

Aging and Comprehension of Pronouns: How do Older Adults interpret Pronouns?

Hayo Ottens, s2197839, hayo.ottens@gmail.com
Margreet Vogelzang, Jennifer Spenader,
Artificial Intelligence & Language, Cognition and Neuroscience,
Rijksuniversiteit Groningen,
Netherlands

2014/2015

Abstract

Pronouns are used to replace parts of sentences. But the use of pronouns can cause ambiguity in the listeners interpretation. Many factors govern pronoun resolution, but we focus on two of them: parallel interpretation and grammatical constraints. In this study, older adults (65+) did the same experiment used in Vogelzang, Van Rijn, and Hendriks (submitted) to test children and young adults. Participants heard short discourses, followed by a question regarding one of the characters. Participants needed to resolve a pronoun to answer this. Results indicate that for older adults the parallel interpretation theory holds. This factor was so strong that it did not matter whether the subject form was a full noun phrase or a pronoun. The form of the sentential object did matter. Participants resolved reflexive objects more consistently than pronoun objects.

Keywords: Ambiguity resolution, pronouns, parallel interpretation, aging

1 Introduction

This research aims to investigate how older adults interpret pronouns in language. We set up an experiment to test this older adults' interpretation on short stories containing two different characters with ambiguous pronouns as well as the time it took them to answer. The participants were asked

questions about the characters in those stories, and had to indicate which character they thought was meant. This way we could measure their preferred interpretation and reaction times.

- (1) a. The Pig is making bread.
 b. Yesterday the Pig asked the Elephant how to make the bread,
 c. while **he** was washing **himself** in the kitchen.

Subject **he** and object **himself** are ambiguous here, meaning that they can refer to both the Pig and the Elephant. Most young adults would in this example say that the antecedent of *he* would be 'the Pig'. But since both are possible, what makes them prefer 'the Pig' over 'the Elephant'? It seems that when resolving antecedents, people take pragmatic and semantic factors into account. The grammatical role factor suggests that the subject *he* refers to the subject of the previous sentence. In literature this is also known as *parallel interpretation preference* of which previous research has shown that people prefer subject antecedents for subject pronouns and object antecedents for object pronouns. Also, people use more strict grammatical factors to resolve antecedents. In Example (1-c), there is a grammatical rule that says that the reflexive object (here *himself*) must refer to the subject and thus not the object. These discourse factors will be elaborated in section 2.

This research builds on the study of Vogelzang et al. (submitted) where children and young

adults performed a comprehension task. Participants heard short discourses, like example (1), with potentially ambiguous pronouns referring to one of two starring characters. At the end of every discourse, participants were asked about their interpretation of a pronoun. But in the current research, we tested older adults (65+) on which pronoun interpretation they prefer. The discourses are built to distinguish the influences of different forms of sentential subjects and pronominal objects on the participant's interpretation of these arguments. By testing how the referential forms of the pronoun (subject or object) influences the participants' preferences, we can see whether or not older adults have this parallel interpretation preference. To test the grammatical factor, we tested reflexive objects versus object pronouns. Ambiguous cases with pronominal subjects were balanced with unambiguous cases with NP subjects.

This means we have three independent variables:

- form of the subject (NP or pronoun)
- form of the object (pronoun or reflexive)
- question type (subject or object)

The dependant variables are then the participant's interpretation and their reaction time. This research aims to answer the question: Do changes in working memory and language experience, caused by aging, affect the comprehension of referential pronouns? We found that the parallel constraint is just as strong in cases of ambiguity as in cases without ambiguity, and that grammatical constraints were adhered to significantly more consistently than the pragmatic/semantic constraints. This is because we found that for older adults it makes no significant difference on the interpretation whether the subject is a pronoun or NP. We did however find a significant difference in pronoun interpretation when using a reflexive rather than a pronoun as the pronominal object.

