Full title:

Pronominal anaphora resolution in Polish: investigating online sentence interpretation using eye-tracking.

Short title:

Establishing the mechanism of pronominal anaphora resolution in Polish.

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Abstract

The mechanism of anaphora resolution is subject to large cross-linguistic differences. The most likely reason for this is the different sensitivity of pronouns to a range of cues of reference. In the current study, we explored the mechanism of anaphora resolution in Polish. First, in an ambiguous sentence-interpretation task, we explored the natural biases that occur during the interpretation of null or overt pronouns. More specifically, we investigated whether Polish speakers prefer to relate overt pronouns to antecedents which are in the syntactic position of a subject or an object. Subsequently, we tested the consequences of violating this bias when tracing the online sentence-interpretation process using eye-tracking. Our results show that Polish speakers have a strong preference for interpreting null pronouns as referring to antecedents in a subject position and for interpreting overt pronouns as referring to antecedents in an object position. However, in online sentence interpretation, only overt pronouns showed sensitivity to violation of the speaker's preferences for a pronoun-antecedent match. It suggests that null pronoun resolution is more flexible than that of overt pronouns. Our results indicate that it is much easier for Polish speakers to shift the reference of a null pronoun than an overt one whenever a pronoun is forced to refer to a less-preferred antecedent. These results are supported by the naturalness ratings, which showed that null pronouns are considered equally natural regardless of their reference, while overt pronouns referring to subject antecedents are rated as considerably less natural than those referring to overt pronouns. We propose that this is because the interpretation of null and overt pronouns is sensitive to the different cues which determine their reference.

Introduction

Understanding a sentence requires appropriate identification of what each word refers to.

For example, to fully comprehend the sentence:

When Mary crossed the street, she looked back at the monument.

the reader needs to know that “she” in the second clause refers to “Mary” in the first clause, and that both words are supposed to denote one and the same person. This sentence is an example of pronominal anaphora, which is a particularly interesting instance of reference assignment.

Understanding a pronoun requires a reader or listener to identify the appropriate referent from among the grammatically correct and pragmatically possible antecedents. For example, in the following sentence:

Mom waved to Mary when she was crossing the street.

both Mom and Mary are possible antecedents for the pronoun “she” that appears in the subordinate clause. However, as shown by the example above, very often the pronouns themselves do not provide enough information to identify the intended referent: the reference assignment depends mainly on the features of the antecedent itself. As a consequence, pronouns are inherently ambiguous: their reference depends on a range of different constraints, including morpho-syntactic, semantic and discourse-related cues (1,2). In this paper, we report two studies that experimentally explored how different factors influence the pronominal anaphora resolution mechanism in Polish, a Slavic language whose mechanism of anaphora resolution has not yet been empirically tested. First, we tested Polish native speakers’ preference for anaphora resolution in ambiguous sentences. In the next step, we tested the robustness of this preference by testing how its violation influenced the online sentence-interpretation process.

What determines the mechanism of pronominal anaphora resolution in different languages?

The mechanism of anaphora resolution can be influenced by a range of factors which affect different stages of pronoun interpretation: from syntactico-semantic processing to constructing mental representations of discourse. However, the degree to which anaphora resolution relies on different factors depends on the language used. In consequence, there are substantial cross-linguistic differences between typologically distant languages (3). For example, anaphora resolution strategies differ between *discourse-oriented languages* such as Korean, Chinese or Japanese, and *sentence-oriented languages* such as English, Italian or Spanish (3). In order to establish the referent of an anaphorical expression, the latter group of languages relies on morpho-syntactic, sentence-internal cues related primarily to subject-verb agreement. For example, in some languages with subject-verb agreement (like Spanish, Italian or Polish), information about the gender and number of the predicate's referent is morphologically encoded into the verb form. In the following Polish sentence:

Tata pomacha-ł Marys-i i Kas-i kiedy **one przechodzi-ły** przez ulicę.

Dad.NOM.SG waved-1SG.M.PST Mary-DAT.SG and Kate-DAT.SG when they cross-3PL.F.PST the street.ACC.SG.

the verb's suffix ("przechodzi-ły") encodes both the grammatical gender (feminine) and the grammatical number (plural), both of which unambiguously relate the pronoun ("one" / "they") to the antecedent (Mary and Kate) from the preceding clause. A consequence of subject-verb agreement is that whenever a mismatch between a pronoun and a verb occurs (i.e., the pronoun refers to a less-preferred, non-topical or unexpected antecedent), a speaker needs to adjust the interpretation of the sentence and re-identify the referent of the anaphorical expression (3).

In contrast to sentence-oriented languages, discourse-oriented languages which do not have a verbal agreement system, such as Japanese, Chinese or Korean, can rely much less (or not at all) on morpho-syntactic constraints (4). Therefore, other cues of reference that are derived from discourse become much more important for the correct resolution of an anaphoric expression (3,4).

Different sensitivity to morpho-syntactic and discourse-related factors can account for differences between discourse- and sentence-oriented languages; however, even languages which are typologically close, such as Spanish and Italian (both of which are sentence-oriented languages), can have different anaphora resolution preferences (5). Several theories have been proposed to explain the mechanisms of how anaphorical expressions are interpreted. These theories provide a set of generalized rules that make it possible to formulate specific predictions for particular languages and identify the potential sources of the differences between them. Below, we discuss some of the most prominent theories which explain the basis of the anaphora resolution mechanism.

Anaphora resolution mechanism theories.

Most anaphora resolution theories agree that the crucial factor for reference assignment is the salience and prominence of the referent (antecedent) itself: the more salient the referent is, the more reduced an anaphorical expression can be (6,7). According to this proposal, the most-reduced pronominal expression (the *null* pronoun) is bound to the most salient of the possible antecedents. On the other hand, less-reduced expressions, like *overt* pronouns, refer to less-prominent antecedents (see Fig 1, adapted from Kaiser & Trueswell (1)).

Fig 1. Relationship between the prominence of an antecedent and the form of the pronominal expression that is necessary to refer to it: the more prominent the antecedent, the more reduced the pronominal form.

The crucial issue for theories of anaphora resolution is to identify the source of the salience of an antecedent and define the relationship between different types of anaphoric expressions and the

antecedents they retrieve. Several factors have been suggested to influence the salience of antecedents. Kaiser and Trueswell (1) proposed that they can be divided into two categories: syntactico-semantic or discourse-related, the latter of which influences the comprehender's mental model of discourse. The former group of constraints includes factors like subjecthood or thematic roles. Subjecthood refers to the fact that an antecedent occupies the position of a syntactic subject in a sentence; it has been shown that syntactic subjects are considered more prominent than antecedents in other syntactic positions (e.g., 8). Thematic roles describe the role that an antecedent plays with respect to the verb; it has been shown that agents are considered more prominent than patients of actions (9). On the level of discourse, the salience of antecedents was argued to be driven by an information structure such as topicalization, which predicts that discourse topics are more accessible than other possible antecedents (10,11), or focus, which predicts that entities that convey new or unexpected information are more prominent than other antecedents (12–15). It has also been shown that there is a preference for the antecedent that was mentioned first in a given sentence or utterance (e.g., 16) or that pronouns prefer a referent that occupies the same grammatical role in another clause – so-called *grammatical parallelism bias* (17). However, a growing number of studies suggest that the salience of an antecedent is in fact bound by multiple constraints or factors (13,18).

To sum up, the existing literature suggests that pronoun resolution is driven by the salience of the possible antecedents. However, different theories indicate different sources of antecedents' salience. In the following section, we discuss some of the most important theories which address this question.

Accessibility Theory

The first theoretical proposal that describes the relationship between the salience of an antecedent and the types of anaphoric expressions (i.e., null, overt, stressed pronouns etc.) is the Accessibility Theory (henceforth: AT (6)), which proposes that the salience of an antecedent depends on the degree of its accessibility in memory. AT proposes that the accessibility of an antecedent can be derived from three universal characteristics of the referring expression: informativity, rigidity and

attenuation (6). The *informativity* of a given lexical marker such as an anaphorical pronoun is defined by the amount of semantic information it encodes. Therefore, the emptier a lexical marker is, the more informative the antecedent to which it refers. The *rigidity* of a lexical item describes how uniquely referring an expression is. This criterion can be context sensitive, but AT argues that there are markers which are inherently more rigid than others (e.g., proper names, like *Ernest Hemingway*, vs. personal pronouns, like *he*). According to AT, more-rigid expressions tend to refer to less-prominent lexical items. The last dimension, *attenuation*, is related to the phonological size of the lexical marker: more-conspicuous phonological markers tend to refer to less-accessible antecedents (e.g., stressed vs. unstressed pronouns).

Summing up, AT predicts that *null* pronouns will refer to more-accessible and more-prominent antecedents than *overt* pronouns because null pronouns are less informative, less rigid and more attenuated than overt ones. However, differences on the three dimensions of accessibility can give rise to differences between languages that are driven by language-specific sensitivity to different constraints on pronoun resolution.

