = 5.42, $p = 0.001$, and VWM: t (19) = 3.792, $p = 0.001$. There was a significant positive correlation between years of education and MoCA (r = 0.597, N = 39, $p < 0.01$), and between MoCA and VWM scores (r = 0.611, N = 39, $p < 0.01$). There was a significant negative correlation between age and MoCA scores (r = -0.607, N = 39, $p < 0.01$), and between age and VWM scores (r = -0.495, N = 39, $p < 0.001$). All tests were two-tailed.

3.2 Experimental Measures

Accuracy and RTs of understanding *wh*-dependencies were analyzed in a mixed-model, repeated-measures analysis of variance (ANOVA), with a between-subject factor comparing groups (LM, NM, Y) and within-subject factors comparing the extraction site in a sentence (subject/object) and the type of *wh*-word (*who*/*which*).

Experiment 1: Direct Questions. The accuracy analyses showed that the main effect of group was significant, i.e., there were statistically significant differences in the participants' overall sentence comprehension between the groups (F(2,36) = 30.421, $p = 0.001$). The results of a post-hoc Tukey test showed significant differences in comprehension between the Y group and the LM group ($p <$ 0.005), and between the NM group and the LM group ($p <$ 0.005). In both comparisons, the LM group had lower accuracy. The difference between the Y and the NM groups was not significant ($p = 0.81$). The main effect of extraction site (subject/object) was significant (F(1,36) = 4.564, $p <$ 0.04), reflecting better comprehension of object structures, whereas the main effect of *wh*-word was not significant (F(1, 36) = 0.187, $p = 0.668$).

The analysis of RTs also showed that the main effects of the group (F(2,36) = 37.844, $p < 0.001$) and extraction site were significant (F(1,36) = 4.479, $p = 0.041$), and so was the effect of the two-way interaction between the extraction site and group (F(2,36) = 3.593, $p = 0.038$). Tukey test showed significant differences between the Y group and the NM group ($p < 0.005$), between the Y and LM groups ($p <$ 0.005), and between the NM and the LM groups ($p <$ 0.001), with the LM group reacting slower in both cases.

Experiment 2: Embedded Questions. Comprehension of EQs did not show a significant effect of extraction site (subject/object) (F(1,36) = 3.517, $p = 0.69$). However, the main effect of *wh*-word (*who/which*) was significant (F(1,36) = 5.623, $p = 0.023$), and so was the interaction between the extraction site and type of *wh*-word (F(1,36) = 5.001, $p = 0.032$). The type of *wh*-word also interacted with PP (F(1,36) = 5.454, $p = 0.025$). There were significant differences in the participants' overall sentence comprehension (F(2,36) = 61.990, $p < 0.001$). The results of Tukey test showed significant differences for every pair of groups (LM vs. Y: $p < 0.005$; LM vs. NM: $p < 0.005$; NM vs. Y: $p < 0.001$), where the Y group was the most accurate, while the LM group was the least accurate. Since the lowest scores were achieved on tasks in Experiment 2, percent correct responses across all conditions are given in Table 2 as another view into the data.

Table 2: Percent correct responses on Experiment 2.

	Who S1PP	Who O1PP	Who S2PP	Who O2PP	Whi S1PP	Whi O1PP	Whi S2PP	Whi O2PP
LM	60	51	57	58	56	65	55	45
NM	69	62	87	70	88	83	85	78
Y	94	93	97	92	98	94	98	94

Since questions in all experiments required a choice between two possibilities, 50% correct represented chance performance on all tasks, and scores between 26-75% were considered to be within the range of chance. A score of 75% or better was considered better than chance performance, while a score of 25% or below was taken to indicate a systematic reversal in the interpretation of a particular construction (there were no such scores in our data).