2 Background

This research is all about the interpretation of referential expressions. Let us take a step back and focus on what referential forms exist. In language, there are two major referential expressions types: (Cann (1993))

1. Noun phrases, shortened **NP's**, such as 'the teacher', 'the Pig', or 'the girl I met yesterday'.
2. Noun-phrase surrogates, i.e. **pronouns**, such as 'he', 'she' or 'himself'.

As mentioned in section 1, the use of pronouns is prone to ambiguity. Recall the example given in that section, example (1). In sentence (1-c), 'he' can refer to both 'the Pig' and 'the Elephant'. Still, the majority of people would agree that the antecedent of this pronoun is 'the Pig', which makes it the preferred interpretation. Previous research has found that there are multiple discourse factors which guide people, consciously or subconsciously, to this preferred interpretation.

2.1 Factors governing referential expressions

Previous research found five factors which are known to influence the interpretation of a pronoun.

- grammatical role parallelism (e.g. Branigan, Pickering, Liversedge, Stewart, and Urbach (1995); Frazier, Taft, Roeper, Clifton, and Ehrlich (1984))
- gender information (Arnold (2000); Badecker and Straub (2002)),
- antecedent prominence, accessibility and topicality (Arnold, Eisenband, Brown-Schmidt, and Trueswell (2000); Chafe and Li (1976); Cunnings, Patterson, and Felser (2014); Givón (1983); Järvikivi, Pykkönen-Klauck, Schimke, Colonna, and Hemforth (2014); Spennader, Smits, and Hendriks (2009); Rij, Rijn, and Hendriks (2013))
- interference of prominent competitor antecedents (Badecker and Straub (2002); Clackson, Felser, and Clahsen (2011))
- grammatical constraints (Hendriks, Van Rijn, and Valkenier (2007); Van Rij, van Rijn, and Hendriks (2010)).

In this research we focus on grammatical and semantic factors and how manipulating those affects our participants' interpretation of pronouns.

2.1.1 Parallel factor vs Subject Assignment

Pronouns can have multiple antecedents. The preferred interpretation of those ambiguous pronouns has been studied widely for a long time. People used to believe that the sentential subject would be the preferred interpretation of subject and object pronouns. In Crawley, Stevenson, and Kleinman (1990), Crawley gives an example like the following:

- (2) Liz and Melanie were always fighting in the playground. Frank often joined in when he got the chance.
- a. Liz tried to catch Melanie and Frank chased *her*.
 - b. Liz tried to catch Frank and Melanie chased *him/her*.

The majority of the participants, around 60%, indicated they interpreted object pronouns as having a subject antecedent. Crawley calls this resolving strategy *Subject Assignment (SA)*, which supports that people prefer subject antecedents for both subject and object pronouns.

But other researchers were skeptical. They thought parallel interpretation might play a role and came with a *Parallel Factor (PF)* hypothesis, which says that if a sentence is parallel enough, subject pronouns are interpreted as having a subject antecedent and object pronouns as having an object antecedent (Smyth, 1994). Smyth argued that the sentences used in Crawley’s experiment were not fully parallel, so the PF did not apply. He says that the SA strategy would be the default resolution strategy only when the PF fails. In his words:

When two clauses are fully parallel, the probability of coindexing a pronoun with a parallel NP by the feature-match process is at its maximum, but as the clauses deviate from parallelism in terms of the grammatical or thematic roles of the NPs, the constituent structures of the clauses, or their attachment sites, pronoun assignment is less definitive.

(Smyth, 1994, p. 221)

Take a look at the following examples:

- (3) a. The man stopped the policeman and *he* waved to the woman.

- b. Jane tickled Diana and Andrew laughed at *her*.
- c. Minnie told Dorothy that *she* made Superman cry.
- d. Minnie told Betty that Tinman liked *her*.

