(Reversed) Mismatch Asymmetry in English Subject-Verb Agreement

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ABSTRACT: This paper investigates, in English, the widely reported *mismatch asymmetry*, or *plural attraction* in the production of subject-verb agreement and the relatively less observed *reversed mismatch asymmetry*, or *singular attraction* in comprehension. Through a self-paced reading experiment, a read-aloud production task and a pen-and-paper questionnaire, we examined whether *singular attraction* is a genuine effect in comprehension or it could be due to the experimental materials in the few studies that reported it. The results support the view that *singular attraction* in comprehension is genuine, at least for structures that include three nouns in the subject, and *plural attraction* extends to sentences with complex subjects that include three nouns when the task is not too demanding. The (reversed) mismatch asymmetry in subject-verb agreement is attributed to the differential mechanisms involved in sentence comprehension and production.

Keywords: English, subject-verb agreement, mismatch asymmetry, production, comprehension

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İngilizce özne-yüklem uyumunda eşleşmeme (ters) asimetrisi

ÖZ: Bu çalışma İngilizce özne-yüklem uyumunda dil üretiminde geniş çaplı olarak raporlanan uyumsuzluk asimetrisi ya da çoğulun çekime etkisini ve cümle anlamada nispeten daha az gözlemlenen ters uyumsuzluk asimetrisi ya da tekilin çekime etkisini araştırmaktadır. Bir kendi hızında okuma deneyi, bir sesli okuma deneyi ve bir yazılı anket ile, anlamada tekilin çekime etkisinin özgün bir etki mi yoksa bu etkiyi ortaya koyan çalışmaların deneysel materyallerinin bir ürünü mü olduğunu araştırdık. Sonuçlar, en azından öznesinde üç isim bulunan yapıların anlaşılmasında, tekilin çekime etkisinin özgün olduğunu, çoğulun çekime etkisinin ise deneyin bilişsel kaynaklar üzerinde çok zorlayıcı olmadığı durumlarda üç isim içeren özneli yapılarda da görüldüğü görüşünü desteklemektedir. Özne-yüklem uyumundaki bu (ters) uyumsuzluk asimetrisi, cümle anlama ve üretmede kullanılan mekanizmalardaki farklılıklarla açıklanabilir.

Anahtar sözcükler: İngilizce, özne-yüklem uyumu, ters uyumsuzluk asimetrisi, cümle üretme, cümle anlama

1 Introduction

Agreement has been defined by Quirk and colleagues "as the relationship between two grammatical units such that one of them displays a particular feature (e.g., plurality) that accords with a displayed feature on the other" (Quirk et al., 1972, p. 755). Subject-verb number agreement (henceforth, S-V agreement), a common instance of agreement across languages, occurs when a verb and its subject agree in their number feature. In English, verbs overtly agree with their subjects in number (Quirk et al., 1972), as illustrated in (1), and the agreement is morphologically marked on the copula or the auxiliary form of the verb *be* in the present and past tense, third person singular *-s* or the auxiliaries (*has/have*) in the perfect aspect of present tense.

(1) a. The key was rusty.
b. The keys were rusty.

It is possible to encounter instances of S-V agreement errors when the verb fails to agree with its subject in number as in (2b), in which the subject consists of a complex noun phrase (NP) and the verb erroneously agrees with the plural local noun *the cabinets,* but the grammatical subject, i.e., head noun, *the key* is singular. (Compare to the grammatical form in (2a).)

(2) a. The key to the cabinets was lost.
b. *The key to the cabinets were lost.

(Bock & Miller, 1991, p. 56)

There has been much research examining the source of such S-V agreement errors in production and sensitivity to them in comprehension. Several models have been proposed to explain the operations of the human language processing mechanism (henceforth, the parser) in computing S-V agreement. (See *Approaches to S-V agreement* Section below.) This paper examines what is referred to as *reversed mismatch asymmetry* or *singular attraction*, which is the observation that comprehenders are less sensitive (and hence more attracted) to agreement errors when the head noun is plural and the intervening noun with a mismatching number feature, i.e., *attractor noun*, is singular (Pearlmutter, 2000), against a widely reported phenomenon, *mismatch asymmetry* or *plural attraction*, which is the observation that speakers are more likely to produce S-V agreement errors when the head noun is singular and the attractor is plural (Bock & Miller, 1991; Bock & Cutting, 1992; Bock & Eberhard, 1993). Using the same set of materials in production and comprehension, this study examines whether the (reversed) mismatch asymmetry is due to the differential operations in which the parser engages in for production and comprehension or an artifact of the experimental items in previous studies.