The analysis of the RT data has shown that the main effects of *wh*-word and extraction site were not significant, but the interaction between these two factors was significant (F(1,36) = 11.263, $p = 0.002$). There was a significant effect of PP (F(1,36) = 22.369, $p < 0.001$), and it interacted with the group ($F(2,36) = 4.139$, $p = 0.024$). A three-way interaction between PP, group, and *wh*-word was also significant ($F(2,36) = 3.315$, $p = 0.048$). RTs differed significantly among the groups ($F(2,36) = 14.049$, $p < 0.001$), and the post-hoc Tukey test showed that the Y group was faster than the LM group ($p = 0.001$) and the NM group ($p = 0.031$). The difference in RTs between the latter two groups was also significant ($p = 0.05$).

Thus, the results of Experiment 2 indicate that embedded questions containing additional phrases such as PPs are in general difficult to process for cognitively healthy older adults, in particular to those with mildly affected general cognition and VWM.

Experiment 3: Relative Clauses. There were no significant within-subject effects in participants' comprehension of RCs. Neither the main effect of extraction site was significant ($F(1,36) = 1.651$, $p = 0.2$) nor its interaction with the group ($F(1,36) = 0.744$, $p = 0.42$). There were significant differences in the participants' overall comprehension of RC among the groups ($F\ (2,36) = 9.662$, $p < 0.001$). The results of Tukey test showed that there were significant differences in the comprehension between the Y and the LM groups ($p = 0.001$), and between the NM group and the LM group ($p = 0.024$). In both cases the LM group had lower accuracy. RTs differed significantly among the groups ($F(2,36) = 26.784$, $p < 0.001$), and the Tukey test showed significant differences between every pair of groups: the Y group was the fastest, while the LM group was the slowest one.

3.3 Summary of results

Overall, lower accuracy and longer reaction times in comprehension of DQs and RCs were found in LM compared to NM participants. Comprehension of EQs was also worse in the LM group compared to the NM group (accuracy), but this was not associated with significant differences in RTs between the two groups. The Y group showed significantly better comprehension accuracy and speed in all tasks. Adding one or two PPs to the *wh*-structures in EQs pushed the comprehension of the LM group to the chance level on all EQs, as well as comprehension of the NM group of 3 out of 4 types of *who* EQs. Note that adding the PPs only extended the length of sentences, without adding new layers of structure. Thus, extra processing load, even if imposed only linearly and not hierarchically, leads to a difficulty in comprehension of *wh*-structures in healthy elderly adults. This finding supports the notion that excessive processing demands may turn the cueing strategy ineffective.

4. Discussion

The fact that the LM group turned out to be significantly older than the NM group may reflect dynamics of language deterioration associated with aging. While the results of evaluative measures showed that age affected both MoCA and VWM scores (the higher the age, the worse the results), education also affected the scores, with the more years of education being associated with the better scores. However, lack of a statistically significant difference in years of education between the LM and NM groups indicates that the differences in results of cognitive tests between these two groups cannot be explained in terms of a general difference in years of education. Our results generally agree with previous findings on more accuracy errors and longer RTs in syntactic processing in elderly native speakers of English (Obler et al., 1991).

4.1 Subject vs. object

An interesting finding of the present study is better comprehension of object than subject *who* DQs. Given that the distance between the moved *wh*-word and its trace is longer in object questions (2) than in subject questions (1), we would expect object structures to be more demanding for processing. According to distance-based accounts, the shorter distance between the trace and its gap poses less burden on WM in subject- than in object-*wh*-questions, which explains the data from English discussed in the Introduction. However, our finding that object DQs were better comprehended than subject DQs is not in line with such accounts.

The idea that processing in structurally different languages reflects the structural differences among languages and that in different languages different types of information may serve as cues in sentence processing is the backbone of the competition model (Bates & MacWhinney, 1987; MacWhinney, 1987). According to this model, the language processor chooses which information to attend to in determining sentence meaning based on specific characteristics of cues. For instance, the preposition *a* in Spanish is not a highly available cue, because it appears only with animate direct objects. It is not a highly reliable cue, because it can convey several different meanings. However, it is not costly to process, and despite its weak cue validity, it can guide sentence comprehension: the preposition *a* has "an extremely high contrast validity… Among normal speakers, in fact, it is the most overriding cue in determining semantic role" (Benedet et al., 1998, p. 332).