In Smyth’s results, it appeared that most people thus do prefer role parallelism. In sentence (3-a), ‘he’ is a subject pronoun. Since ‘the man’ in the preceding clause is also a subject, this is the preferred interpretation of ‘he’. In the next sentence, sentence (3-b), we see an object pronoun ‘her’. As Smyth expected, people mainly preferred the preceding clause’s object ‘Diana’ as the antecedent. The same strategy holds for (3-c) and (3-d). In (3-c) ‘she’ refers back to Minnie, and in (3-d) ‘her’ was preferred as antecedent ‘Betty’.

2.1.2 Grammatical factor

Another factor we manipulate, though we focus on less, is the ‘grammatical constraints’ factor. This is manipulated by making a distinction between pronoun form and reflexive form of the sentential object. The effect of manipulating this factor becomes clear when we replace ‘himself’ for ‘him’, for example in (1-c):

- (4) The Pig is making bread. Yesterday the Pig_i asked the Elephant_j how to make the bread,
- a. while he_i was washing *him*_j in de kitchen.
 - b. while he_i was washing *himself*_i in de kitchen.

Binding theory governs the difference between pronouns and reflexives, and says that reflexives must be bound in their local context (the clause in which they occur) and that pronouns, on the contrary, must not be bound in their local context (Chomsky, 1981). In the literature, the rules of binding theory are explained by indices. When the indices of a pronoun and antecedent match, they are likely to be related. If they do not match, it is very unlikely that the pronoun refers to that antecedent. Because ‘himself’ in example (4-b) is a reflexive object, it is required by grammatical constraints to refer to the sentential subject (the Pig) so those indices (index *i*) match, whereas object pronoun ‘him’ in example (4-a) could refer to anything but the subject an-

tedecedent, in this case leaving one option: the Elephant (index j).

2.2 Effects of aging

The research of GréGoire and Van Der Linden (1997) showed a decline in working memory when age progresses. Here, people of all ages were asked to perform a working memory task, the digit span task. Although they found that educational level and working memory capacity correlated the most, there was also a small relation between age and working memory capacity. Since a persons working memory affects the processing of information (Gathercole and Baddeley (1995)), is it then the case that a decline in working memory could affect the processing of pronouns by not taking into account all the discourse factors? According to Vogelzang et al. (submitted), the resolving process is cognitively effortfull. In this study it was concluded that more ambiguity in possible referential interpretations leads to wider pupils, which means that more effort is needed to process (Engelhardt, Ferreira, and Patsenko (2010); Just and Carpenter (1993)).

Take a look at the following example in Example (5), taken from (Song and Fisher (2005)).

- (5) . . . Alice. . . thought it would be as well to introduce some other subject of conversation. *While she was trying to fix on one, the cook took the cauldron of soup off the fire* [italics added], and at once set to work throwing everything within her reach at the Duchess and the babythe fire-irons came first. . .
(Carroll, 1872)

When you take the italic line in isolation, you would think that ‘she’ would refer to ‘the cook’, but when we look at the example as a whole, it is clear that ‘she’ refers to ‘Alice’. This is clear to people who have a sufficient working memory to integrate the information across sentences and use all the factors needed. But, as stated in Burke and MacKay (1997), memory performance that requires the formation of new connections, for example, recall of recent autobiographical experiences, new facts or the source of newly acquired facts is relatively impaired in old age.

To examine in what proportion older adults’ interpretations differ from the preferred interpretations (via semantic or grammatical factors), we tested older adults with the same materials as used in the research of Vogelzang et al. (submitted). Here, the participants heard short discourses, followed by a question regarding their interpretation of a pronoun. Their interpretation could either be the preferred interpretation or not. All discourses are built to distinguish the influences of different sentential subjects on the interpretation and processing of different pronominal objects. To encourage a parallel interpretation, we used the word ‘while’. According to Andrew Kehler, ‘while’ marks events that are occurring at the same time (Kehler, Kertz, Rohde, and Elman (2008)). In other words, it suggests a parallel activity and should support an interpretation of parallel activities, so it should bias participants to following parallel responses rather than a simple subject-preference as argued for by e.g. (Smyth, 1994).