1.1 S-V Agreement in Production and Comprehension

Agreement errors similar to those in (2b) above have been observed in language production in several languages (e.g., English: Bock & Cutting, 1992; Bock & Eberhard, 1993; Bock et al., 1999; Bock & Miller, 1991; Italian: Vigliocco et al., 1995; Spanish: Vigliocco, Butterworth, & Garrett, 1996; Dutch and French: Vigliocco, Hartsuiker, et al., 1996). Studies have also shown that comprehenders are less sensitive to such agreement errors as they were either less accurate in their acceptability ratings for sentences such as (2b) compared to their grammatical counterparts such as (2a) (Clifton, Frazier, & Deevy, 1999; Häussler & Bader, 2009) or they had shorter reading times for the verbs in (2b) than their ungrammatical counterparts with no matching attractor noun such as *the key to the cabinet were* (e.g., Dillon et al., 2013; Pearlmutter et al., 1999; Wagers et al., 2009).

The probability of an agreement error has also been reported to be higher when the attractor noun is plural as in *the key to the cabinets* than when the attractor noun is singular as in *the keys to the cabinet* (Bock & Miller, 1991; Bock & Cutting, 1992; Bock & Eberhard, 1993; Bock, 1995; Dillon et al., 2013; Nicol et al., 1997; Pearlmutter, 1999). This *mismatch asymmetry* or *plural*

attraction is often attributed to the markedness (i.e., saliency) of the plural nouns which considers singular nouns to be the default, unmarked form; and plurals to be the non-default, marked form (Eberhard, 1997). A marked plural noun is more salient and attracts the verb more than a singular noun, resulting in more attraction errors.

A previous study by Pearlmutter (2000) reported a *reversed mismatch asymmetry*, i.e., *singular attraction,* in comprehension for sentences with complex subjects that included three NPs such as *the pond near the trail for the horse*. A later production study by Franck et al. (2002) using materials very similar to Pearlmutter's, however, reported equal attraction for plural and singular attractors. Several other studies examined S-V agreement in comprehension with materials not necessarily like Pearlmutter's and Franck et al.'s. Wagers et al. (2009), for instance, reported plural attraction in comprehension for subject NPs that included one attractor noun such as *the key to the cell.* But note that Wager et al.'s study did not include sentences with plural heads and singular attractors. So, it is not clear whether or not the plural attraction they observed in comprehension could be the usual mismatch asymmetry. This study, using the materials from Franck et al. examines whether the widely reported *plural attraction* can extend to comprehension or there is a consistent *singular attraction* in comprehension in sentences with complex subjects including three NPs. If the former is true, the singular attraction in Pearlmutter (2000) could be due to some inherent biases in the materials; but if the latter is true, then it would show a genuine singular attraction in comprehension and could shed light on the processes involved in computing S-V agreement in comprehension and production.

Several approaches to S-V agreement have been put forward in the literature. Before moving on to the details of the present study, a review of previous research on S-V agreement is presented.

1.2 Approaches to S-V agreement

Earlier studies of S-V agreement attributed agreement errors to the operations of the working memory (e.g., Bock & Miller, 1991; Quirk et al., 1972). In this view the *linear distance* between an NP and a verb is important because in sentences with complex NP subjects the verb erroneously agrees with the closely preceding local noun whose number feature is easier to retrieve from memory than that of the head noun (Bock & Miller, 1991; Jespersen, 1924; Quirk et al., 1972). It has also recently been shown that speakers with lower working memory (WM) capacity made more agreement errors in production under verbal memory load conditions (Hartsuiker & Barkhuysen, 2006).

The structural distance between a head noun and an attractor noun has also been shown to be important in the probability of an S-V agreement error (Franck et al., 2002; Vigliocco & Nicol, 1998). That is, the attractor noun that is syntactically closer to the head noun is predicted to cause more agreement errors than a syntactically distant noun because syntactically closer noun's features can more easily percolate to the head noun. Vigliocco and Nicol (1998) showed in two production experiments that agreement errors occur due to syntactic distance between the head noun and the attractor noun rather than the linear distance between the attractor noun and the verb. In their experiments the participants were presented with sentence preambles such as *safe / the helicopter for the flights* and were asked to produce declarative sentences or *yes/no* questions. The syntactic distance hypothesis predicted no difference between declarative sentences and questions as the syntactic distance between the attractor noun and the head noun would be the same across both types of sentences. The linear distance hypothesis predicted more agreement errors in declarative sentences as the attractor noun would be linearly closer to the verb even though its syntactic distance to head noun is the same across the two conditions. The results showed no difference in the frequency or distribution of errors between the two experiments, supporting the syntactic distance hypothesis.