Position of the Antecedent

AT describes the relationship between the characteristics of a referring expression and the salience of the antecedent. However, it focuses on the properties of the referring expression itself and, as such, it does not propose any direct criteria for defining the salience of an antecedent. This issue has been addressed by the Position of Antecedent strategy (henceforth PoA (19)). Similarly to AT, PoA assumes that anaphora resolution relies on the prominence of possible antecedents: the more prominent an antecedent is, the more reduced an anaphorical expression can be. PoA proposes that the accessibility of an antecedent depends on the universal syntactic roles of anaphorical expressions in sentences. According to PoA, a null pronoun should prefer the antecedent to be in a specific syntactic position: Spec IP (Specifier of the Inflectional Phrase). On the other hand, an overt pronoun would be more likely to relate to an antecedent which is not in a Spec IP position. Spec IP is a syntactically defined role in a sentence: it is occupied by an argument that defines an inflectional phrase which contains all

information related to the tense and agreement features of a verb (20). The precise type of the expression in a Spec IP position is further defined by the Extended Projection Principle (EPP), according to which the Spec IP of a given clause must be occupied by a pre-verbal subject (20). Importantly, the EPP is not specific to any particular kind of clause: it is a general grammatical property of sentences. Therefore, the predictions of EPP are generalizable over different languages (19). As such, PoA refers to the universal syntactic properties of sentences in order to describe the anaphora resolution mechanism in different languages. It predicts that equivalent expressions (i.e. pronouns) in two different languages should manifest the same interpretational bias when identifying the antecedent of the pronominal anaphora. This prediction is supported by experimental evidence in the case of the most-reduced pronominal form for a given language (e.g. a null pronoun in the case of Italian or Spanish, or a non-stressed pronoun in English): it has consistently been shown that the most-reduced pronoun relates to the antecedent in the Spec IP position in different languages, such as Italian (5,19), Spanish (5,21) or English (22). However, the cross-linguistic consistency of anaphora resolution decreases when less-reduced, overt (or stressed) pronouns are taken into account (5). The inconsistency of the empirical findings suggests that – contrary to the PoA’s assumption concerning the cross-linguistic universality of syntax-based rules for anaphora resolution – different languages can show varying sensitivity to syntactic cues of prominence.

The Form-Specific, Multiple-Constraint Approach

One way of accounting for cross-linguistic variability that contradicts the syntax-based rules of reference assignment can be derived from a theory proposed by Kaiser and Trueswell (1): the Form-Specific Multiple-Constraint Approach. According to this proposal, reference assignment takes context-dependent or discourse-dependent factors into account. Based on experimental evidence on anaphoric pronoun resolution in Finnish, Kaiser and Trueswell (1) showed that besides syntactic criteria such as those described by PoA, as well as mere word order, the prominence of an antecedent is also sensitive to the informational-structural factors encoded in the mental representation of a given discourse. Discourse representation includes information about the situation being described and the

involved entities (such as people or objects – possible antecedents of a given clause). This information, which inherently is totally context-dependent, can influence the salience of antecedents and thus override syntactically encoded biases. According to Kaiser and Trueswell (1), referential expressions differ in their degree of sensitivity to different types of cues that determine the prominence of an antecedent. What follows is that anaphoric expressions, both within and between languages, can assign different weights to the same types of cues. Therefore, differences in pronouns' reference resolution do not necessarily need to be associated with typological differences between languages. This approach provides a plausible explanation of the divergent pattern of overt pronoun interpretation that is observed not only between Italian and Spanish (5) but also between sentence-oriented and discourse-oriented languages, which use different types of cues to assign the reference to an anaphoric expressions. For example, in the case of overt pronoun interpretation in Italian and Spanish, the increased processing cost resulting from forcing a shift of reference from the syntactic subject of a sentence (which is also the first-mentioned referent) to the syntactic object is observed for Italian but not for Spanish. Within the Form-Specific Multiple-Constraint Approach, this cross-linguistic difference can be explained by referring to the different sensitivity of pronouns to syntactico-semantic cues in both these languages: in Italian, pronoun resolution seem to rely more heavily on this type of cue than in Spanish. Similarly, differences between sentence-oriented and discourse-oriented languages can be accounted for by referring to the much higher sensitivity of pronouns to the informational structure of discourse in discourse-oriented languages than in sentence-oriented languages.

Coherence-driven and Centering-driven Theories

Among the anaphora resolution theories which argue that discourse-related factors are crucial in establishing the reference of a pronoun, the two most prominent proposals are the Coherence-driven approach (23,24) and Centering Theory (e.g., 25). The former indicates the coherence of a discourse as a crucial notion in interpreting pronouns (23,26). According to Hobbs (e.g., 23), the

coherence of a discourse and the consequent pronoun interpretation is predominantly driven by semantics, causal interference and world knowledge. Importantly, the coherence-driven accounts have long argued that constraints derived from the grammatical form or information structure are not necessary to explain the pronoun resolution mechanism. On the other hand, according to the Centering Theory (25), semantics and world knowledge do not play a role in pronoun resolution: it depends mostly on factors like grammatical roles in a sentence and information structure (e.g., word order, topic transitions etc.). A recent proposal by Kehler and Rhode (24) attempts to reconcile these two accounts: it proposes that pronoun interpretation is determined on one hand by probabilistic, coherence-driven expectations of what the following utterance will refer to; on the other hand, it is determined by constraints proposed by the Centering Theory, like grammatical role and information structure. Kehler and Rhode propose that referential expressions are resolved in several stages (achieved by following the SMASH algorithm: Search, Match, And Select using Heuristics). Their theory differentiates between “hard” constraints of reference, which in the case of sentence-oriented languages relate to the morpho-syntactic features that determine the subject-verb agreement (such as gender, number, person etc.), and “soft” constraints, i.e., the heuristics (such as grammatical or thematic roles, syntactic function, coherence etc.). While “hard” constraints define the subset of the available and grammatically correct antecedents (“Search” and “Match” steps), “soft” ones modify their prominence and, as such, influence the pronoun resolution process (“Select using Heuristics” stage).

Anaphora resolution in *pro*-drop languages: experimental evidence

One way of testing a speaker’s preference for pronominal anaphora resolution is to test the most-preferred interpretation of an ambiguous sentence in which the anaphorical pronoun might refer to at least two different antecedents (17,19,27). In ambiguous sentences in languages like Spanish (28) and Italian (19), antecedents in the position of both subjects and objects are grammatically coherent. The preference for anaphora resolution in ambiguous sentences usually follows the predictions of PoA: the null pronoun usually relates to the antecedent that is in a Spec IP position (i.e. the subject of the

main clause), while the overt pronoun refers to the antecedent in a non-Spec IP position (i.e. the object of the main clause).

The anaphora resolution mechanism can also be explored by analyzing the consequences of violating the natural pronoun-antecedent match. This refers to situations in which a pronoun is forced to co-refer with an antecedent that does not match its resolution preference. This violation forces the reader to shift the reference and override the bias for pronoun interpretation. As previously discussed, the interpretational bias might be a syntactically based preference for interpreting sentences as referring to the antecedent in the syntactic position of a subject (1,19,29), but it can be also driven by discourse-related factors like preference for the first-mentioned antecedent (e.g., 16,29), for the topic (10,12), for the focused entity (10,11,14), or for the agent (9) of the sentence. Regardless of the source of the preference for pronoun interpretation, the process of reference-shifting incurs cognitive effort, which can be observed in behavioral and eye-tracking measures as an increase in reading times (self-paced reading: 5) or fixation times (eye-tracking: 21,30).

In a self-paced reading experiment, Filiaci and colleagues (5) tested native Italian and Spanish speakers. Participants were asked to read unambiguous sentences which either did or did not match the natural anaphora resolution preference. While both languages showed consistent processing costs (also referred to as *processing penalty*) for the null pronoun that was forced to refer to the object antecedent, the pattern of results showed cross-linguistic differences for the overt pronoun. In Italian, interpretation of an overt pronoun that is forced to refer to a subject antecedent resulted in a significant processing penalty. This was not the case for native Spanish speakers, who were able to accommodate the unnatural pronoun-antecedent match effortlessly. Importantly, the effects of the overt pronoun reference shift from the naturally preferred object antecedent to the less-natural subject antecedent were observed only in the late part of sentences: the processing penalty was observed only for wrap-up parts of sentences which *followed* actual anaphorical expressions (5).

The consequences of a violation of the natural preference for pronominal anaphora resolution has also been explored using eye-tracking (21). In a sentence-reading experiment with Spanish

speakers, no processing penalty was observed for sentences which violated the referential preference of null pronouns. At the same time, the additional processing cost was pronounced for overt pronouns: fixation times were much longer for pronominal verb phrases (VPs) that referred to an antecedent in the subject position than for those in the object position (21). This pattern of results stands in contrast to the findings of a self-paced reading experiment carried out by Filiaci and colleagues (5), which showed the opposite effect in Italian: violation of a null pronoun's referential preference was related to a much larger processing penalty than violation of the preference of overt pronouns. However, no differences in the sensitivity of null and overt pronouns to the violation of their preferences was observed for Spanish. Differences in whether the processing penalty is observed for sentences with null or overt pronouns referring to their less-preferred antecedents can be accounted for by differences in the design between the studies by Chamorro and colleagues and Filiaci and colleagues. In particular, it can be accounted for by differences in the clause order: the stimuli in Chamorro and colleagues' study (21) followed the Main-Subordinate order, while in Filiaci and colleagues' study (5) the order was Subordinate-Main. For further discussion, see *Discussion*). Interestingly, despite the discrepancies between the results of these two experiments, the results of the experiment by Filiaci and colleagues (5) demonstrate that a preference for null pronoun resolution is similar for Italian and Spanish, while differences emerge for overt pronouns.

