Syntactic Ambiguity Resolution in Sentence Processing: New Evidence from a Morphologically Rich Language

Daria Chernova (chernovadasha@yandex.ru)
Laboratory for Conitive Studies, St. Petersburg State University,
190000, 58-60 Galernaya St., St.Petersburg, Russia

Tatiana Chernigovskaya (tatiana.chernigovskaya@gmail.com)
Laboratory for Conitive Studies, St. Petersburg State University,
190000, 58-60 Galernaya St., St.Petersburg, Russia

Abstract

An experimental study dedicated to structurally ambiguous sentences processing was carried out. We analyzed the case of participial construction attachment to a complex noun phrase. In Experiment 1, we used self-paced reading technique which enables to measure reading times of each word in a sentence and error rates in the interpretation of the sentences. Error rates in locally ambiguous sentences reveal high attachment preference – for sentences with low attachment error rates are higher. However, high attached modifiers are processed slower than low attached ones. In experiment 2, we use eye-tracking technique. Early effects (first-pass time) show that high attachment requires more time to process than low or ambiguous attachment (as Late Closure principle predicts). However, late effects (dwell time and regressions into the target region and out of it) show that adjunct attachment to a more discourse prominent NP (i.e. head of the complex NP) is more preferable. Regressions to competing NPs also show that NP1 is reread more often. Online eye-movements data correspond to offline data - answers to questions forcing to choose between two possible interpretations of the sentence which also show strong high attachment bias. Therefore we see two stages of sentence processing: the first one is driven by locality principles and the second one is discourse-driven.

Keywords: sentence processing; ambiguity resolution; late closure principle; comprehension

Introduction

We live in the world where we constantly face ambiguous information. Still we have to make decisions decoding the input in accordance to relevant situational context. It is true for all the modalities well described by fuzzy-sets (Zadeh 1965, 2002). The idea is especially valid for human language and it contradicts traditionally accepted main language function – communication.

Decision-making - a final stage of recognition - is a critical issue in cognitive research. Cognitive mechanisms employed in processing ambiguous information that involve various linguistic hypotheses describing morphological, lexical, syntactical levels as well as ambiguity in interpreting different text types are the important point of interest.

Ambiguity resolution has always been the most important testing ground in linguistics for parsing models. Among various constructions, modifier attachment ambiguity in a complex noun phrase, as in (1), provoked one of the hottest debates in the history of psycholinguistics.

(1) *I met the servant of the lady that was on the balcony*.

In (1), the relative clause can be attached either high (HA) or low (LA), i.e. to the first (head) noun or to the second (dependent) noun. Based on the first experiments on English indicating LA preference, Frazier and Fodor (1978) suggested that this kind of ambiguity is resolved according to the Late Closure Principle. This principle states that incoming lexical items tend to be associated with the phrase or clause currently being processed. However, LA preference was not confirmed cross-linguistically, which *prima facie* contradicted the very idea of universality of parsing principles. Cuetos and Mitchell (1988) were the first to report HA preference in Spanish, and then it was found in many languages, while LA preference was discovered in some others.

Since then, various theories have been suggested to explain why languages differ in this respect (e.g. Baccino De Vincenzi & Job 2000; Desmet, Brysbaert & De Baecke 2002; Fodor 1998; Grillo & Costa 2013), but the question is still unresolved. Another important problem revolves around the processing cost of ambiguity resolution (e.g. Frazier & Clifton 1996, Traxler, Pickering & Clifton 1998, Van Gompel et al. 2005). There are most provoking neurolinguistic data on cerebral mechanisms of ambiguity resolution (Mason et al. 2003; Fiebach, Vos & Friederici 2004; Frisch et al. 2002; Christensen 2010 etc.)

Theoretical background

As (2) shows, modifier attachment ambiguity arises not only with relative clauses (RCs), but also with other types of modifiers, e.g. with participial constructions and PPs. Most studies focused on RCs, several experiments examined other modifiers, and very few studies offer a comparison of several modifier types.