We are testing the sentential subjects, pronouns (such as ‘he’) and noun phrases (from now on abbreviated as *NP*’s), such as ‘the Pig’ versus each other. The pronominal objects that are tested are pronouns (such as *him*) versus reflexives (*himself*). With this, we have four variations per story. In Example (6) we see the variations of (1-c).

- (6) The Pig is making bread. Yesterday the Pig asked the Elephant how to make the bread,
- a. **Pronoun - pronoun**
While *he* saw *him* at the supermarket.
 - b. **Pronoun - reflexive**
While *he* was washing *himself* in the kitchen
 - c. **NP - pronoun**
While *the Pig* saw *him* at the supermarket.
 - d. **NP - reflexive**
While *the Pig* was washing *himself* in the kitchen

The experiment is set up to manipulate and exclude some of the discourse factors stated above. Gender information for example, is left out: every character is a male and therefore participants do not have to take this factor into account.

The factor ‘grammatical constraints’ is being manipulated by making a distinction between pronoun

and reflexive in the object form: the difference between ‘He was washing him’ and ‘He was washing himself’. The reflexive is required by grammatical constraints to only refer to the subject. Pronouns on the contrary must refer to an antecedent that is not the subject of the current clause. In this experiment, there are two antecedents a pronoun can refer to. Therefore, pronouns are more ambiguous than reflexives and are more likely to be interpreted the other way. Thus, we do expect a difference in items such as (6)-a and c and items as (6)-b and d. The PF, or grammatical role parallelism factor, predicts that subject pronouns refer back to subject antecedents and object pronouns to object antecedents. This is tested with items like (6)-a.

To be able to draw conclusions about the participants’ executive functioning, we did additional tests. To test a person’s ability to inhibit their first response, we use the Stroop test. Our second additional test would be the digit span test. This task is used to measure working memory’s number storage capacity (GréGoire and Van Der Linden, 1997). As mentioned before, working memory might affect the interpretation of pronouns. Since growing older correlates with a mental decline, also working memory capacity decreases. The study of Waters and Caplan (2001) shows that people of younger ages performed clearly better than older adults at a lexical working memory test.

2.3 Expectations

Like the expectations and results of Vogelzang et al. (submitted) in their experiment, we too expect that when ambiguity in sentences increases, more cognitive effort is needed and fewer people will choose the preferred interpretation as their answer. Since (6)-a is the most ambiguous, we expect that, compared to other cases, relatively few people interpret both subject and object pronouns as the preferred interpretation. Interpretations as in cases such as (6)-c and (6)-d the least ambiguous: the NP in (6)-c rules out one option for the pronoun, leaving just one option. Also in (6)-d, grammatical constraints on the reflexive leaves the NP as only option. We expect these cases to have the highest preferred interpretation rate. Case (6)-b would be somewhere inbetween. The results of Vogelzang et al. (submitted) of the performances of young adults support these expectations.

3 Methods

3.1 Participants

For the experiment we recruited 14 participants (mean age 71.7 years with a standard deviation of 6.2 years, 5 females). All of the participants were native speakers of Dutch and reported no cognitive difficulties.

3.2 Design and procedure

All materials of the main experiment were taken from the research of Vogelzang et al. (submitted). At the start of the experiment, the participants were explained what they had to do and they could also read the instructions on a laptop screen. To practise, the participants were given some test trials first. When they felt comfortable, the real experiment would start.