To conclude, the cross-linguistic differences in anaphora resolution might stem from the divergent sensitivity of null and overt pronouns to cues of prominence of antecedents, which can be driven by syntactico-semantic or discourse-related constraints (1,24). Therefore, in order to provide an accurate description of pronominal anaphora resolution in a given language, experimental evidence is needed to assess the varying sensitivity of pronouns to syntactico-semantic and discourse-related factors. The aim of the current paper is to provide an empirically based description of pronominal anaphora resolution in Polish.

Pronouns in the Polish language: introductory remarks

Before discussing the details of our research questions, a couple of introductory remarks regarding the Polish language seem essential. Polish is a Slavic language whose dominant sentence structure is SVO (subject – verb – object); however, Polish is characterized by a relatively free word order. Polish is a morphologically rich language with two number classes, three gender markings, and a declension with seven cases that is reflected in the morphological form of nouns, adjectives, and some pronouns (31). Verbs in Polish are also highly inflected and, *inter alia*, categories such as person, number and gender are marked by almost each verb form. Nouns (or pronouns) and verbs have to agree in person, number, and often gender. Polish is also a *pro*-drop language with a strong tendency to omit pre-verbal pronouns, which are redundant in most cases as the morphological form of a verb encodes the information that allows the referent of a verb to be identified. In this aspect, Polish is similar to Romance languages such as Spanish or Italian, although the families of Slavic and Romance languages are generally typologically distant. To the best of our knowledge, neither the preference for anaphora resolution in Polish speakers nor the influence of this preference on online sentence interpretation have yet been empirically tested. The only known empirical report on Polish speakers' preference for pronominal anaphora resolution was published by Carminati (19); however, it is based on data from only two participants. Carminati asked two Polish speakers to provide their preferred interpretation of an ambiguous sentence containing a null or overt pronoun; she found that the null pronoun sentence was interpreted as referring to the antecedent in the subject position, while the overt pronoun was assigned to the antecedent in the object position. However, given the limited participant sample, such data cannot be treated as fully informative and reliable.

The current research

The primary aim of the two studies presented in the current paper was to empirically test the pattern of anaphora resolution in Polish. As previously discussed, the anaphora resolution pattern is bound to the notion of the prominence of an antecedent. Previous studies have shown that the

grammatical role (especially the subjecthood) of the antecedent allows accurate predictions of how the pronominal anaphora will be interpreted, but only for the most-reduced pronominal form allowed by a given language (which is usually a null or a non-stressed pronoun 5,19,32). However, less-reduced anaphorical forms (i.e., overt pronouns in *pro*-drop languages, stressed pronouns, or noun phrases) can be prone to the influence of other cues of prominence of the antecedent. These factors can lead to vast cross-linguistic differences in anaphora resolution preference (e.g., 5). Therefore, in order to provide an accurate description of the pronominal anaphora resolution preference in Polish, the predictions derived from the theoretical frameworks need to be experimentally validated.

To this aim, we conducted two studies. In the first one, we established the preference for anaphora resolution in Polish native speakers. We asked native Polish speakers to interpret ambiguous sentences and rate their naturalness. In the subordinate clause, each sentence contained either a null or an overt pronoun which might refer to either the subject or the object antecedent introduced in the preceding ambiguous main clause (for examples of the sentences used in the study, see Method). To the best of our knowledge, no empirical study (besides the anecdotal evidence provided by Carminati (19)) has yet addressed the question of the pronominal anaphora resolution pattern in Polish.

In the second study, we examined how the offline preference for anaphora resolution in Polish influenced the online sentence-interpretation process. We used eye-tracking to follow the time course of the interpretation process of sentences containing null and overt pronouns that referred to either matched or unmatched antecedents. Following the design proposed by Chamorro and colleagues (21), we manipulated the grammatical number of an antecedent in the subject and object positions so that only one interpretation of a main clause containing a singular verb would be grammatically correct (for examples, see Methods). Analysis of the online sentence-interpretation process using an eye-tracker allowed us to assess the sensitivity of Polish pronouns to violation of the syntax-based pattern of anaphora resolution preference. Additionally, participants were asked to rate the naturalness of the sentences they read.

Study 1 – What is the natural pattern of anaphora resolution in Native Polish speakers?

The aim of the first study was to explore the natural tendency of native Polish speakers to interpret sentences that contain an overt or null pronoun. We tested if the presence of a pronoun influences the interpretation of a subordinate clause as referring to either the subject or the object of the main clause.

Certain predictions regarding the pronoun interpretation preference in ambiguous sentences in Polish could be formulated on the basis of the available theoretical proposals or empirical evidence from experiments on other *pro*-drop languages. The theoretical accounts of pronominal anaphora resolution predict that more-reduced pronouns refer to the most prominent of the possible antecedents. The syntax-based criterion of prominence proposed, e.g., by PoA predicts that the most-salient antecedent. In Study 1, we showed that null and overt pronouns are usually the subject of the main clause in the Spec IP position (19). A similar prediction can be formulated based on the advantage of the first-mentioned antecedent (16,29) or the fact that the first-mentioned antecedent is typically interpreted as the topic of a given sentence (33). Therefore, we expected that the null pronoun of the subordinate clause would be interpreted as referring to the subject of the main clause, while the overt pronoun would be interpreted as referring to the object of the main clause. Further support for our prediction stems from the fact that a similar pattern of anaphora resolution in ambiguous sentences is shown in *pro*-drop Romance languages (5,19,28). In Polish, the sentence structure is analogous to that of Italian or Spanish: the antecedent in a Spec IP position is always the preverbal subject. Moreover, following the studies of Alonso-Ovalle and colleagues (28) and Chamorro and colleagues (21), we expected that *null* pronoun sentences would be interpreted as more natural than those containing *overt* pronouns. Raw data and the script necessary to reproduce the statistical analysis reported in Study 1 are freely available online: <https://osf.io/dynwp/>.

Materials and methods

Participants

Seventy native Polish speakers (8 males) took part in the experiment. They were recruited from among students of Jagiellonian University and received course credits for their participation. Participants provided an informed consent for participation in the study in an online form (in which there was an option to consent to participate in the study or leave the experiment) before they started the experiment. After completing the survey, they were provided with a short explanation of the aim of the study. The experiment met the requirements of the Ethics Committee of the Institute of Psychology of Jagiellonian University concerning experimental studies with human subjects.

Stimuli

In order to test whether a pronoun can influence the natural tendency to interpret the antecedent of a sentence, we created 48 ambiguous sentences in Polish which allowed interpretation of a subordinate clause as referring to either the subject or the object of the main clause. Each sentence consisted of a main clause containing subject and object antecedents of the same number and gender, followed by a temporal adjunct subordinate clause (henceforth referred to as a *subordinate clause* introduced by the conjunction *kiedy* – “when”). The conjugation form of a verb in the subordinate clause matched the gender and number of the subject and object antecedents of the main clause, thus allowing ambiguous interpretation of the sentences. Two versions of each sentence were created that corresponded to two different conditions: the verb of the subordinate clause was preceded by either an overt or a null pronoun (both are allowed according to the morpho-syntactic rules of Polish). Each experimental stimuli followed the same sentence structure:

subject / verb / object / time conjunction (“when”) / pronoun (null or overt) / verb / complement

By manipulating the *Pronoun*, two different conditions of each sentence were created:

Condition 1: **null pronoun**

Mama pomacha-ła córce, kiedy ∅ przechodzi-ła przez ulicę.

381 *Mother.NOM.SG waved-1SG.F.PST daughter.DAT.SG when ∅ (she) cross-1SG.F.PST street.ACC.SG.*

382 Condition 2: **overt pronoun**

383 Mama pomachała córce, kiedy ona przechodziła przez ulicę.

384 *Mother.NOM.SG waved-1SG-F-PST daughter.DAT.SG when she cross-1SG.F.PST the street.ACC.SG.*

385 Procedure

386 The experiment was conducted via an online survey platform (Qualtrics). It was preceded by
387 written instructions (containing comprehension questions which made it possible to confirm that
388 participants had read the instructions carefully) and a short training session, after which participants
389 were allowed to re-read the instructions in case they had doubts regarding the experimental
390 procedure.

391 Participants were instructed to read each sentence and proceed to the next screen, which
392 contained a disambiguation question asking for their interpretation of the sentence (i.e., “Who crossed
393 the street?”). The participants were provided with two possible answers: one always referred to the
394 subject, while the other always referred to the object of the main clause. Participants made their
395 decisions by clicking the corresponding button. After progressing to the next screen, they were asked
396 to rate the naturalness of the sentence on a scale from 0 (completely unnatural) to 5 (perfectly
397 natural). After rating the naturalness, they proceeded to the next sentence.

398 Each participant was presented with 48 experimental sentences in one of the two conditions:
399 null or overt pronoun. There were two versions of the task, each of which contained different variants
400 of each sentence (null or overt), which were counterbalanced between participants. Additionally, the
401 same number of filler sentences was presented. Filler sentences were of a similar form to the
402 experimental sentences, but they contained different conjunctions (e.g., “before”, “albeit”, “since”
403 etc.).