(2) *the servant of the lady that was on the balcony / standing on the balcony / with red hair*

Examples discussed above are globally ambiguous, but modifier attachment ambiguity can also be resolved locally, as in (3a-b):

(3) a. *I met the servant of the ladies that (unexpectedly) was on the balcony*.

b. *I met the servants of the lady that (unexpectedly) was on the balcony*.

This is crucial when the time course of ambiguity processing is studied. Firstly, we can compare reading times for two locally ambiguous sentences, like (3a) and (3b), and reveal early parsing preferences. Secondly, reading times for locally and globally ambiguous sentences can be compared to determine whether the ambiguity has a processing cost.

Different parsing models make different predictions about the processing cost of ambiguity resolution. Serial, or two-stage, models (e.g.; Ferreira & Clifton 1986; Frazier & Rayner 1982) claim that for every type of syntactic ambiguity, there is one preferable interpretation that is always chosen in the beginning. If it contradicts the following context, we come back and reanalyse, which results in a slow-down (so-called garden-path effect). These theories predict that if we are not forced to reanalyse, ambiguity has no special cost. Increase of processing time is predicted only for unambiguous sentences with a non-preferred type of attachment.

Parallel, or competition-based, models (e.g. Clifton & Staub 2008; McDonald 1994) predict an increase of processing time for ambiguous sentences, as working memory is loaded with several possible interpretations that compete with each other. If both interpretations are equally plausible, the competition becomes stronger and requires more and more processing resources.

Finally, underspecification models (e.g. Swets et al. 2008) and unrestricted race models (e.g. Traxler et al. 1998; van Gompel et al. 2005) predict an ambiguity advantage. According to them, when we process a sentence, we make hypotheses about its possible interpretations, and for an ambiguous sentence all hypotheses are correct. An unambiguous sentence can potentially lead to a garden path while an ambiguous sentence cannot.

We conduct a study on participial construction modifiers (in Russian, participles agree in number, gender and case with the noun they refer to), comparing globally ambiguous sentences and locally ambiguous sentences (with HA and LA) using disambiguation by case.

Experiment 1. Self-paced reading

Participants

60 native speakers of Russian from 18 to 30 years old (12 males, 48 females) participated in the experiment on a voluntary basis. All participants were unaware of the purpose of the study.

Material and design

24 sets of experimental stimuli, as in (2a-c), were constructed. In each sentence a complex noun phrase was followed by a participial construction, which could be attached either to the first or to the second noun (hence N1 and N2). The case form of the participial either disambiguated the modifier attachment towards N1 or N2 or left it ambiguous (this happened when the form was homonymous).

(3)

a. AMB condition
Svidetel' upomjanul naparnika voditelja, pozavčera videvšego eto ograblenie.
witness mentioned workmateACC driverGEN yesterday having-seenACC=GEN this robbery

b. LA condition
Svidetel' upomjanul o naparnike voditelja, pozavčera videvšego ograblenie.
witness mentioned about workmatePREP driverGEN yesterday having-seenGEN robbery

c. HA condition
Svidetel' upomjanul o naparnike voditelja, pozavčera videvšem ograblenie.
witness mentioned about workmatePREP driverGEN yesterday having-seenPREP robbery

N1 and N2 always had the same number and gender, animacy was balanced across sets.

All participial constructions contained a word modifying the participle (most often an adverb), the participle and two words following the participle. They always had roughly the same length (12-13 syllables).

Every participant saw each target sentence once, in one of the three conditions and each participant was exposed to 8 HA sentences, 8 LA sentences and 8 AMB sentences. Each sentence was followed by a question with a choice of two answers that forced the participant to choose between two interpretations. The reciprocal order of the two nouns was counterbalanced to avoid any order bias. The question and two answers for the target sentence set in (5a-c) are given in (4a-b).

(4)
a. *Ograblenije videl…*
the robbery was seen by…
b. *1) voditel 2) naparnik*
driver workmate

Each experimental list included 32 fillers. Fillers were also followed by a question that forced the participant to choose between two NPs mentioned in the sentence. As a result, we had three experimental lists with 56 sentences.