The predictions of the linear and syntactic distance hypotheses were further tested, by Pearlmutter (2000), in sentences with complex subjects that had three NPs such as *the pond near the trail for the horse*. The syntactic distance hypothesis would predict more processing difficulty when the intermediate noun, *the trail*, had a number mismatch with the head noun, *the pond*, as it is syntactically closer to the head noun; the linear distance hypothesis would predict more processing difficulty when the local noun, *the horse,* had a number mismatch with the head noun as it is linearly closer to the verb. The number feature of the head noun was also manipulated. The self-paced reading data confirmed the predictions of the syntactic distance hypothesis for plural-head and singular-attractor conditions. But there was no effect of number mismatch (either for local or for intermediate NPs) with singular-head plural-attractor conditions. Unlike previous studies that reported plural attraction, Pearlmutter's study included complex subjects with three NPs all of whose number feature needed to be processed. Pearlmutter argues that this type of distance may have weakened the strength of the number feature of the plural head noun, showing syntactic distance effect in plural head conditions. He concluded that although the "… feature-tracking system relies on hierarchical structure to determine how features are manipulated, … this hierarchical structure is not independent of working memory" (p. 97) due to distance and interference effects.

Franck and colleagues (2002) used materials like those in Pearlmutter's (2000) study in a production experiment in French and English. They found in both French and English that the speakers were more likely to produce agreement attraction errors when the head noun had a number mismatch with the intermediate noun than when it had a number mismatch with the local noun. But unlike Pearlmutter's study, they observed the syntactic distance effect both with plural and singular head nouns. Franck et al. argued that the syntactic proximity of the intermediate noun would allow it to percolate its number feature to the head noun resulting in the increased probability of agreement errors.

Wagers et al. conducted self-paced reading and acceptability judgment tasks to test the predictions of the *feature percolation* (i.e., syntactic) *account* and showed that agreement attraction could be explained through reference to *cue-based information retrieval from memory* (see below) rather than *feature percolation* through syntactic proximity. Their experiments investigated S-V agreement computation in embedded object relative clauses (RCs) such as *the musicians who the reviewer praise* in complex sentences as well as S-V agreement in matrix clauses with complex subjects with PPs such as *the key to the cell.* The RC constructions were important because in these structures the subject of the main clause, *the musician*, was the attractor for the S-V agreement in the verb in its RC, *praise,* and dominated the subject of the RC, *the reviewer.* The feature percolation account did not predict downward percolation of the attractor's features; even if it did, the number of heads that it would need to percolate its features through would be too many. The results of the self-paced reading tasks showed agreement attraction for conditions with a plural RC head (e.g., *The musicians who the reviewer praise …*) whose RTs were similar to their grammatical counterparts (e.g., *The musicians who the reviewer praises …*). This was not the case with singular RC head conditions. The number attraction in RCs showed evidence against the feature percolation account and its more liberal download percolation version which would predict reduced attraction effects with RCs than with PPs, but the attraction effects were similar across PP and RC constructions.

In Wagers et al.'s RC sentences number attraction was observed in ungrammatical sentences. Previous studies, whose materials included complex subjects with PPs, showed it in grammatical sentences. Wagers et al. conducted three experiments with complex subjects with PPs to examine if the grammaticality effect would also hold true for complex subjects with PPs. The results were in line with the RC experiments showing agreement attraction in ungrammatical sentences only. They argued that the agreement attraction being present only in ungrammatical sentences could be due to the incorrect retrievals of targets from memory.