Data analysis

The preference for sentence interpretation was analyzed in R (34) using a general linear mixed-effects model (glmer) of a binominal family, as implemented in lme4 package (version 1.1.26; 35). We fitted a model predicting the preferred antecedent (subject or object) based on a categorical predictor *Pronoun* (null or overt), which was dummy-coded prior to running the analysis. Random intercept and slope by participants and random intercept by items were included in the model. Naturalness ratings were analyzed using a cumulative ordinal model with flexible thresholds created in the Stan computational framework (<http://mc-stan.org/>) and implemented in the brms package (version 2.15.0; 36). The model included the main effect of *Pronoun* (null or overt) as well as the main effect of *Antecedent* (subject or object), which referred to the participant's interpretation of a given sentence. The interaction between the effects of *Pronoun* and *Antecedent* was also included in the model. Random intercept and slopes for *Pronoun* and *Antecedent* by participants and items were included in the model. It has recently been shown that Bayesian-based ordinal models are a better choice for rating scale analyses as they can model responses as discrete and not necessarily equidistant data points. As such, they provide a much better fit for the data obtained from any type of rating scales (36,37). The effect sizes (Cohen's *d* statistic) were calculated using the lme.dscore function from the EMAtools package (version 0.1.3; 38)

Results

Interpretation of the sentences

The aim of the experiment was to determine if the preference for interpreting ambiguous sentences in Polish was modulated by the nature of the pronoun. We found a significant difference between the two *Pronoun* conditions ($z = -15.608$, $p > 0.001$, $d = -5.58$, see Fig 2). The results revealed that the preferred interpretation of the sentences strongly depends on the pronoun type: sentences containing a null pronoun were interpreted as matching the subject antecedent (percentage of

subject-match answers: $M = 79.7\%$, $SE = 4.81\%$), while sentences containing an overt pronoun were interpreted as matching the object antecedent (percentage of object-match answers: $M = 90.8\%$, $SE = 3.45\%$).

Fig 2. Preference for sentence interpretation. Proportion of subject- and object-match answers for sentences containing a null or overt pronoun. Error bars represent the standard error of the model's predictions.

The naturalness of sentences

Apart from examining Polish speakers' preference when interpreting ambiguous sentences, we also wanted to determine whether they judge sentences as more natural depending on the use of a pronoun. Participants rated the naturalness of each sentence on a scale from 0 to 5. We found a strong effect of *Pronoun* (b coefficient = -0.44 , 95% CI $[-0.63 -0.26]$), thus indicating that native Polish speakers find sentences containing a null pronoun more natural than sentences containing overt pronouns. No main effect of *Antecedent* was observed (b coefficient = -0.07 , 95% CI $[-0.27 0.14]$); however, we found a significant interaction between *Pronoun* and *Antecedent* (b coefficient = -0.98 , 95% CI $[-1.24 -0.73]$). Direct comparisons between the two *Antecedent* conditions (i.e., subject- and object-matching sentences) revealed significant effects for sentences containing a null pronoun (b

coefficient = -0.42, 95% HPD [-0.62 -0.20]): subject-matching sentences were rated as more natural than object-matching sentences as well as for sentences containing overt pronouns (b coefficient = 0.56, 95% HPD [0.29 0.81]); also, subject-matching sentences were rated as less natural than object-matching sentences. The results of the analysis as well as the mean scores for all conditions are presented in Table 1 and Fig 3.

Fig 3. Naturalness judgement of Study 1. The naturalness rating of the sentences collected in Study 1. Error bars represent the standard error of the model's predictions

Table 1. Mean scores and SD for the naturalness judgement of the experimental stimuli

Pronoun	Interpretation (Antecedent)	Naturalness rating
Null	Subject	3.69 (1.26)
	Object	3.14 (1.32)
Overt	Subject	2.62 (1.52)
	Object	3.31 (1.31)

Study 1 – Summary

The results of Study 1 showed that the preference for anaphora resolution in Polish is as follows: the null pronoun of a subordinate clause is interpreted as referring to the subject of the main clause; the overt pronoun of a subordinate clause is interpreted as referring to the object of the main

clause. In the subsequent study, we investigated the online processing of pronominal anaphoric structures in Polish and assessed the extent to which it is influenced by the preference for anaphora resolution established in Study 1.

Study 2 – eye-tracking measures of anaphora resolution in

Polish

Based on experimental evidence from studies on Italian and Spanish (5,19,28), we expected that online pronoun resolution in Polish would be driven by the prominence of the available antecedents. As such, the interpretation of a null pronoun would refer to the most-prominent antecedent, which in our study was the first-mentioned one, and which occupies the syntactic position of a subject. On the other hand, we expected that the interpretation of the overt pronoun would refer to the antecedent in the less-prominent syntactic position of the object, which is also the second-mentioned antecedent in a sentence and is a less likely topic of a given utterance. As discussed in the Introduction, violation of the natural preference for anaphora resolution can result in a *processing penalty*: i.e., increased cognitive cost related to the reference shift. In eye-tracking, this cost should be reflected in longer reading times (measured by *first-pass time*, *go-past time*, and *total time*) in the critical region containing the VP of the subordinate clause. The eye-tracking experiment's critical manipulation involved forcing the pronoun to refer to the mismatching antecedent (i.e., a null pronoun matched with an object antecedent, or an overt pronoun matched with a subject antecedent). This should allow us to observe the reaction of a reader to violation of the anaphora resolution preference.

Our experiment closely followed the design of the study by Chamorro and colleagues (21). While many previous experiments used eye-tracking to assess pronoun resolution strategies, they either used a visual-word paradigm (e.g., 1,29,39–41), or if they were based on sentence-reading paradigms, they were designed to test different research questions than ours, e.g., questions related to resolution of intra-sentential anaphora (e.g., processing costs for using "they" as a singular pronoun in English; 42), pronoun resolution bias related to the verb's implicit causality (43), or the influence of

cleft focus on pronoun accessibility (14)). Eye-tracking has also been used to assess the influence of immersion in a second-language environment on pronoun resolution (21,30). One of these studies is the experiment by Chamorro and colleagues (21), which, to the best of our knowledge, is also the only experiment which used eye-tracking to assess the sensitivity of pronominal anaphora to violation of the preference for a pronoun-antecedent match. Still, it is important to note that the main focus of the study by Chamorro and colleagues (21) concerned how the natural pattern of anaphora resolution is modulated by long-term immersion. Therefore, the only condition that would be informative when compared with the current study is the monolingual group. As such, all comparisons between our results and the study by Chamorro and colleagues (21) always refer to the monolingual condition. Chamorro and colleagues (21) observed differences in online interpretation of null and overt pronouns in three eye-tracking measures: *first pass time*, *go-past time* and *total time*. In the current experiment, we analyzed the same eye-tracking measures. This allowed us to interpret the processes engaged in sentence interpretation, which range from early (captured by the *first-pass time*) to cumulative (captured by *total time*) measures, which should be sensitive to different stages of syntactic processing.

On the basis of Study 1 and the previous literature, it can be expected that reading times indexed by *first-pass time*, *go-past time* and *total time* would be longer for the VPs of sentences in which null pronouns are forced to refer to object antecedents and overt pronouns are forced to refer to subject antecedents as compared to the VPs of sentences in which null pronouns refer to subject antecedents and overt pronouns refer to object antecedents. However, these predictions are not entirely in line with the results of previous studies which showed that null and overt pronouns exhibit different sensitivity to violation of their referential preferences. Based on the results of a previous eye-tracking experiment by Chamorro and colleagues (21), it could be expected that overt pronouns would be sensitive to violation of their resolution preference, while null pronouns would be more flexible and would more easily accommodate the mismatching antecedent. On the other hand, based on the results of the study by Filiaci and collaborators (5), the opposite effect could be expected as, in their

experiment, a processing penalty was observed in the case of violation of the referential preference of a null pronoun. At the same time, Filiaci and colleagues showed that the sensitivity of an overt pronoun to a violation of its resolution preference is subject to cross-linguistic differences, while no such differences were observed for violation of null pronoun preferences.

To sum up, based on previous experiments it is plausible to assume that a processing penalty will be observed when a pronoun is forced to refer to a less-preferred antecedent. However, the discrepancy between the results of previous studies suggest that, due to nuances in the experimental design or cross-linguistic differences, null and overt pronouns may exhibit different sensitivity to violation of their preferences. As revealed by analysis of the naturalness of sentences used in Study 1, Polish speakers tend to interpret sentences containing null pronouns as more natural than those containing overt pronouns. As such, if Polish pronouns differ in their sensitivity to violation of a preferred antecedent match, it is plausible to expect that forcing a less-preferred antecedent match in the case of generally more-natural null pronouns will incur smaller processing costs for a reader than violation of the preferred antecedent match in the case of less-natural overt pronouns.

Additionally, similarly to Study 1, after each sentence the participants were asked to rate its naturalness. We expected the results of the naturalness rating to reflect the online anaphora resolution bias. Specifically, we expected that null pronoun sentences would obtain higher naturalness scores than overt pronoun sentences, and sentences following the preference for anaphora resolution (i.e., a null pronoun referring to the most-prominent antecedent and an overt pronoun referring to a less-prominent antecedent) would obtain higher scores than those violating it. Data and the script necessary to reproduce the statistical analysis for Study 2 are freely available online: <https://osf.io/dynwp/>.