To guarantee that both interpretations of ambiguous target sentences are plausible we conducted a norming study. 32 native speakers of Russian who did not take part in the main study were asked to rate the naturalness of possible modifier attachment interpretations.

No significant differences were found between two sentences in any pair (according to the chi-square test).

Procedure

The non-cumulative self-paced reading paradigm was used. The experiment was run on a PC using Presentation software (http://www.neurobs.com/).

Results

We analyzed participants' reading times and answers to the questions.
Offline measures
The accuracy rate for filler sentences is relatively high:

87.8% of answers were correct, and no participant made more than 6 (18.8%) mistakes. However, participants made surprisingly many mistakes with the experimental sentences, especially in the LA condition. LA sentences were misinterpreted as HA significantly more often than HA sentences were misinterpreted as LA ($F1(1, 119) = 93.9$, $p < 0.001$; $F2(1, 47) = 56.4$, $p < 0.001$). Thus, participants very often ignored the case morphology on the participle that unambiguously indicated which noun it agrees with.

As for AMB sentences, participants' answers show that they were interpreted as HA more often than as LA (323 vs. 157, or 67.3% vs. 32.7% respectively). This difference is statistically significant ($F1(1, 119) = 127.6$, $p < 0.001$; $F2(1, 47) = 34.2$, $p < 0.001$). It total, we can conclude that participants interpreted about two thirds of target sentences as HA paying little attention to case morphology.

Online measures

We analysed reaction times from five interest regions in target sentences: N1, N2, ADV (a word modifying the participle, usually an adverb), PART (participle) and two regions after the participle (POST1 and POST2). Every region consisted of one word.

The analysis of all trials revealed a significant effect of attachment type in the PART region. LA sentences were read faster than HA sentences ($F1(1,59) = 10.49$, $p < 0.01$, $F2(1,23) = 4.43$, $p = 0.05$). The difference between LA and AMB sentences approaches significance ($F1(1,59) = 9.07$, $p < 0.01$, $F2(1,23) = 3.48$, p = 0.07). In the POST1 region, there is a significant effect of attachment type in the subject analyses, but not in the item analyses: LA is processed faster than HA ($F1(1,59) = 7.32$, $p < 0.01$; $F2(1,23) = 1.88$, $p = 0.18$) and AMB sentences ($F1(1,59) = 11.12$, $p < 0.01$; $F2(1,23) = 4.03$, $p = 0.06$). No other differences in any region were statistically significant, in particular, readings times for HA and AMB sentences virtually coincide in all interest regions. In total, this means that LA sentences are easier to process than HA sentences.

There are no significant differences in the time course of processing between disambiguated sentences interpreted correctly and incorrectly in both HA ($F (1, 478) = 0.046$, p=0.829) and LA ($F (1, 478) = 1.485$, p=0.228) conditions. However, focusing on the correlation between the time course of processing and the interpretation chosen, AMB sentences are processed differently depending on the interpretation a reader eventually chooses: AMB sentences interpreted as LA are read faster than those interpreted as HA ($F (1, 478) = 6.055$, p=0.014).

Discussion

There is a clear HA-preference in comprehension, despite this, HA is processed slower as the agreement between a noun and a participle is not local. Similar difference between online and offline measures are reported for Italian (De Vincenci & Job 1993) and Portuguese (Maia et al. 2006). More detailed data about the time course of this kind of ambiguity resolution can be obtained in an eye-tracking study.

Experiment 2. Eye-tracking

Participants

36 native speakers of Russian from 20 to 30 years old with normal or corrected-to-normal vision participated in the experiment on a voluntary basis. All participants were unaware of the purpose of the study.

Material and design

Materials and design were the same as in Experiment 1, except for the questions: no variants were given to the participants, they had to complete the sentence as in (4a) orally.

Procedure

After the calibration procedure the participant read the sentence from the computer screen. After he/she finished, he/she pressed a button, the sentence disappeared and the task appeared on the screen. After the answer was given, the participant pressed the button and the next sentence appeared. Drift correction was performed before each trial.