This is a more recent approach to S-V agreement which maintains that the linguistic dependencies between verbs and their subjects could be explained through cue-based memory retrievals (e.g., Lewis & Vasishth, 2005; Lewis et al., 2006). In the *cue-based memory retrieval model*, the retrieval of a target item (e.g., the subject) from memory is driven by a set of retrieval cues that are generated by the probe (e.g., the verb). In S-V agreement, upon processing the verb, retrieval cues such as [±plural] are generated and are checked against the features of the subject (Wagers et al., 2009; Tanner & Bulkes, 2015). The target item with the matching cues is then retrieved through an associative, content-addressable retrieval process. The process of retrieving the correct target item is constrained by *activation-based decay* and *similarity-based interference*. Activation-based decay refers to the time interval between the target and the probe being processed. That is, the nouns that are encoded later than the target noun may have higher levels of activation when the probe is encountered, and hence, may be incorrectly retrieved. Similarity-based interference refers to the idea that as similarity of distractors to the target item increases, retrieving the target item becomes more difficult because the retrieval cues at the verb are checked against all memory representations that have been encoded. Two types of similarity-based interference are possible: *inhibitory interference* and *facilitatory interference*. Inhibitory interference is predicted in grammatical sentences when, instead of the target, an intervening noun with features partially matching with those of the target might be retrieved, resulting in delay in processing. Facilitatory interference is predicted in ungrammatical sentences such as (2b) above. In (2b) the features of the attractor noun partially match with those of the verb and when it is retrieved erroneously instead of the head noun, the agreement between the attractor noun and the verb might cause facilitation in processing where the mismatch effect between the head noun and the verb would be reduced.

Tanner and Bulkes (2015) conducted an ERP study to examine the effect of plural markedness and cue strength in processing S-V agreement using sentences such as *Some/The cookies taste the best when dipped in milk.* They predicted that multiple cues to the number feature of an NP (e.g., *some* vs. *the*) would enhance the encoding of that NP and create stronger predictions for the upcoming verb's number feature or ease the access to the retrieval targets for the verb. The results were in line with the predictions in that while both quantified and unquantified ungrammatical sentences elicited a P600 response (positive-going deflection around 600 milliseconds, indicating late syntactic processing or reanalysis), quantified ungrammatical sentences resulted in greater P600 effects.

2 The Present Study

Previous studies examined S-V agreement both in production and comprehension. The production studies consistently reported a mismatch asymmetry in favor of plural attraction. One comprehension study (Pearlmutter, 2000), which involved sentences with complex subjects with two PPs, reported a mismatch asymmetry in favor of singular attraction. Pearlmutter (2000) argued that when the complex subject included two PPs the number feature of three NPs (the head noun and the intervening nouns) needed to be processed and this type of distance may have weakened the strength of the number feature of the plural head noun, showing syntactic distance effect in plural head conditions. This may be the reason that Franck et al. did not observe the usual plural attraction in their study, neither in French nor in English. Plural attraction has mostly been observed for production and given that in a production study that had materials similar to Pearlmutter's the effect disappeared, the present study examines if the reversed mismatch asymmetry in comprehension could be attributed to processes required in comprehension (as opposed to production) to process number features of multiple NPs or it is a result of the complexity of the subject NP. We used the complex subject NPs with three NPs such as *the e-mail from the secretary of the manager* from Franck et al. (2002), who reported both singular and plural attraction in production, and tested those in comprehension in the same design as Pearlmutter (2000) who reported singular attraction for sentences with complex subjects with three NPs similar to Franck et al.'s (2002) materials. The complex subjects with three NPs would also allow for testing the effects of the number feature of the syntactically or linearly closer noun on the computation of S-V agreement as in previous studies examining S-V agreement in English.

The experiments and the tasks were presented to the participants in the following order: the self-paced reading experiment, the read-aloud production task and the pen-and-paper questionnaire, with breaks in between them.

2.1 Participants

Forty native speakers of English (15 females, mean age = 31.5) participated in the study. All the participants lived in New York City at the time of data collection. The participants received 10$ to compensate for their participation in the study. All the participants reported normal or corrected-to-normal vision.

3 Experiment 1: Self-paced reading

Experiment 1 employed a self-paced reading paradigm to test whether or not the real-time computation of S-V agreement would be influenced by the number

feature of the head noun and the attractors; and whether the syntactic or linear distance of the attractor nouns would modulate the participants' sensitivity to S-V agreement.

3.1 Materials

The materials in Experiment 1 (and also in Experiments 2 and 3) were adapted from Franck et al.'s (2002) production study in English, which employed complex subject NPs with three nouns as in *the e-mail from the secretary of the manager*. In all the conditions in Experiment 1, the verbs agreed with the subjects in terms of their number marking, and hence, the sentences were all grammatical. There were eight conditions, manipulating (i) the number of the head noun, N1, (singular vs. plural), (ii) the number of the intermediate noun, N2, (singular vs. plural) and (iii) the number of the local noun, N3, (singular vs. plural). The head noun was either singular as in (3a-d) or plural (P) as in (3e-f). The number feature of the intermediate and local (i.e., attractor) nouns either matched that of the head noun as in (3a,e) or mismatched it as in (3b-d) and (3f-h). The N2 would be syntactically closer to the head noun and N3 would be linearly closer to the verb.