Materials and methods

Participants

Thirty-six native Polish speakers took part in the experiment. Unlike in Study 1, we only recruited participants who did not declare high proficiency or frequent use of a foreign language. While high proficiency or frequent use of a foreign language should not cause any problems in a study measuring the preference for anaphora resolution in which respondents have unlimited time to provide responses, it has been shown that near-native proficiency and immersion in a second language can influence online measures of the anaphora resolution mechanism (2,21). Therefore, only participants who reported proficiency lower than B2 and occasional use of their second language (less than 1–2 days per week) took part in the experiment. Apart from the initial pre-screening of language proficiency and use, during the experimental session the participants’ proficiency in 5 language skills in the first language (L1: Polish) and the second language (L2: English) was assessed via a questionnaire (see Table 2). Prior to data analysis, 3 participants were excluded because their second-language proficiency and use was higher than allowed by our criteria. The reported analysis was carried out using the data from 33 participants (31 females, 2 males, age $M = 22.15$, $SD = 2.95$). Participants were recruited from among students of Jagiellonian University and received course credits or monetary remuneration. All participants provided a written consent for participation in the study and were informed that they can withdraw their consent at any point of the procedure. The experiment met the requirements of the Ethics Committee of the Institute of Psychology of Jagiellonian University concerning experimental studies with human subjects.

Table 2. Proficiency in the selected skills in L1 (Polish) and L2 (English) reported by the participants in a self-rated questionnaire. Participants were asked to assess their proficiency in respect to each of the 5 language skills on a scale from 0 to 10. Values in brackets correspond to standard deviation.

skill	understanding spoken language	understanding written language	fluency of speaking	accent	writing
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L1 (Polish)	9.79 (0.56)	9.69 (0.97)	9.48 (1.45)	9.34 (1.47)	9.38 (1.37)
L2 (English)	5.79 (1.97)	6.62 (1.61)	4.79 (1.86)	4.62 (1.80)	5.45 (1.50)

Stimuli

Following Chamorro and colleagues (21), we created 32 experimental sentences in Polish. Each sentence consisted of the main clause, which contained a subject and an object antecedent of the same grammatical gender but different grammatical number, and the subordinate clause. The subordinate clause was introduced by a temporal conjunction (*kiedy* – “when”) and it contained a verb conjugated in the third-person singular preceded by an overt or null pronoun. The antecedents were always common nouns depicting people (such as names of professions, social roles etc.); proper names were never used. We manipulated the grammatical number of the antecedents: in half of the sentences, the subject was singular and the object was plural; in the other half, the subject was plural and the object was singular. The pronoun and verb of the subordinate clause were always singular, allowing only one interpretation of the subordinate clause as referring either to the subject or the object of the main clause, depending on which one of them was singular in a given sentence. The verbs in the subordinate clause were matched in terms of length and frequency. The length of the main clause, as well as the frequency of nouns in the subject and object position, were also matched between sentences. Each sentence followed the same structure:

subject / verb1 / object / time conjunction (“when”) / pronoun (null* or overt) / verb2 / rest1 / rest2

*null pronoun was equivalent to omission of the pronoun; no empty space or other replacement were provided in place of the pronoun in the sentence

By manipulating the *Pronoun* and the *Antecedent* match, four different versions of each sentence were created (conditions following the less-natural pronoun-antecedent match are marked with *). Note that in Polish the nominative case is always used for a noun in the grammatical position of a subject. In our experiment, the antecedent in the object position always uses the instrumental case; however, this is not a rule as the case of the object of a sentence depends on the verb directly preceding it.

585 Condition 1 *: **overt pronoun / subject match:**

586 Nauczyciel porozmawia-ł z uczniami, kiedy on wrócił do szkoły jesienią.

587 *Teacher.NOM.SG talk-1SG.M.PST with students.INS.PL when he come back.1SG.M.PST to school.GEN.SG fall-in-the.*

588 Condition 2: **overt pronoun / object match:**

589 Nauczyciele porozmawia-li z uczniem, kiedy on wrócił do szkoły jesienią.

590 *Teachers.NOM.PL talk-1PL.M.PST with student.INS.SG when he came back.1SG.M.PST to school.GEN.SG fall-in-the.*

591 Condition 3: **null pronoun / subject match:**

592 Nauczyciel porozmawia-ł z uczniami, kiedy ∅ wrócił do szkoły jesienią.

593 *Teacher.NOM.SG talk-1SG.M.PST with students.INS.PL when ∅ came back.1SG.M.PST to school.GEN.SG fall-in-the.*

594 Condition 4 *: **null pronoun / object match:**

595 Nauczyciele porozmawia-li z uczniem kiedy ∅ wrócił do szkoły jesienią.

596 *Teachers.NOM.PL talk-1PL.M.PST with student.INS.SG when ∅ came back.1SG.M.PST to school.GEN.SG fall-in-the.*

597 Subsequently, four different experimental lists of 32 sentences were created. Each list contained eight
598 sentences corresponding to each of the four conditions (i.e., 8 sentences in Condition 1, 2, 3 and 4). A
599 complete list of sentences is provided in Appendix A. Additionally, 64 filler sentences were created and
600 added to the experimental lists. They contained different grammatical structures, inanimate referents,
601 proper names and plural pronouns. Each of the lists contained the same 64 filler sentences. In total,
602 each experimental list contained 96 sentences (32 experimental + 64 filler sentences).

603 Procedure

604 The experiment was run using an Eyelink 1000 Desktop Mount eye-tracking system by SR
605 Research. The stimuli were displayed on a 24" screen (BenQXL2411) with screen resolution set to
606 1920x1080. The screen was situated approximately 70 cm from participants. The sampling rate was
607 set at 1000 Hz. Eye movements were recorded from the right eye only (except for one participant, for
608 which the calibration for the right eye failed, therefore the movements of the left eye were recorded
609 instead). Before the experiment started, a calibration process was carried out until it was successful.
610 The calibration was repeated during the main task (between trials) whenever necessary. Each trial

started with a drift-correction point displayed in the center of the screen. Subsequently, a fixation point was displayed for 500ms on the left side of the screen in the place corresponding to the beginning of the sentence that appeared after it. Participants were instructed to read each sentence carefully and press a mouse button when finished. Subsequently, they were asked to rate the sentence they had just read on a 1–5 naturalness scale by clicking on the corresponding number displayed on the screen. Before the experiment proper, participants completed three training trials.

Data Analysis

Prior to the analysis of eye-tracking measures, we conducted a standard, 2-step cleaning procedure using DataViewer software (SR Research). First, we merged all the fixations shorter than 80ms with the adjacent fixations if the distance between them was shorter than 0.5 angular degrees, which constituted 0.26% of the total fixation number. Subsequently, we deleted all the fixations shorter than 80ms or longer than 1200ms, as well as fixations that fell outside any of the regions of interest; this constituted a further 0.54% of the data.

We conducted the analyses on two different types of data: eye-tracking data and behavioral data (naturalness rating of each sentence). For the eye-tracking analysis, we chose three measures, following the study by Chamorro and colleagues (21): *first-pass time* (summed duration of all the fixations in a particular region from the first time the eye enters the region until it leaves the region in either the left or right direction); *go-past time* (the sum of all of the fixations after the first entry into an area of interest, including regressions to previous regions, as well as returns to the area of interest in question until the eye enters any subsequent region); and *total time* (sum of all the fixations in a particular region during the whole trial). *First-pass time* is presumed to be sensitive to processes that occur relatively early in sentence comprehension (43,44). *Go-past time* is a hybrid measure that is sensitive to both early and late processes in sentence comprehension. Therefore, these measures should be informative about the processing load related to the integration of the given word and the reader's predictions (45), which are based on native Polish speakers' natural preference for anaphora resolution. *Total time* is a measure which is sensitive to the overall difficulty of processing the relevant

word; it is related not only to the automatically constructed predictions but also to conscious reflection on the naturalness and adequacy of a given syntactic structure.

For the eye-tracking data, we performed separate analyses for null and overt pronoun sentences as we found comparing the overt and null pronoun conditions in one analysis problematic due to differences in the size of the critical area of interest, namely the verb phrase of the subordinate clause, which only contained a verb in sentences with a *null* pronoun, and a pronoun and a verb in sentences with an *overt* pronoun. As such, the reading times in the overt pronoun condition would always be longer than in the null pronoun condition due to the additional word. Therefore, we decided to analyze overt and null pronoun sentences separately. Even though this did not allow us to compare the differences in overt and null pronoun sentences directly, we were still able to focus on the most important and informative aspects of the present study: the influence of the pronoun-antecedent match on online sentence interpretation. For both null and overt pronoun conditions, we performed separate analyses for two areas of interest: **verb2** (or pronoun + verb in case of overt pronoun sentences) and **rest1**. The analyses of eye-tracking data were performed using linear mixed-effect models, as implemented in lme4 package (version: 1.1.26; 35). Each model was fitted using one within-participant factor, *Antecedent*, with two levels, *subject* and *object*. As *Antecedent* was a categorical predictor, it was dummy-coded prior to running the analysis. The effect sizes (Cohen's *d* statistic) were calculated using the lme.dscore function from the EMAtools package (version: 0.1.3; 38). Similarly to Experiment 1, naturalness data were analyzed using a cumulative ordinal model with flexible thresholds created in the Stan computational framework (<http://mc-stan.org/>) implemented in the brms package (version 2.15.0; 36). The model included a main effect of *Pronoun* (null or overt), a main effect of *Antecedent* (subject or object), as well as an interaction between the main effects. Random intercept and slopes for *Pronoun* by participants and items were included in the model.