Thus, the finding that object DQs were comprehended better than subject DQs reflects a strategy based on syntactic cueing: object DQs in our experiments are introduced by a PP (*a qué*), beginning with the preposition *a*, which signals the grammatical role of object and the thematic role of Patient. Therefore, it is possible for the processor to rely on *a* in correctly predicting the grammatical function and temporarily assign a thematic role to the initial constituent in a sentence such as (2) before encountering the gap. Once it encounters the gap, the temporarily assigned thematic role is confirmed or disconfirmed. Our data show that this information was utilized by the LM group in the comprehension of direct object *who* questions. This strategy reduces the processing demands on WM and facilitates comprehension when WM resources are reduced. However, if the processing demands are too high, as in examples of EQs extended with additional PPs, the cueing strategy is not effective.

Another indicator that comprehension of EQs in two groups of elderly was at chance due to processing limitations is related to the finding that their comprehension of RCs was accurate. This finding shows that in older Spanish speakers this cuing strategy can be effective in syntactically more difficult conditions (e.g., object RCs and DQs), but it may not be effective when processing load is too high, regardless of syntactic complexity (extended EQs). Since the strategy of reliance on the preposition *a* is language-specific, it is not available to speakers of English, and therefore the patterns of comprehension of object structures differ in the elderly speakers of these two languages.

4.2 Who vs. which

Wh-word-order in Spanish requires that a *wh*-word occupies a sentence- or clause-initial position, prohibiting preverbal subjects (Jaeggli, 1982; Goodall, 2004). *Wh*-words in multiple *wh*-questions, however, can switch between subject and object positions, as shown in (4-7):

(4) ¿Quién compro qué?
"Who bought what?"
(5) ¿Qué compro quién?
"What did who buy?"
(6) Juan sabe qué dijo quién.
"Juan knows what who said."
(7) Juan sabe quién dijo qué.
"Juan knows who said what." (Jaeggli, 1982, p.156).

Since *quién* and *qué* can switch their positions in a sentence, it appears that they do not obey the Superiority requirements (Chomsky, 1973; Pesetsky, 1987). This further means that there are no syntactic differences between *quién* and *qué*, and thus no syntactic reason to expect differences in their processing.

There are, however, differences between *quién* and *qué* at the discourse level: *quién* "who" is non-referential and non-discourse-linked, while *qué* "which" is referential and discourse-linked (D-linked). Some researchers argue that this difference affects processing (Hickok & Avrutin, 1995): D-linked expressions are easier to comprehend, because they refer to a set of objects that is already known to the hearer. By contrast, *who/what* refers to an unlimited set of objects with which the hearer is not familiar, which makes them more difficult to process. Other researchers, however, pointed out that it is precisely their D-linked nature that makes *which* expressions more difficult, because they require processing and integration of information at two levels – syntax and discourse (Avrutin, 2000). Our data support the former view, showing the effect of *wh*-word in EQs, i.e., better comprehension of *which* questions. However, additional processing load of 1 or 2 PPs cancelled out the cuing strategy based on structural sentential features, which facilitated comprehension of direct object *who* questions.

In conclusion, the main finding of the present study is a decline in comprehension of *wh*-structures and reliance on cueing as a compensatory mechanism in sentence comprehension in older native-Spanish-speaking adults. This strategy is effective in syntactically demanding conditions, when WM demands are not too high. However, excessive WM load prevents the use of the strategy. Thus, our results agree with previous findings in suggesting that it is not syntax per se, but limitation of WM resources which are necessary for processing that is affected in aging.

Further research needs to address questions pertaining to language-memory interface in older people with lower scores on tests of global cognition, such as MoCA, whose language, although appears to be normal, shows signs of decline when tested more carefully. Studying the compensatory mechanisms and strategies employed in language processing in such individuals may help us to understand better the transition from healthy aging to mild cognitive impairment and the AD continuum.

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