(3) a. SSS:The e-mail from the secretary of the manager was confidential.
b. SSP:The e-mail from the secretary of the managers was confidential.
c. SPS:The e-mail from the secretaries of the manager was confidential.
d. SPP:The e-mail from the secretaries of the managers was confidential.
e. PPP:The e-mails from the secretaries of the managers were confidential.
f. PPS:The e-mails from the secretaries of the manager were confidential.
g. PSP:The e-mails from the secretary of the managers were confidential.
h. PSS:The e-mails from the secretary of the manager were confidential.

The conditions in which there is no number mismatch between the head noun and the attractor nouns were predicted to be processed the fastest. For the other conditions in which there is a mismatch between the head noun and the attractor nouns, the predictions differ. The experimental items manipulated the number feature of the head noun and the attractor nouns to test whether the reversed mismatch asymmetry, i.e., singular attraction, would be confirmed, or the widely reported plural attraction (Bock & Miller, 1991; Bock & Cutting, 1992; Bock & Eberhard, 1993; Bock, 1995; Dillon et al., 2013; Nicol et al., 1997; Wagers et al., 2009) would extend to comprehension for sentences with complex subject NPs that included two singular attractors. If there is a reversed mismatch asymmetry in comprehension, the participants would show more sensitivity to the number mismatches in conditions with plural heads and

singular attractors as in (3f-h) but not to those with singular heads and plural attractors as in (3b-d).

The experimental items also allowed to test the effects of the linear or syntactic distance of the attractor nouns to the head noun/verb. If the linear distance hypothesis is correct, then the participants' processing of the mismatch sentences such as (3b,f) would be slower than the baseline match sentences such as (3a,e) as the S-V agreement on the verb would be distracted by the linearly closer NP's (NP3) number feature. But if the syntactically closer NP's number feature affected S-V agreement computation, then the participants' processing of the sentences such as (3c,g) would be more difficult than the baseline sentences. The double mismatch conditions such as (3d,h) are predicted to be processed slower than their baseline in either scenario. But, if both syntactic and linear distance affect the parsing of S-V agreement, then these conditions would be the most difficult to process. The cue-based parsing view makes a similar prediction to the linear distance hypothesis. In the cue-based memory retrieval model as the distance between a target and a probe increases, the activation level of the target decays. Although the distance between the target and the probe is the same in all the conditions in the present study, the attractor in NP3 position is closer to the verb. As such, its features could be more active in memory than the features of NP2 causing processing delay in linear mismatch conditions such as (3b,f) but not in syntactic mismatch condition such as (3c,g). In the double mismatch conditions such as (3d,h) the features of the intervening NPs would be enhanced and may cause more interference.

There were 32 experimental sentence sets which were distributed across eight lists counterbalancing for the number feature of N1, N2 and N3. Each list, thus, contained 32 experimental sentences, which were intermingled with 64 filler sentences which involved structural dependencies or (temporarily) ambiguous constructions in English. Each list also contained six practice items and six implicit warm-up items, three of which were presented after practice, and the remaining three were presented half-way through the experiment after the participants were offered a break. Each list consisted of 108 sentences in total. All the sentences in each list were followed by a comprehension question which required a *Yes* or *No* response.

3.2 Procedure

Experiment 1 (and also Experiment 2) was conducted using DMDX, version 4.0.4.8 (Forster & Forster, 2003). Sentences were presented using a non-cumulative, self-paced reading paradigm where each sentence was presented one word at a time. The participants were instructed to read the words at their own

pace and press the space bar marked as *next* to move to the next word. They were asked to answer the comprehension questions that followed. The task lasted 20-25 minutes.

3.3 Data Analysis

The data in Experiment 1 (and in Experiments 2 and 3) were analyzed using the R statistical computing software (R Core Team, 2020) with linear or logistic mixed effects models (Baayen et al., 2008). The *lmer* and *glmer* functions of the *lme4* package (Bates et al., 2015) were used for the analyses. Linear and logistic mixed effects models allow to include both subject and item level variance in the same model (Baayen et al., 2008). The models with the two-way interaction were compared to simpler models via a likelihood ratio test. The *p*-values reported for the predictors in linear models were calculated using Satterthwaite approximations for degrees of freedom (Luke, 2017), which was available in the *lmerTest* package (Kuznetsova et al., 2017).