In the experiment we made use of several short Dutch auditory discourses with all the same structure of three sentences:

- First sentence: The first character is being introduced, which will be the subject in the last sentence.
The Pig is making bread.
- Second sentence: A second character is now introduced.
Yesterday the Pig asked the Elephant how to make the bread.
- Third sentence: A sentence with a subject and an object, the subject either in full NP or pronoun, and the object either in reflexive or pronoun. This makes four variations in this sentence per story:
 1. Pronoun - pronoun
While he saw him at the supermarket.
 2. NP - pronoun
While the Pig saw him at the supermarket.
 3. Pronoun - reflexive
While he was washing himself in the kitchen
 4. NP - reflexive
While the Pig was washing himself in the kitchen

After these sentences the participants heard a question of which the answer would be one of the characters in the story. The question could either be a subject question (who saw someone?) or an object question (who was asked something?). To answer this question, the participants had to look on the screen where both characters were displayed: one left and the other one on the right side. Now they could use the shoulder buttons on a controller to indicate which character they think is the answer.

In total, the participants were given 60 stories with time for breaks after every 15 stories. This caused the main experiment to take approximately half an hour. Both the digit span task and Stroop task were done on paper. We made use of the Stroop task used in Jensen (1965) and the digit span task of GréGoire and Van Der Linden (1997).

4 Results

4.1 Responses

For the analysis of the responses, we used `lme4` in R to make a generalised linear mixed effect model. The model investigates what (interaction) effect the subject case, object case and question type have on the participants' pronoun interpretation. Also as fixed effects, (without interaction term) we entered Stroop and digit span results. As random effects, we had intercepts for subjects and stories. We found no obvious deviations from normality nor homoscedasticity after looking at visualization of residual plots. P-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question.

With the pronoun/pronoun case and subject question type as baseline, we report the effects in the context of the intercept $\beta = -3.99$; $z = 1.60$; $p = 0.11059$. The results indicate that the participants more often selected the preferred interpretation in sentences with an object reflexive rather than an object pronoun ($\beta = -0.845258$; $z = -2.918$; $p = 0.00353$). Even when only considering subject questions (so no effect of the combination of object reflexive and object questions occur), this remains the only significant effect on the participants' pronoun interpretation. The full table of fixed effects is added in the Appendix.

We expected that, like the young adults in Smyth

(1994), older adults apply the parallel function. In the graphs of Figures 1a and 1b, we can see that our expectations were reached. The parallel interpretation theory holds that people prefer subject antecedents for subject pronouns and object antecedents for object pronouns, when the sentences are parallel enough. The figures do indeed show that questions referring to subjects make participants mainly choose a subject antecedent. This could mean that both Crawley et al. (1990)'s Subject Assignment theory and Smyth (1994)'s Parallel Function theory can be applied, since they both account for subject assignment in subject referent cases. But on the other hand, the figures also show that questions referring to objects are not interpreted as subject antecedents. Here, participants mainly chose object antecedents, which was predicted by the PF.

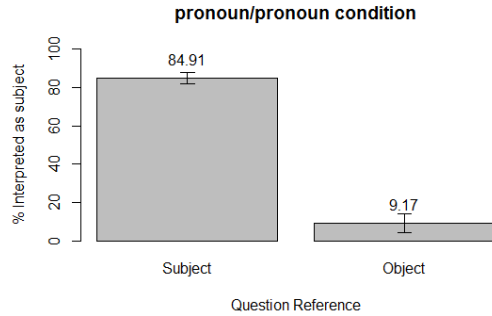
4.2 Reaction times

As we can see, the ambiguous pronoun/pronoun case in Figure 1a is very much like the less ambiguous NP/pronoun case in Figure 1b: participants seem to keep interpreting pronouns the same way. But do they take longer to make their choice? We tested whether there was a difference in reaction times. The reaction time data is visualized in Figure 2.

