Prediction in Sentence Processing

1. Introduction

Humans can effortlessly and accurately comprehend sentences at speeds within a few hundred milliseconds. This is impressive, especially considering the complex grammatical rules and structures inherent in natural language. A fundamental question in cognitive science and psycholinguistics is how this is possible. In the investigation of this question, some have suggested that the mind, in the course of processing a sentence, can make predictions about what will come next, facilitating swift and precise comprehension. In other words, the language processing mechanism uses existing knowledge and expectations to make hypotheses about yet to be seen information [5, 6].

Although researchers in cognitive science and psycholinguistics [8, 9, 11, 5, 6] largely agree that language processing is predictive, the mechanisms driving such predictions remain unclear, and uncovering the nature of the predictive mechanism is one of the most central issues in recent psycholinguistic studies. Consequently, elucidating the nature of this predictive mechanism stands as a significant concern in contemporary psycholinguistic investigations. Given this context, the aim of the proposed research is to uncover the existence/nature of prediction in language processing. In other words: What elements are predicted during real-time language processing? How does prediction occur? What factors trigger prediction to occur?

2. Proposed Studies

The majority of my studies on prediction thus far, and indeed the vast majority of studies in the field of psycholinguistics, have been conducted on English. Although English exhibits grammatical differences from other languages, there are also significant commonalities which theoretical linguistics has helped to uncover. In the literature, it is argued that in real-time sentence processing, grammatical differences, rather than commonalities have much more influence on how sentences are processed. Thus, a common claim is that speakers of, for example Japanese, process sentences differently from speakers of English in many respects [2, 4].

This research intends to shed light on not only the question of prediction, but also the question of cross-linguistic processing differences. Therefore, I am requesting funding for two sets of experimental studies concerning prediction in sentence processing, one to be conducted in Russian, and one in Japanese. In the long term, conducting studies in English, Russian, and Japanese can give us better confidence that our hypotheses about prediction do/do not generalize, as well answer some of the pressing questions regarding cross-linguistic processing differences. Given that a sufficient

number of native-speaking subjects cannot be acquired via the Northwestern subject pool, these studies require the use of web-based experiments, which require the funding I seek.

2.1. Study 1: Russian

This study will undertake an experimental investigation into the real-time reading of Russian sentences containing the accusative and genitive forms of a noun, as well as a negated verb. First, consider the sentence in Ex.[1a]. Bring your attention to the object of the verb, *podarki* (gifts). Russian, like many languages, marks which noun is the object of the verb by using a form called the accusative. Thus, I have written the gloss below *podarki* with -acc. However, this is not the only way one can say this sentence. We can replace *podarki* with another form of the word, *podarok*. This form is called the genitive, and I have marked this in the gloss below with -gen. Turning to Ex.[1b], the key thing to note is that the genitive form requires a negative verb. In other words, if *gifts* is bearing genitive form, negation *ne* is required, otherwise, the example is not grammatical. I have marked the genitive form in Ex.[1b] with an asterisk (*) to indicate the ungrammaticality resulting from the genitive being combined with a positive verb.

(1) a. Roditeli dogovorilis' **podarki/podarok** ne darit'
parents agreed gifts-(acc/gen) not give
'The parents agreed to not give gifts.' (−)

b. Roditeli dogovorilis' **podarki/*podarok** darit'
parents agreed gifts-(acc/*gen) give
'The parents agreed to give gifts.' (+)

From this information, we can see that if the genitive form is used on the object of the verb, the verb can *not* be positive, only negative. We can then make the following hypothesis: If Russian speakers see the genitive form of a noun as an object of a verb, they will predict that the upcoming, corresponding verb must be negative. The next step is to conduct a web-based sentence reading experiment to test this hypothesis on negative constructions like those outlined in Ex.[2]. The experiment will be conducted remotely. The web-based reading experiment can measure how long participants will take to read each word in a sentence. If a word is difficult to read for some reason, then the time spent reading that word (reading time, RT) will be longer, but if a word is easy to read, then the RT for that word is shorter. Thus, it is hypothesized that if a word is predicted correctly, then the RT for the predicted word should be shorter. On the other hand, if a word is

predicted, but the prediction is not consistent with the actual sentence, the RT should be longer.

(2) Roditeli dogovorilis' $\left\{\begin{matrix}\text{podarki (acc)}\\\text{podarok (gen)}\end{matrix}\right\}$ $\left\{\begin{matrix}\text{sejchas}\\\text{nikogda}\end{matrix}\right\}$, v takix usloviax, ne darit'

'The parents agreed to now/never not give gifts(acc/gen) under such circumstances.'

If Russian speakers indeed predict a negative verb upon seeing the genitive *podarok*, we should expect that the presence of *nikogda* (never) is perfectly normal for the reader, as this is a standard way to form a negative sentence in Russian. On the other hand, if the reader has predicted a negative verb and encounters the positive element *sejchas* (now), we should expect a significantly longer RT than in the *nikogda* (never) condition. This would constitute evidence for a prediction having occurred. Finally, as a control, the accusative *podarki* should not trigger any prediction, and we therefore do not expect any RT difference at *sejchas/nikogda*.