The data were first inspected for accuracy on comprehension questions. All the participants had ≥ 95% accuracy (mean accuracy = 97%), confirming that they were actively reading the sentences for comprehension. The data were then cleaned from incorrect responses and RTs to incorrect responses. This resulted in elimination of 7.2% of the data. The main analyses were run on the reading times (RTs) of the critical region (the 9th word, the main verb) and its spillover region (the 10th word). Although normality is not an assumption of linear regression models, the data were first inspected for distribution for the critical region and the spillover region. The data showed deviation from normality for both the critical region (W = .64, p < .001, D = .21, p < .001) and the spillover region (W = .69, p < .001, D = .23, p < .001). The RTs were hence log-transformed.

The RTs were then entered into a mixed effects model using the *lmer* function in the *lme4* package (Bates et al., 2015). Fixed effects were the number feature of the head noun (singular vs. plural), feature match between the head noun and the intervening nouns (match, N2 mismatch, N3 mismatch and double mismatch); random effects were subjects and items. Overly influential subjects and items on the models were also inspected, using the *influence.ME* function (Nieuwenhuis et al., 2012). Both Cook's distance values and plots were employed in this inspection. The subjects or items that overly influenced the models were eliminated from the data and the models were re-fit after these steps. The analyses also controlled for longitudinal effects of familiarization or fatigue for both the critical region, β = .11, SE = .02, t = -6.00, p < .001, and the spillover region, β = .22, SE = .03, t = -7.31, p < .001 (Baayen, 2008; Baayen et al., 2008).

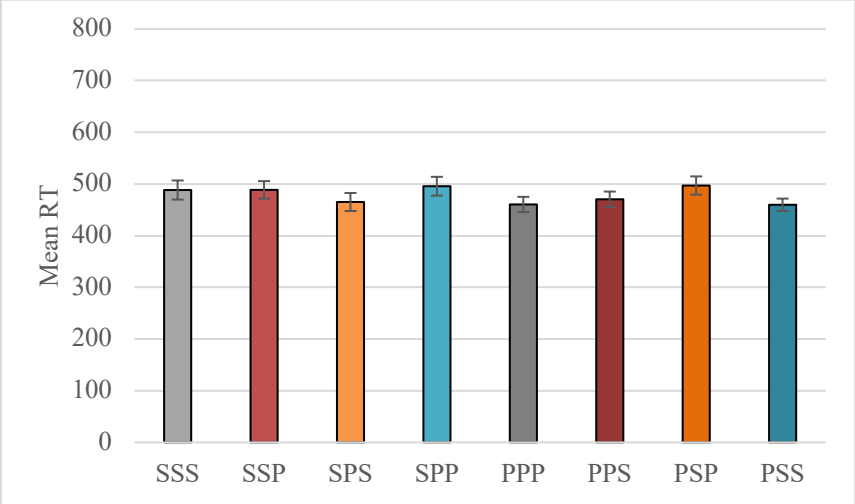
3.4 Results

The results are reported below separately for the critical region and the spillover region.

Critical Region

Figure 1 shows the data for the critical region after removing outliers and influential subjects, items and observations.