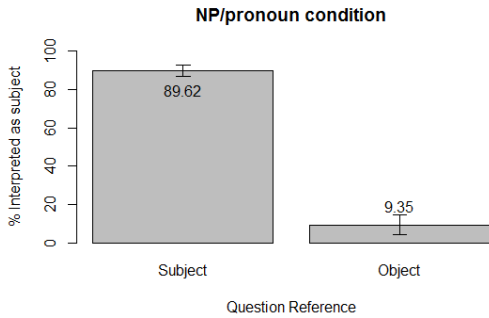
Participants achieved mean reaction times of 1299 ms on subject pronouns (SE = 127, 95%) and 1366 ms (SE = 117, 95%) on subject NP's. The t-test revealed that this difference was not statistically significant; $t = -0.3867$, $df = 212.918$, $p\text{-value} = 0.6994$. A p-value this high says that we can not reject the hypothesis that both means are equal. This means that it is very likely that participants are equally fast to make a decision in ambiguous and less ambiguous cases. This would mean that the parallel preference factor is a really strong constraint for interpreting pronouns for older adults.

5 Discussion

In this paper we did a research on pronoun interpretation by older adults. The experiment was set up to test the hypothesis that more ambiguity in sentences would cause participants to interpret pronouns less consistently.



(a) Left: classified as preferred interpretation, Right: preferred object interpreted as subject antecedent, in the case of a pronoun subject.



(b) Left: classified as preferred interpretation, Right: preferred object interpreted as subject antecedent, in the case of a NP subject.

Figure 1: Barplots of percentages interpreted as a subject antecedent.

5.1 Grammatical factors

Results show that indeed the most ambiguous case (pronoun/pronoun) has the lowest rate of the preferred interpretations, though, the difference compared to the other cases was not significant. The only significant factor was the form of the sentential object. Participants chose the preferred interpretation more often when there was an object reflexive, rather than an object pronoun. This was expected, because pronouns are more ambiguous than reflexives. Reflexives are bound to grammatical constraints and are therefore easier to resolve than pronouns.

Reaction Times in cases of Object Pronoun and QuestionRef Object

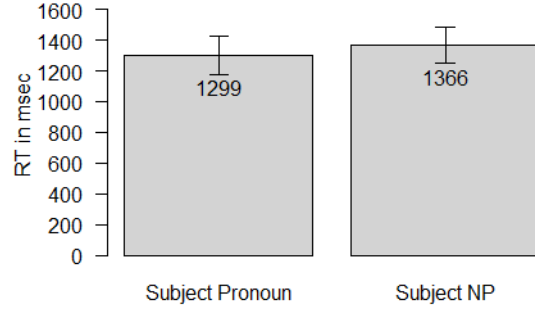


Figure 2: Mean reaction times in cases with hi-j/hem and NP/hem condition

5.2 Semantic factors

We did not expect that the form of the object would be the only effect. We expected the subject form (NP or pronoun) to have a significant influence on the participants' interpretation. A pronoun is, of course, way more ambiguous than a full NP. Therefore we expected participants to choose the preferred interpretation more often in unambiguous cases (NP/pronoun) compared to the ambiguous cases (pronoun/pronoun).

Our main explanation for why this did not happen is because the parallel function is a really strong constraint, as seen in the results. After all, we did find evidence that the Subject Assignment theory of Crawley et al. (1990) does not hold here. Instead, the parallel preference theory of Smyth (1994) is being followed, since most object pronouns were being interpreted as preceding objects and most subject pronouns as subject antecedents. This parallel function even appeared at the same rate in ambiguous (pronoun/pronoun) and unambiguous cases (NP/pronoun), since there was no significant difference in reaction times. The strong PF seems to overrule our hypothesis that the form of the sentential subject would have a significant influence on the participants' pronoun interpretation.

Our results can be compared to these of Hendriks, Koster, and Hoeks (2014). In this research,

children (aged 4-7), young adults (aged 18-35) and older adults (aged 69-87) were doing a pronoun production task and a pronoun comprehension task. In the comprehension task, short discourses were told with either a topic shift or not, and in the end, participants indicated their interpretation of a pronoun. They found that older adults did not perform significantly different from young adults. In the production task older adults appeared to lack the necessary cognitive capacities to keep track of the prominence of discourse referents, producing more potentially ambiguous pronouns than young adults.