2.2. Study 2: Japanese

When forming questions in Japanese, any question word (i.e., who, what, etc.) must be accompanied by a suffix called a question particle (QP) which attaches to the verb in the same clause. This is the case in Ex.[3], where *dare-ga* is accompanied by *-no* in the main clause and *nani-o* is accompanied by *-ka* in the subordinate clause.

(3) [$_{main}$ **Dono gakusei-ga** [$_{sub}$ Keiko-ga **nani-o** tabeta-**ka**] tazuneta-**no**?]
Which student-nom Keiko-nom **what**-acc ate-**QP** asked-**QP**
'Which student asked what Keiko ate?'

However, Japanese allows some flexibility in that a question word inside a subordinate clause does not require its QP to be in the subordinate clause. Rather, its QP can be in the main clause. In this way, a single, main-clause QP can cover two question words at once. This is the case in Ex.[4], where *dare-ga* and *nani-o* are both covered by *-no*.

(4) [$_{main}$ **Dono gakusei-ga** [$_{sub}$ Keiko-ga **nani-o** tabeta-to] itta-**no**?]
Which student-nom Keiko-nom **what**-acc ate-that said-**QP**
'What did which student say that Keiko ate?'

The variability of a QP inside the subordinate clause presents a chance to test for prediction. If it is the case that a QP is required whenever a question word is encountered, then we can hypothesize that readers will predict a QP when encountering a question word and no corresponding QP.

I propose to conduct a web-based reading experiment in the same way as Study 1 to test the prediction hypothesis on constructions like those in Ex.[5].

(5) $\left\{\begin{matrix}\text{dono gakusei-ga}\\\text{sono gakusei-ga}\end{matrix}\right\}$ Keiko-ga nani-o tabeta $\left\{\begin{matrix}\text{-ka}\\\text{-to}\end{matrix}\right\}$ tazuneta-no?

'Which/That student asked what/that Keiko ate?'

If it is the case that a QP is required whenever a question word is encountered, then we can hypothesize that *dare-ga* should trigger a prediction of a QP *-no* in the main clause. Then, upon reaching the subordinate clause question word *nani-o*, readers can associate it with the already-predicted *-no* in the main clause. If this is the case, the need for a QP for *nani-o* is filled and thus it should not trigger a prediction. How would we know if the previous steps occured?

The answer should come when readers reach the end of the subordinate clause. If *nani-o* has been associated with the main clause QP *-no*, then seeing another QP *-ka* should require readers to reassociate *nani-o* with *-ka*. This should result in a longer reading time, which would constitute evidence for a prediction having occurred. *Sono* and *-to* act as controls whereby *sono* is not expected to trigger any prediction since it is not a question word, and *-to* has no relation to question words since it is not a question particle. Results consistent with this hypothesis have been shown on a small number of subjects in experiments conducted thus far, but more participants are needed to increase confidence.

3. Innovation and Impacts

This research is situated within a larger project which works to provide a theoretically well motivated and computationally explicit theory of prediction in sentence processing. This provides a framework in which hypotheses about prediction can be empirically tested cross-linguistically, answering not only questions about prediction, but more general features of sentence processing across languages. Such findings relate to the larger cognitive science community in that they can give us a better understanding of the underlying cognitive capabilities of humans and the processes which the mind carries out [7, 3, 1, 8].

Regarding the academic community, due to its connections to both theoretical and experimental research, publications and presentations stemming from the proposed research should help stimulate cross-disciplinary interest among both researchers in sentence processing who are interested in predictive processing, as well as formal linguists who study the nature of grammatical structure.

In addition, given its experimentation in languages other than English, this research can expand the breadth of the sentence processing research community, increasing confidence that results are generalizable.

Related to my own academic progress, these two studies will form one chapter each of my dissertation. These chapters are part of a larger experimental section which also includes similar work on English. Up to now, my chapters on English have been drafted due to relatively easy access to experimental participants. In addition I have drafted theoretical background of the Russian and Japanese studies. In summary, these funds will provide me the means to finish a large portion of my disseration.

4. Feasibility

I aim to conduct two experiments with the funds received from this grant: one in Russian and one in Japanese. All experiments will be conducted on an online platform for participant recruitment, Prolific (https://www.prolific.co). Prior training is complete, as I have previous experience working with this online platform. In addition, I have already received IRB approval (see attached).

In the past, running similar experiments on Prolific took approximately 4-5 hours. Since the experiments are online-based, I do not need to stay at a lab to conduct the experiment. In addition, since my experiment designs are complete, I can begin as soon as funding is acquired. Statistical analysis is a similarly quick process given that lab analysis tools in R are already provided, and I have ample experience using them. I estimate statistical analysis to take a day at most for each experiment.

Participants will be paid $6.00 per hour, which Prolific specifies as a fair amount. This amount is also standard in my field. I propose to test 180 subjects for each reading experiment (i.e., 360 total) which is safely within range for sufficient statistical power for this type of reading experiment, as several previous studies have shown [10, 12]. Thus $6.00 x 360 = $2160.00 is requested for human subject fees. In addition, Prolific asks for a fee of $2.00 per participant. Thus, $2.00 x 360 = $720.00 in Prolific fees is requested. In total, this comes to $2880.00 in order to complete all experiments.

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