Results

Eye-tracking task

Overt pronoun sentences: subject and object antecedent interpretation

The present section presents the analyses that were conducted for the sentences with an overt pronoun in which the area of interest contained the pronoun and the verb of the subordinate clause. For each eye-tracking measure, we fitted a separate linear mixed-effects model with one within-participant factor: *Antecedent*. We found a significant effect of *Antecedent* for *first-pass time* ($t = 2.52$) and *total time* ($t = 2.109$). In both cases, the reading times were longer for the sentences with an antecedent in the position of a subject. No significant effect of *Antecedent* was found for *go-past time* ($t = 1.288$). The results for the three measures are presented in Fig 4A and Table 3.

Table 3. Linear mixed-effect models' estimates for fixed and random effects for the *first-pass*, *go-past* and *total time* analyses on the critical area of interest in sentences containing overt pronouns.

Fixed effects												
First pass					Go past				Total time			
	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>d</i>	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>d</i>	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>d</i>
<i>Intercept</i>	466.01	25.21	18.49		538.49	27.69	19.45		893.13	59.85	14.92	
<i>Antecedent</i>	46.54	18.43	2.53	1.21	36.73	28.51	1.29	0.47	74.08	35.12	2.11	0,19
Random effects												
	<i>Variance</i>	<i>SD</i>	<i>Correlation</i>		<i>Variance</i>	<i>SD</i>	<i>Correlation</i>		<i>Variance</i>	<i>SD</i>	<i>Correlation</i>	
by subject												
<i>Intercept</i>	17237	131.29			18022	134.20			93121	305.20		
<i>Antecedent</i>	1603	40.03	-0.28		11178	105.70	-0.11		-	-	-	
by item												
<i>Intercept</i>	1561	39.51			3136	56.00			93121	305.20		-
<i>Antecedent</i>	1287	35.87	-0.09		-	-	-		-	-	-

Fig 4. Mean fixation times for sentences containing an overt pronoun. (A) The eye-tracking measures for the critical area of interest (pronoun + verb). (B) The eye-tracking measures for the post-critical area of interest (*rest1*). Error bars represent standard errors of the model's predictions.

Furthermore, we conducted analyses in the area of interest immediately following the critical region: the post-critical region (*rest1*). In each of the sentences, this area of interest always contained two words: a preposition and a noun or adjective. For each of the eye-tracking measures, we fitted a separate linear mixed-effects model with one within-participant factor: *Antecedent*. We found no significant effects of *first-pass time* ($t = -1.96$) or *go-past time* ($t = 0.41$). However, a significant effect of antecedent was observed for *total time* ($t = -2.47$). Interestingly, it was in the opposite direction compared to the effects observed for the critical area of interest: reading times were longer for sentences with the antecedent in an object position than in a subject position. The results for the three measures are presented in Fig 4B and Table 4.

Table 4. Linear mixed-effect models' estimates for fixed and random effects for *first-pass*, *go-past* and *total time* analyses on the post-critical area of interest in sentences containing overt pronouns.

Fixed effects

First pass					Go past				Total time			
	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>d</i>	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>d</i>	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>d</i>
<i>Intercept</i>	381.22	22.54	16.91		677.94	61.67	10.99		682.33	47.33	14.42	
<i>Antecedent</i>	-29.85	15.25	-1.96	1.12	26.20	64.59	0.41	0.31	-95.95	38.81	-2.47	0.22
Random effects												
	<i>Variance</i>	<i>SD</i>	<i>Correlation</i>		<i>Variance</i>	<i>SD</i>	<i>Correlation</i>		<i>Variance</i>	<i>SD</i>	<i>Correlation</i>	
by subject												
<i>Intercept</i>	10616.40	103.04			48883	221.10			50192	224.04		
<i>Antecedent</i>	-	-	-		-	-	-		5991	77.40	0.05	
by item												
<i>Intercept</i>	4948.40	70.35			52547	229.20			18058	134.38		
<i>Antecedent</i>	543.80	23.32	0.06		34714	34714	186.30		8917	94.43	0.11	

689

690 Null pronoun sentences: subject and object antecedent interpretation

691 This section presents the analyses that were conducted for sentences with a null pronoun in which the
692 area of interest contained only the verb of the subordinate clause. For each eye-tracking measure, we
693 fitted a separate linear mixed-effects model with one within-participant factor: *Antecedent*. We did
694 not find a significant effect of Antecedent for *first-pass time* ($t = 1.28$), or *go-past time* ($t = 0.13$), or
695 *total time* ($t = -0.54$). The results for the three measures are presented in Fig 5A and Table 5.

696 **Table 5.** Linear mixed-effect models' estimates for fixed and random effects for the *first-pass time*, *go-*
697 *past time* and *total time* analyses on the critical area of interest in sentences containing null pronouns.

Fixed effects												
First pass					Go past				Total time			
	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>d</i>	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>d</i>	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>d</i>
<i>Intercept</i>	325.75	19.55	16.66		371.786	23.137	16.069		695.71	53.1	13.103	
<i>Antecedent</i>	19.67	15.36	1.28	0.99	2.593	19.394	0.134	0.47	-16.82	31.26	-0.538	0.19
Random effects												
	<i>Variance</i>	<i>SD</i>	<i>Correlation</i>		<i>Variance</i>	<i>SD</i>	<i>Correlation</i>		<i>Variance</i>	<i>SD</i>	<i>Correlation</i>	
by subject												
<i>Intercept</i>	9807	99.03			12716	112.76			71817	268		
<i>Antecedent</i>	3322	57.63	0.48		3424	58.52	0.32		-	-	-	
by item												

<i>Intercept</i>	1575	39.69		2526	50.25		12276	110.8	
<i>Antecedent</i>	-	-	-	-	-	-	-	-	-

698

699

700 **Fig 5. Mean fixation times for sentences containing a null pronoun.** (A) The eye-tracking measures for
701 the critical area of interest ($\emptyset$ + verb). (B) The eye-tracking measures for the post-critical area of
702 interest (*rest1*). Error bars represent the standard errors of the model’s predictions.

703

704 We also conducted an analysis for the area of interest immediately following the critical region (*rest1*).
705 For each eye-tracking measure, we fitted a separate mixed-effects model with one within-participant
706 factor: *Antecedent*. Similar to the analysis of the critical region, we did not find a significant effect of
707 *Antecedent* for *first-pass time* ($t = -1.60$) or *go-past time* ($t = -1.04$). However, we found a significant
708 effect of *total time* ($t = -2.22$). Similarly to the effects observed in the post-critical area of interest in
709 sentences containing overt pronouns, reading times for *total time* were longer for sentences with the
710 antecedent in an object position. The results for the three measures are presented in Fig 5B and Table
711 6.

712 **Table 6.** Linear mixed-effect models’ estimates for fixed and random effects for the *first-pass*, *go-past*
713 and *total time* analyses on the post-critical area of interest in sentences containing null pronouns.

Fixed effects												
First pass					Go past				Total time			
	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>d</i>	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>d</i>	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>d</i>
<i>Intercept</i>	388.54	23.46	16.56		694.22	67.22	10.33		773.68	45.88	16.86	
<i>Antecedent</i>	-24.49	15.31	-1.60	1.11	-72.18	69.52	-1.04	0.47	-71.88	32.39	-2.22	0.19
Random effects												
	<i>Variance</i>	<i>SD</i>	<i>Correlation</i>		<i>Variance</i>	<i>SD</i>	<i>Correlation</i>		<i>Variance</i>	<i>SD</i>	<i>Correlation</i>	
by subject												
<i>Intercept</i>	12364.70	111.20			108049	328.70			55203	234.95		
<i>Antecedent</i>	-	-	-		54657	233.80	-0.93		54657		-	
by item												
<i>Intercept</i>	4703.70	68.58			21340	146.10			9555	97.75		
<i>Antecedent</i>	455.30	21.34	-		-	-	-		-	-	-	

714

715 Naturalness judgement task

716 For the analysis of naturalness rating, we fitted a cumulative ordinal model with two within-participant
717 factors, *Pronoun* and *Antecedent*, and their interaction. Random intercept and slopes by participant
718 and by item were included in the model. Unlike in the eye-tracking analysis, we were able to include
719 both factors in one analysis as the uneven number of words in the subordinate clause in sentences
720 containing overt and null pronouns was not problematic for the behavioral data. The means for each
721 condition are presented in Table 7. We found a strong effect of *Pronoun* (b coefficient = -0.40; 95% CI
722 [-0.69 -0.10]): sentences containing null pronouns were rated as more natural than sentences
723 containing overt pronouns. We also found evidence that the naturalness of sentences depends on the
724 *Antecedent* (b coefficient = -0.72; 95% CI [-0.96 -0.49]): sentences referring to object antecedent were
725 rated on average as more natural than sentences referring to subject antecedent. Importantly, we did
726 find evidence for the interaction of *Pronoun* and *Antecedent* effects (b coefficient = -1.12, 95% CI [-
727 1.39 -0.84]). Direct comparisons between the two *Antecedent* conditions (i.e. subject- and object-
728 matching sentences) revealed that there was no evidence for differences in naturalness score in
729 sentences containing a null pronoun (b coefficient = 0.15, 95% HPD [-0.10 0.42]) but there was a strong

effect in sentences containing overt pronouns (b coefficient = 1.27, 95% HPD [0.99 1.52]): subject-matching sentences were rated as less natural than object-matching sentences (see Table 7 and Fig 6)

Fig 6. Naturalness judgement. The naturalness rating of the sentences used in the eye-tracking study.