Comparing the results from the young adults in Vogelzang et al. (submitted) and the results from the older adults in the current study, interpretation rates are mostly the same, though older adults have overall slightly lower rates in preferred interpretation. Also, for the young adults there was a significant difference in interpretation between the different forms of the subject.

5.3 Future research

It could be that we did not find the exact same conclusions as Vogelzang et al. (submitted) because we lacked participants. Future studies should have more participants. If there is still no difference between older and young adults then, this needs to be investigated. We suggest to also test the young adults with the Stroop and digit span task to be able to compare those with older adults.

It would also be interesting to see the effect of different levels of parallelity on young and old adults. Now, we used the word ‘while’, which is known for making two clauses highly parallel (Kehler et al., 2008). Future studies can focus on the effect of linking words with other levels of parallelity on the preferred interpretation rate. Then we can answer the question who (young or older adults) is more sensitive to changes in parallelism: who will apply Smyth’s Parallel Function more and who Crawley’s Subject Assignment?

References

- Eisenband J. Brown-Schmidt S. Trueswell J.C. Arnold, J.E. The rapid use of gender information: Evidence of the time course of pronoun resolution from eyetracking. *Cognition*, page 76, 2000. ISSN B13-B26.
- Jennifer E Arnold, Janet G Eisenband, Sarah Brown-Schmidt, and John C Trueswell. The rapid use of gender information: Evidence of the time course of pronoun resolution from eyetracking. *Cognition*, 76(1):B13–B26, 2000.
- William Badecker and Kathleen Straub. The processing role of structural constraints on interpretation of pronouns and anaphors. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 28(4):748, 2002.
- H P Branigan, M J Pickering, S P Liversedge, A J Stewart, and T P Urbach. Syntactic priming - investigating the mental representation of language. *Journal of Psycholinguistic Research*, 24(6):489–506, 1995. ISSN 0090-6905.
- Deborah M Burke and Donald G MacKay. Memory, language, and ageing. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 352(1363):1845–1856, 1997.
- Ronnie Cann. *Formal semantics: an introduction*. Cambridge University Press, 1993.
- Wallace L Chafe and Charles N Li. Givenness, contrastiveness, definiteness, subjects, topics, and point of view in subject and topic. 1976.
- Noam Chomsky. *Government and binding*. 1981.
- Kaili Clackson, Claudia Felser, and Harald Clahsen. Childrens processing of reflexives and pronouns in english: Evidence from eye-movements during listening. *Journal of Memory and Language*, 65(2):128–144, 2011.
- Rosalind A Crawley, Rosemary J Stevenson, and David Kleinman. The use of heuristic strategies in the interpretation of pronouns. *Journal of Psycholinguistic Research*, 19(4):245–264, 1990.
- Ian Cummings, Clare Patterson, and Claudia Felser. Variable binding and coreference in sentence comprehension: evidence from eye movements. *Journal of Memory and Language*, 71(1):39–56, 2014.