Figure 1. Mean RTs in the critical region



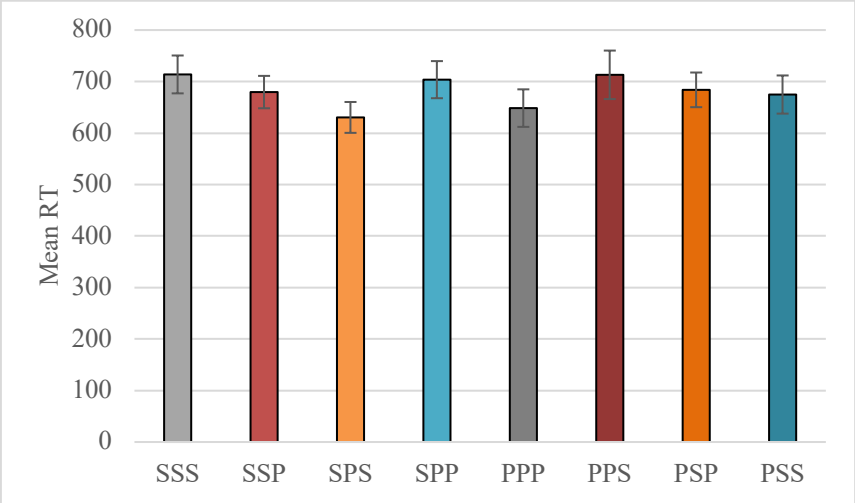
The analyses showed that the model with the interaction of head noun number and feature match explained the data better than the simpler model with only feature match, $\chi^2(4) = 9.52$, $p < .05$. Thus, to investigate if there is any potential mismatch asymmetry, as well as the predictions of the syntactic and linear distance hypotheses, the data were split by head noun number. The conditions in which the number features of the head noun and the intervening nouns matched (i.e., SSS and PPP) were taken as the baseline in the analyses. In the conditions with singular head nouns, there was no difference between the SSS and any of the mismatch conditions, β's ≤ 23.05, SE's ≤ 15.05, t's ≤ 1.52, p's $\geq .13$. In plural head conditions, the PSP condition had longer RTs than the PPP condition, $\beta = 27.02$, $SE = 13.65$, $t = 1.99$, $p < .05$; there were no significant differences between the PPP and the other mismatch conditions, β's ≤ 7.26, SE's ≤ 13.41, t's $\leq .55$, p's $\geq .58$.

During model criticisms for all the models examining the data, data points with standardized residuals below/above 2.5 standard deviations were excluded from the analyses. In the retained models, 1 subject in the conditions with singular head nouns and 1 subject, 1 item and 13 observations in the conditions with plural head nouns deviated from group statistics; and thus, eliminated from the analyses.

Spillover Region

Figure 2 shows the data for the spillover region after removing outliers.

Figure 2. Mean RTs in the spillover region



The analyses showed that the model with the interaction of head noun number and feature match did not explain the data better than the simpler models with only head noun number, $\chi^2(6) = 1.67$, $p = .95$, or feature match, $\chi^2(6) = 1.44$, $p = .84$. But to keep parallel with the critical region data analysis, the data in the spillover region were also split by head noun number. There were no significant differences between the baseline and any of the mismatch conditions in either the conditions with singular, β's ≤ 44.77, SE's ≤ 26.47, t's ≤ 1.67, p's $\geq .10$, or plural head nouns, β's ≤ 27.81, SE's ≤ 27.04, t's ≤ 1.08, p's $\geq .28$.

As in the critical region, during model criticism for all the models examining the data points with standardized residuals below/above 2.5 standard deviations were excluded from the analyses.

3.5 Discussion

The results of the self-paced reading experiment showed a syntactic distance effect only in plural head conditions, in the critical region. That is, the RTs were longer for PSP than the baseline PPP condition.

Similar to Pearlmutter's (2000) study, in comprehension, the participants showed number attraction for plural head and singular attractor conditions only. This contradicts the widely-reported *plural attraction* phenomenon (Bock & Miller, 1991; Bock & Cutting, 1992; Bock & Eberhard, 1993; Bock, 1995; Wagers et al., 2009) but is in line with the previous report for comprehension by Pearlmutter (2000). Pearlmutter argued, for his findings, that when there are multiple intervening nouns (as in subjects with three NPs) all of whose number features must be computed, the markedness of the plural head nouns weakens. This, as a result, increases the vulnerability of plural head nouns to attraction effects. Like Pearlmutter's study, our study had complex subjects with three NPs. This may, therefore, have caused plural head nouns to be more susceptible to agreement attraction effects, showing singular attraction.

4 Experiment 2: Production

Previous research with materials similar to the present study (i.e., complex subjects with three NPs) has shown both plural and singular attraction for production (e.g., Franck et al., 2002) but singular attraction for comprehension (Pearlmutter, 2000). The self-paced reading experiment in this study confirmed the singular attraction for comprehension. To examine whether or not this finding is a general comprehension/production difference Experiment 2 included a read-aloud task.

4.1 Materials

The experimental materials were the same as those in Experiment 1 except that the copula verb was missing and was replaced by a length-neutral underscore. The participants would fill in the missing copula as they read the sentences. The conditions were the same as those in Experiment 1 in which the number of the head noun was either singular or plural and the intervening NPs' number features either matched that of the head noun or mismatched it.

It was predicted that S-V agreement production would be the most accurate in the baseline conditions (SSS or PPP). For the conditions in which the intervening nouns had a number mismatch with the head nouns, the predictions vary. Given the results of Experiment 1, it is reasonable to predict an effect of syntactic distance. In that case, the participants would be more likely to produce

S-V agreement errors when the syntactically closer NP's (i.e., N2) number feature mismatched that of the head noun.