Apparatus

EyeLink 1000, sampling rate 500 Hz monocular, head-free mode.

Results

For PART region, the first-pass time was longer in HA condition in comparison to LA: F=3.634, p=0.042. However, no difference is found in total dwell time in PART region across conditions. Regressions to PART region are made more often in LA ($\chi^2=4.29$, p=0.04) and AMB ($\chi^2 =12.95$, p=0.0003) condition in comparison to HA. Also, more regressions are made from PART region to other parts of the sentence in LA and AMB conditions ($\chi^2 =3.94$, p=0.05).

Regressions to competing NPs show that NP1 is reread twice more often than NP2 ($\chi^2= 187.76$, p<0.001). It corresponds to offline data of answer analyses. Ambiguous sentences are interpreted as HA in 64.6% cases. Only 2.9% of answers pointed that the sentence is ambiguous and there are two ways to interpret it. Sentences in HA condition received 75.6% correct answers, but in LA condition – only 38.6% correct answers which means that there is strong HA preference for adjunct attachment in Russian.

Discussion

Early effects (first-pass time) show that high attachment requires more time to process than low or ambiguous attachment - as *Late Closure principle* predicts. However, late effects (dwell time and regressions into the target region and out of it) show that adjunct attachment to a more discourse prominent NP (i.e. the head of the complex NP) is more preferable. Online eye-movements data correspond to offline data – interpretations of the sentences given by participants– which also show strong high attachment bias.

General Discussion

According to our data there are two stages of sentence processing, the first is driven by *locality principles* and the second one is *discourse-driven*.

For early stages of processing, the easier a structure is, the better. According to *Late Closure Principle* (Frazier & Fodor1978) low attached modifiers are easier to process as they require less working memory resources. This is what we find in our online measures: LA sentences are processed significantly faster in SPRT and with shorter first-pass time in eye-tracking.

Interpretation process, however, corresponds to the second stage of processing and seems to be guided by absolutely different factors.

We report strong HA-preference for interpreting Russian participial construction modifiers, which is compatible with data on interpreting of Russian RC (Sekerina 2003, Fedorova& Yanovich 2006). NP1 is chosen as answer is more often and attracts more regressions. Unpreferable LA-variants are dispreferred, and lead to comprehension errors. Also, LA sentences provoke more regressions to and from participle which may reflect difficulties of discourse integration.

A possible explanation is that for interpretation discourse factors have more weight, according to Relativized Relevance Principle (Frazier 1990): the head of a complex noun phrase is more prominent in discourse (sentence about the workmate of a driver is about the workmate and not about the driver) thus it attracts the modifier.

A crucial point is a surprising neglect of case endings of the participles when interpreting a sentence, the result of which is an unusual number of mistakes the distribution of which supports the idea that high attachment is preferable in Russian. Case agreement in postposition seems to be more vulnerable in speech production (Rusakova 2013) and may turn out to be vulnerable in interpretation as well. The same effect was found for gender agreement in French (Baccino et al. 2000). So syntactic preferences seem to be more important in comprehension than case morphology.

Our data support the *serial model* in part of the processing cost for unambiguous sentences with a non-preferred type of attachment, but preferred and non-preferred variants differ on two stages of sentence processing.

Acknowledgments

References

Baccino, T., De Vincenzi, M., & Job, R. (2000). Cross-linguistic studies of the Late Closure strategy: French and Italian. In M. De Vincenzi & V. Lombardo (Eds.),*Cross-Linguistic Perspectives on Language Processing* (pp. 89-118). Dordrecht: Kluwer.

Clifton, C., Jr., & Staub, A. (2008). Parallelism and competition in syntactic ambiguity resolution. *Language and Linguistics Compass,* 2, 234-250

Cuetos, F. & Mitchell, D.C.(1988) Cross-linguistic differences in parsing: Restrictions on the use of the Late Closure strategy in Spanish. *Cognition*, 30, 73-105.