Error bars represent standard errors of the model's predictions

Table 7. Mean scores and SD for the naturalness judgements of the experimental stimuli

Condition	Naturalness rating
Null pronoun – Subject antecedent	3.77 (1.13)
Null pronoun – Object antecedent	3.89 (1.06)
Overt pronoun – Subject antecedent	2.47 (1.22)
Overt pronoun – Object antecedent	3.53 (1.10)

Study 2 – summary

The results of Study 2 revealed that in Polish speakers the violation of a natural pronoun-antecedent match did not result in increased difficulty in processing sentences containing null pronouns. However, in the case of sentences containing overt pronouns, we observed a substantial increase in cognitive effort whenever a reader was forced to interpret the overt pronoun as referring

to the antecedent in the position of a subject. The naturalness rating supports the eye-tracking results. It revealed that sentences containing null pronouns were rated as equally natural, regardless of the pronoun-antecedent match, while sentences containing overt pronouns which referred to the antecedent in the position of a subject were rated as much less natural than those referring to the antecedent in an object position. Our results also revealed an unexpected yet very interesting effect: in the analysis of the post-critical area of interest, the reading times were much longer for sentences referring to the antecedent in the object position, regardless of the pronoun-antecedent match. This suggests that processing pronouns which do not refer to the most prominent subject antecedent always incur additional cognitive effort.

General Discussion

The aim of the research presented in this paper was to investigate the natural pattern of pronominal anaphora resolution in Polish. In the first study, we established a preference for interpreting pronominal anaphora in Polish; in the second study, we explored whether a violation of this established preference impedes sentence processing. The results of the first experiment reveal that native Polish speakers prefer to interpret sentences containing a null pronoun as referring to an antecedent in the syntactic position of the subject. Native Polish speakers also prefer to interpret sentences containing overt pronouns as referring to an antecedent in the syntactic position of the object. The second experiment extends these findings by showing how the preference for anaphora resolution influences online sentence interpretation. There are two key findings of the second study. First, the analysis of the critical area of interest (the pronoun + the verb of the subordinate clause) indicates that the interpretation of a null pronoun is not disrupted by a violation of its preference; a null pronoun can easily be interpreted as referring to the antecedents in subject and object positions. On the other hand, the interpretation of an overt pronoun is much more sensitive to the violation of a pronoun-antecedent match preference: whenever an overt pronoun is forced to refer to an antecedent in the syntactic position of a subject, a substantial increase in processing cost is observed.

773 The second key finding of the second study is revealed by the analysis of the post-critical area of
774 interest (the complement of the subordinate clause, following the VP). This analysis shows that,
775 regardless of the pronominal form, sentences in which a pronoun refers to an antecedent in the object
776 position always incur an additional processing cost as compared to sentences that refer to an
777 antecedent in the subject position. This suggests that Polish speakers interpret sentences under the
778 working assumption that the topic of a sentence is the most-prominent, first-mentioned, subject
779 antecedent. During the sentence-interpretation process, the reference can be shifted towards a
780 different antecedent if additional information (like the appearance of an overt pronoun) requires it.
781 However, shifting the predicted reference is always effortful, regardless of the pronoun-antecedent
782 match, which is reflected by increased processing cost in sentences that contain overt pronouns.

783 Additionally, in both Studies we found that Polish speakers considered sentences containing null
784 pronouns as more natural than sentences containing overt pronouns. Interestingly, our results also
785 show that this effect is modulated by the preference for a pronoun-antecedent match. In Study 1, we
786 found that null pronouns interpreted as referring to subject antecedents were rated as more natural
787 than those interpreted as referring to object antecedents. However, no differences in the naturalness
788 of sentences with null pronouns were observed in Study 2. The difference between the two Studies
789 may be related to differences in the task itself: while Study 1 allowed a reader to choose the referent
790 of a pronoun, Study 2 forced the reference with the only grammatically correct antecedent.

791 Nevertheless, despite the differences in both Studies, sentences with null pronouns were rated as
792 more natural than sentences with overt pronouns. In both Studies, we also found that overt pronouns
793 referring to antecedents in the position of the syntactic subject were rated as much less natural than
794 those referring to a syntactic object (i.e., preferred interpretation of an overt pronoun). This pattern is
795 convergent with our eye-tracking results, which show a larger processing cost for overt pronouns
796 forced to match less-preferred antecedents (i.e., subject-antecedents) than for null pronouns forced
797 to much the less-preferred object antecedents. Based on these findings, it could be argued that
798 sentences that are less natural are actually more difficult to interpret and, as such, the increased

processing cost related to the interpretation of sentences with an overt pronoun forced to match an antecedent in the position of the syntactic subject might actually reflect a more general problem related to interpreting very unnatural sentences rather than shifting the preferred reference of a pronoun. However, this interpretation is challenged by the naturalness judgement results in Study 1. Similarly to Study 2, it shows that Polish speakers rate sentences with overt pronouns interpreted as referring to the subject antecedent (i.e., contrary to a general preference) as much less natural than sentences which followed the preference for overt pronoun interpretation. However, in Study 1 we did not force the unnatural pronoun-antecedent match: all pronouns were ambiguous and could refer to either of the antecedents. As such, this shows that not only syntactic factors such as subjecthood or first-mention bias drive the perception of the naturalness of sentences; the speaker's interpretation of the sentence also does so, i.e., the pronoun-reference assignment, once it has been established.

What drives the anaphora resolution mechanism in Polish?

As revealed by the results of our first experiment, the natural preference for anaphora resolution in Polish is similar to that observed in other *pro*-drop languages. In Romance languages like Italian or Spanish, speakers usually prefer to interpret sentences containing null pronouns as referring to a subject antecedent, and they interpret sentences containing an overt pronoun as referring to an antecedent in the position of an object (5,19,28). Our results are in line with these findings. They are also convergent with theoretical accounts according to which the use of a referring expression is determined by the prominence of its referent: the more prominent a referent is, the more reduced should be the referring expression that is used. The prominence of an antecedent in a subject position can be derived either from its grammatical role (the highest SpecIP position; 19) but it can also be driven by a preference for the first-mentioned antecedent in a sentence (16,29) or the fact that the first-mentioned subjects are more likely than other antecedents to be interpreted as topics of a given utterance (12,33). It has been shown that it is very difficult to disentangle these effects, but it is very likely that readers use a combination of different cues of prominence when interpreting pronouns (for comparison of the first-mention account and subjecthood, see 29). Therefore, according to the rules

outlined in AT (6), an antecedent in a subject position is usually referred to by the most-reduced pronominal form, which in the case of a *pro*-drop language like Polish is a null pronoun. The fact that overt pronouns are interpreted as matching the antecedent in a less prominent object position can be attributed either to syntactico-semantic factors, like grammatical role or order of mention, or by referring to discourse-related factors, like topicality or a general discourse coherence. The results of both reported studies suggest that subjecthood and information structure (i.e., order of mention but also topicality and thematic roles) are dominant constraints for pronoun resolution in Polish. This is a typical observation in sentence-oriented languages which rely on the morpho-syntactic determinants of subject-verb agreement in establishing pronouns' reference. In Study 1, we showed that null and overt pronouns are usually bound by antecedents whose prominence can easily be derived from these syntactico-semantic cues. However, the interpretation of ambiguous pronouns also revealed that, in some cases, readers interpreted them contrary to the general resolution preference. Interestingly, even though participants were free to choose whichever antecedent they preferred, the naturalness scores of unnatural antecedent matches (i.e., an overt pronoun referring to a subject antecedent) were much lower than for conditions following a general resolution preference pattern. This result indicates that even though the syntactico-semantic bias for pronoun resolution seems to be the dominant constraint on pronoun interpretation for Polish speakers, it can be overridden by other factors whenever the mental representation of a comprehender's discourse favors an alternative interpretation. Apart from referring to the antecedent's prominence, the preferred pronoun-antecedent match in Polish speakers can also be explained by referring to more pragmatic factors: according to the Accessibility Theory (6), the use of a referring expression depends on the balance between its cost and function. In the case of overt pronouns, their pragmatic function can be to act as a cue which helps to identify the appropriate antecedent that is less prominent (46,47). As such, whenever a speaker encounters an overt pronoun, it can be interpreted as a signal for a reference shift towards a less-prominent antecedent. To sum up, the results of our first study show that the preference for anaphora resolution in Polish is governed by the prominence of an antecedent.