- Paul E Engelhardt, Fernanda Ferreira, and Elena G Patsenko. Pupillometry reveals processing load during spoken language comprehension. *The Quarterly Journal of Experimental Psychology*, 63(4):639–645, 2010.
- Lyn Frazier, Lori Taft, Tom Roeper, Charles Clifton, and Kate Ehrlich. Parallel structure: A source of facilitation in sentence comprehension. *Memory & Cognition*, 12(5):421–430, 1984. ISSN 0090-502X. doi: 10.3758/BF03198303. URL <http://dx.doi.org/10.3758/BF03198303>.
- Susan E Gathercole and Alan D Baddeley. Short-term memory may yet be deficient in children with language impairments: A comment on van der lely & howard (1993). 1995.
- Talmy Givón. *Topic continuity in discourse: A quantitative cross-language study*, volume 3. John Benjamins Publishing, 1983.
- Jacques Grégoire and Martial Van Der Linden. Effect of age on forward and backward digit spans. *Aging, neuropsychology, and cognition*, 4(2):140–149, 1997.
- Petra Hendriks, Hedderik Van Rijn, and Bea Valke-
nier. Learning to reason about speakers alter-
natives in sentence comprehension: A computa-
tional account. *Lingua*, 117(11):1879–1896, 2007.
- Petra Hendriks, Charlotte Koster, and John CJ
Hoeks. Referential choice across the lifespan:
why children and elderly adults produce ambigu-
ous pronouns. *Language, Cognition and Neuro-
science*, 29(4):391–407, 2014.
- Juhani Järvi-kivi, Pirita Pyykkönen-Klauck, Sarah
Schimke, Saveria Colonna, and Barbara Hem-
forth. Information structure cues for 4-year-olds
and adults: tracking eye movements to visually
presented anaphoric referents. *Language, Cogni-
tion and Neuroscience*, 29(7):877–892, 2014.
- Arthur R Jensen. Scoring the stroop test. *Acta
Psychologica*, 24:398–408, 1965.
- Marcel A Just and Patricia A Carpenter. The in-
tensity dimension of thought: pupillometric in-
dices of sentence processing. *Canadian Jour-
nal of Experimental Psychology/Revue canadi-
enne de psychologie expA© rimentale*, 47(2):310,
1993.
- Andrew Kehler, Laura Kertz, Hannah Rohde, and
Jeffrey L Elman. Coherence and coreference re-
visited. *Journal of Semantics*, 25(1):1–44, 2008.
- Jacolien Rij, Hedderik Rijn, and Petra Hendriks.
How w m load influences linguistic processing in
adults: A computational model of pronoun inter-
pretation in discourse. *Topics in cognitive sci-
ence*, 5(3):564–580, 2013.
- Ron Smyth. Grammatical determinants of ambigu-
ous pronoun resolution. *Journal of Psycholin-
guistic Research*, 23(3):197–229, 1994.
- Hyun-joo Song and Cynthia Fisher. Whos she? dis-
course prominence influences preschoolers com-
prehension of pronouns. *Journal of Memory and
Language*, 52(1):29–57, 2005.
- Jennifer Spenader, Erik-Jan Smits, and Petra Hen-
driks. Coherent discourse solves the pronoun in-
terpretation problem. *Journal of child language*,
36(01):23–52, 2009.
- Jacolien Van Rij, Hedderik van Rijn, and Petra
Hendriks. Cognitive architectures and language
acquisition: A case study in pronoun comprehen-
sion. *Journal of Child Language*, 37(03):731–766,
2010.
- Margreet Vogelzang, Hedderik Van Rijn, and Petra
Hendriks. Pupillary responses reflect ambiguity
resolution in pronoun processing. submitted.
- Gloria S Waters and David Caplan. Age, working
memory, and on-line syntactic processing in sen-
tence comprehension. *Psychology and aging*, 16
(1):128, 2001.

Appendix

Formula:

$Response \sim SubjectForm * ObjectForm * QuestionRef + Stroop + DigitSpan + (1|Nr) + (1|Subject)$

Predictor	Estimate	Std. Error	z value	p-value
(Intercept)	3.989041	2.500104	1.595	0.11059
SubjectForm	-0.291890	0.294209	-0.992	0.32114
ObjectForm	-0.845258	0.289722	-2.918	0.00353 **
QuestionRef	0.152453	0.288796	0.528	0.59758
Stroop	-0.009781	0.014666	-0.667	0.50482
DigitSpan	-0.043066	0.133684	-0.322	0.74734
SubjectForm:ObjectForm	-0.073083	0.578834	-0.126	0.89953
SubjectForm:QuestionRef	0.564639	0.578725	0.976	0.32923
ObjectForm:QuestionRef	0.438114	0.577273	0.759	0.44789
SubjectForm:ObjectForm:QuestionRef	-0.091226	1.153869	-0.079	0.93698