De Vincenzi, M., & Job, R. (1993). Some observations on the universality of the Late Closure strategy. *Journal of Psycholinguistic Research*, 22, 2, 189-206.

Desmet, T., Brysbaert, M., & De Baecke, C. (2002). The correspondence between sentence production and corpus frequencies in modifier attachment. *Quarterly Journal of Experimental Psychology*, 55A, 3, 879-896.

Fedorova, O., & Yanovich, I. (2006). Early preferences in RC-attachment in Russian: The effect of Working Memory differences. In: J. Lavine et al. (eds.), *Proceedings of FASL 14* (pp. 113-128). Ann Arbor, MI: Michigan Slavic Publications

Ferreira, F., & Clifton, C. (1986). The independence of syntactic processing. *Journal of Memory and Language*, 25, 348–368.

Fiebach, C. J., Vos, S. H., & Friederici, A. (2004). Neural correlates of ambiguity in sentence comprehension for low and high span readers. *Journal of Cognitive Neuroscience,* 16 (9), 1562–1575

Fodor, J.D. (1998). Learning to parse? *Journal of Psycholinguistic Research*, 27, 285-319

Fodor, J.D. (2002). Prosodic disambiguation in silent reading. In: *Proceedings of the North East Linguistic Society*, 32 (pp. 113-132). Amherst: GSLA, University of Massachusetts.

Frazier, L, & Clifton, C., Jr. (1996). *Construal*. Cambridge, MA: MIT Press.

Frazier, L. & Fodor, J.D. (1978). The sausage machine: A new two-stage parsing model. *Cognition*, 6, 291-325

Frazier, L. (1990). Parsing modifiers. Special purpose routines in the human sentence processing mechanism? In D.A. Balota, G.B. Flores d'Arcais & K. Rayner (Eds.), *Comprehension Processes in Reading* (pp. 303-330). Hillsdale, NJ: Lawrence Erlbaum

Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology*, 14, 178-210.

Frisch, S. Schlesewsky, M., Saddy, D., & Alpermann, A. (2002). The P600 as an indicator of syntactic ambiguity. *Cognition* 85, B83-B92.

Christensen K. Syntactic reconstruction and reanalysis, semantic dead ends, and prefrontal cortex (2010) *Brain and Cognition* 73, 41–50

Grillo, N. & Costa (2013). A novel argument for the universality of parsing principles. *Cognition* 133 (1), 156-187

MacDonald M. C., Pearlmutter N. J., Seidenberg M. S. (1994) The lexical nature of syntactic ambiguity resolution. *Psychological review,*101, 4, p. 676.

Maia M., Fernández E.M., Costa A., Lourenço-Gomes M.D.C. (2006) Early and late preferences in relative clause attachment in Portuguese and Spanish. *Journal of Portuguese Linguistics*, 5, 3-26.

Mason, R.A., Just, M.A., Keller, T.A., & Carpenter, P.A. (2003). Ambiguity in the brain: What Brain Reveals About the Processing of Syntactically Ambiguous Sentences. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29, 1319-1338.

Rusakova M.V. (2013) *Elementy antropotsentricheskoy grammatiki russkogo jazyka*. M.: Jazyki slavianskoj kultury. 568 p.

Sekerina, I. (2003) The Late Closure Principle in Processing of Ambiguous Russian Sentences. *The Proceedings of the Second European Conference on Formal Description of Slavic Languages.* Universität Potsdam, Germany

Swets, B., Desmet T., Clifton, Jr. C., and Ferreira F. (2008) Underspecification of syntactic ambiguities: evidence from self-paced reading. *Memory & Cognition* 36, 201–17.

Traxler, M., Pickering, M., & Clifton, C., Jr. (1998). Adjunct attachment is not a form of lexical ambiguity resolution. *Journal of Memory and Language*, 39, 558-592.

Van Gompel, R. P. G., Pickering, M. J., Pearson, J., & Liversedge, S. P. (2005). Evidence against competition during syntactic ambiguity resolution. *Journal of Memory and Language*, 52, 284-307.