However, based on the results of the first study, it remains unclear to what extent Polish speakers rely on syntactico-semantic or discourse-related cues when they assess the prominence of an antecedent. Study 1 showed that while syntactico-semantic cues are strong constraints on pronoun resolution, it is unclear to what extent they can be easily overridden when the context of a given sentence requires so. The second study of the current paper sheds more light on this problem. Exploring the online interpretation of unambiguous pronouns whose only possible interpretation either was or was not in line with the preference for interpretation of anaphorical sentences allowed us to determine whether these preferences can be modulated by the context of a given sentence. Our results indicate that sentences containing a null pronoun equally easily accommodate verb phrases referring to antecedents in the position of subjects and objects. An important consequence of this is that since null pronouns can be easily and unambiguously interpreted as referring to the antecedent in object and subject positions, any use of an overt pronoun needs to be justified (47). As previously discussed, the pragmatically driven function of a pronoun is to signal the identification of the appropriate antecedent. In this framework, the appearance of an overt pronoun should signal a shift of reference from the most prominent antecedent to a less prominent one. Otherwise, the overt pronoun would provide redundant information and, as such, it should be more difficult to interpret. Our results provide experimental confirmation of this prediction: the observed pattern of online anaphora resolution reveals that interpretation of a sentence containing an overt pronoun that refers to an antecedent in a subject position is much more effortful than when the antecedent is placed in the position of an object. Further confirmation of this pattern comes from the results of the naturalness ratings, which show that sentences in which an overt pronoun refers to an antecedent in the position of the syntactic subject are considered to be less natural than sentences in which an overt pronoun refers to an antecedent in the position of the syntactic object. A similar pattern of results was also reported by a study on online sentence interpretation in Spanish speakers (21). However, in contrast to Polish and Spanish speakers, Italian speakers show exactly the opposite sensitivity to the violation of a natural pronoun-antecedent match, with much bigger processing penalty for null

pronoun preference violation than for overt pronouns (5). One way of accounting for the differences in the sensitivity of null and overt pronouns to the violation of their preference for interpretation is by referring to approaches that assume that pronoun resolution is driven by multiple constraints, such as the Form-Specific Multiple-Constraint approach (1), or the SMASH algorithm for pronoun resolution that was proposed Kehler and Rhode (24). According to these proposals, the prominence of antecedents should be described on multiple dimensions that include syntactico-semantic cues (like subjecthood or order of mention) and discourse-related cues (like topic shifts, focus or discourse coherence). Within these frameworks, our results can be interpreted as indicating that null pronouns are much more sensitive to a wide range of cues of reference, not necessarily those that drive a general pronoun resolution preference; therefore, whenever null pronouns are forced to refer to an antecedent which does not follow the preferred antecedent match, they can easily shift their reference towards a more contextually appropriate referent. On the other hand, overt pronouns do not exhibit similar flexibility; this entails a substantial processing penalty whenever the preference for retrieving the antecedent in an object position is violated. Overall, this suggests that once an overt pronoun has been used in a sentence, its preferred reference cannot be easily overruled by the context of a given utterance. One possible way of explaining the different sensitivity of null and overt pronouns to the violation of their resolution preferences is by referring to the previously discussed pragmatic function of an overt pronoun (46,47): since a pronoun has been explicitly used in a given sentence, it should signal a shift of reference towards a generally less-prominent antecedent. As such, the use of an overt pronoun can be considered a very strong contextual cue which increases the prominence of the object antecedent. The large processing penalty observed for sentences in which overt pronouns are forced to refer to subject antecedents can therefore reflect the overriding of this pragmatically based bias. However, based on the design of our study, it is not possible to tell what the constraints are that drive the anaphora resolution.

Interestingly, the results of Study 2, while replicating the pattern observed by Chamorro and colleagues (21), are at the same time at odds with another study conducted by Filiaci and colleagues

which showed that violation of a natural pronoun-antecedent match incurs a greater processing penalty for null than for overt pronouns (5). In their paper, Chamorro and colleagues point out that these differences may actually be related to the clause order. In our experiment, similarly to Chamorro and colleagues, we used sentences following the Main-Subordinate clause order. In contrast, Filiaci and colleagues (5) followed the Subordinate-Main order. These differences can affect the information structure as they can shift the expectations of a reader, thereby resulting in differences in discourse representations. Furthermore, they can also result in a shift in topicality or a shift of the perceived agentivity of the available antecedents. On the other hand, the discrepancies between our results and results reported by Filiaci and colleagues could be related to cross-linguistic differences in pronoun resolution mechanisms between Polish (our study), Spanish (21) and Italian (5). Within the multiple-constraint frameworks (1,24), it can be argued that even though the “hard” morpho-syntactic constraints in different languages are similar (or the same), their anaphora resolution mechanisms might still differ due to differences in sensitivity to the “soft” cues that define the antecedents’ prominence.

Antecedent in an object position – the source of the unexpected processing cost

So far, we have argued that subjecthood, order of mention and automatic assignment of topicality to the subject-antecedent are the dominant constraints on anaphora resolution in Polish, which in some cases can be overridden to better accommodate a current representation of discourse. To our surprise, our data indicate that the processing of sentences that refer to the antecedent in the syntactic position of an object incurs an additional processing cost, regardless of the pronoun-antecedent match. Interestingly, this effect was only revealed in the analysis of a post-critical area of interest (the *spillover* effect; 48). A number of recent theoretical accounts of this effect have attributed the spillover to the increased difficulty of lexical access (49,50). According to these accounts, the spillover effect results from an interplay of lexical processing and oculomotor control: an increase of

928 lexical access difficulty does not delay a saccade and therefore, lexical processing is concluded *after*
929 the gaze has been moved from the critical word. As a consequence, the lexical processing difficulty
930 results in an increase of reading time in the post-critical region (for discussion see: 51). However, this
931 claim was recently challenged by Remington and colleagues, who showed that lexical access is *fully*
932 *completed* before the saccade occurs, therefore the lexical processing cannot account for the spillover
933 effect (51). Instead, Remington and colleagues proposed that the effect reflects a more general
934 adaptive adjustment that is not necessarily related to reading. Another account which explains the
935 spillover effect without referring to lexical processing is the *integration account* (52), according to
936 which an increase in reading times in the post-critical area of interest reflects the cognitive load related
937 to a sentence-level semantic integration process. In line with this account, a recent paper by Patterson
938 and Felser (14) proposes that pronoun resolution is a process that unfolds over time: in its early stages,
939 the initial bonding or retrieval are reflected by early fixation measures, but late processes related to
940 the integration with discourse only affect later processing stages. Following the *integration account*
941 we propose that in our data the spillover effect reflects the cognitive load related to a shift of a *default*,
942 preferred reference from the most-prominent subject antecedent to a less-prominent object
943 antecedent. As previously discussed, in our experiment the default preferred reference of a given
944 sentence can be explained not only by a preference for a syntactic subject but also by assigning the
945 role of the thematic topic to the first-mentioned antecedent. Under the assumption of the *integration*
946 *account*, the effects observed in the critical area of interest reflect the ease of processing of the word's
947 *meaning* (i.e., identifying the referent of a verbal phrase), while the effects in the post-critical region
948 reflect the updating of the syntactic or discourse-related representation of a sentence. Therefore, even
949 though processing of a less-natural subordinate clause that contains an object antecedent might not
950 impose difficulty for lexico-semantic processing, it could be generally more demanding to process on
951 the *syntactic* and *discourse integration* level. Previous studies on anaphora resolution reported a
952 similar effect: an increased processing cost associated with a topic shift towards a less-prominent, non-
953 focused antecedent which has been cued by the information structure of the current discourse (the

anti-focus effect: 10,11,14,15). In reference to the anti-focus effect, our results can be interpreted as showing that Polish speakers automatically interpret the most-prominent antecedent (the first available antecedent or the subject antecedent) to be the topic of a sentence, but as new information cues another antecedent which is coherent with the current discourse, the reference is shifted. This interpretation can be supported by similar findings from an EEG experiment performed by Schumacher and colleagues (53), which showed that co-reference with a less-prominent antecedent results in additional processing cost reflected by the N400 component, which is responsible for semantic processing and integration of words into a broader discourse. However, they also found that shifting the discourse topic from the antecedent in the initial topical position in a sentence results in an additional late-processing cost reflected by the Late Positivity component. The authors propose that the N400 effect reflects the pronoun-specific prominence computations necessary for the appropriate resolution of the pronoun, while the Late Positivity is driven by a discourse-internal updating process. To sum up, the effects observed in the post-critical region of interest might indicate Polish speakers automatically assign the reference (and the thematic role of a topic) of a sentence to the first-mentioned subject antecedent, i.e., the pre-verbal subject of the main clause. While the interpretation of the pronoun itself can be modulated by a range of different factors, the syntactic or discourse-related representation of a sentence needs to be updated whenever the content of the sentence requires the reference to be shifted towards a different antecedent.

Conclusions

To conclude, the current study provides the first experimental evidence on anaphora resolution preferences in Polish. We have shown that the general bias for anaphora resolution is consistent with theories according to which it is the prominence of an antecedent that governs anaphora resolution (1,6,19,47). Our results indicate that in Polish syntactico-semantic cues such as subjecthood and information structure (i.e., order of mention but also a typical topicality) are the dominant constraints of the prominence of an antecedent; however, they can be overridden by

additional cues whenever this is justified by the coherence of discourse representation. Interestingly, the results of the eye-tracking experiment revealed that null pronouns in Polish are able to flexibly and effortlessly shift the reference towards a less-preferred antecedent, while the referential bias for overt pronouns seems to be much stronger as its violation is related to a significant processing cost. Moreover, the analysis of the post-critical region revealed that, regardless of the anaphora resolution process, an additional cognitive effort occurs whenever the reference needs to be shifted towards to a less-prominent, non-topical antecedent. The fact that this effect is consistent across sentences that contain both null and overt pronouns suggests that it might reflect a different process than the effects observed in the critical area of interest. Altogether, our results suggests that anaphora resolution is an incremental multi-stage process; however, further research is needed to explore the mechanism responsible for the shift of reference in order to better understand the source of the extra cognitive effort it entails.

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- 1117
- 1118 **S1. Appendix A.** A list of experimental sentences used in Experiment 2.