Recall that Franck et al. (2002) found attraction for both singular and plural heads for these materials. It is possible to observe the same effect in Experiment 2. But note that Experiment 2 is slightly different in its methodology. In Franck et al.'s study the participants were given sentence preambles and were asked to produce full sentences using those preambles. Their task, as opposed to ours, was presumably more challenging on the participants' working memory as it would require holding items in memory while producing sentences. The production experiment in the present study employed a simpler methodology so as not to be challenging on memory resources. This would allow us to attribute the effects merely to number attraction. So, it is possible to observe results that are different from Franck et al.'s.

If singular attraction, reported in Pearlmutter (2000) and confirmed in Experiment 1 above, is related to the complexity of the subject head, then the results of Experiment 2 could be similar to Experiment 1 and show lower accuracy for conditions with singular attractors than those with plural attractors. If, however, plural attraction is due to the different processes involved in production and comprehension, then the participants' accuracy would be lower for conditions with singular heads and plural attractors than those with plural heads and singular attractors.

The number of the experimental, filler, practice and implicit warm-up sentences as well as reading lists was the same as those in Experiment 1.

4.2 Procedure

The participants were asked to read the sentences out loud as soon as the sentences appeared on the screen (without preview) and complete the sentences that had a missing component as they read them. Once they finished reading the sentence, they moved to the next sentence with a key press. The computer recorded their utterances.

4.3 Data analysis

The participants' utterances and their copula insertions were listened to and transcribed by the authors. In some proportion of the sentences (2.15%), the participants re-read the sentence and changed their insertions to either a grammatical or an ungrammatical form of the verb. Their sentence completions were therefore categorized as *first reading* and *revised reading* and grammatical accuracy was analyzed separately for each pass.

The grammatical accuracies were then entered into a mixed effects model using the *glmer* function in the *lme4* package (Bates et al., 2015). The random and fixed effects were the same as in Experiment 1. The analyses showed that the participants' accuracy increased towards the end of the experiment (first reading: β =.02, SE = .003, z = 5.22, p < .001; revised reading: β =.02, SE = .004, z = 5.86, p < .001). Trial number was thus included as a predictor in the main analyses.

4.4 Results

The participants overall had high accuracy in their sentence completions in both singular head (first reading: M = 85.9%, revised reading: M = 86.1%) and plural head conditions (first reading: M = 81.6%, revised reading: M = 82.7%). Paired sample t-tests showed that the speakers' accuracy improved after revisions on item-level, $t_2(31) = 2.27$, $p < .05$, but not on subject-level, $t_1(38) = 1.75$, $p = .09$. Table 1 shows mean percent accuracy in the first reading and after revisions.

Table 1. Mean percent accuracies of L1 and L2 speakers in the first reading and after revisions in the production task.

Conditions	Accuracy in the first reading	Accuracy after revisions
SSS	96.2	95.6
SSP	91	91
SPS	84.6	84.6
SPP	71.8	73.1
PPP	85.3	85.9
PPS	82.1	83.3
PSP	80.8	81.4
PSS	78.2	80.1

Since the analyses for the accuracies in the first and revised readings were, in general, rather similar, we report the results of the analyses of the first reading as they would better reflect the participants' initial analyses.

The analyses showed that the model with the interaction of head noun number and feature match explained the data better than the simpler model with only head noun number, $\chi^2(4) = 52.53$, $p < .001$, and feature match, $\chi^2(4) = 24.80$, $p < .001$. Thus, to investigate if there is a potential mismatch asymmetry, the data were split by head noun number. As in Experiment 1, the SSS and PPP conditions were taken as the baseline and the mismatch conditions were compared to them. In singular head conditions, SPS, SPP and SSP conditions had lower accuracy than the baseline SSS condition, SPS: $\beta = -2.48$, $SE = .77$, $z = 3.22$, $p < .05$; SPP: $\beta = -3.86$, $SE = .81$, $z = -4.78$, $p < .001$; SSP: $\beta = -1.52$, $SE = .78$, $z = -1.94$, $p = .05$. There was no number mismatch effect for conditions with a plural head noun, β's $\leq .69$, SE's $\leq .39$, z's ≤ 1.78, p's $\geq .07$.

4.5 Discussion

The results of the production task showed an effect of both linear and syntactic distance in conditions with singular head nouns. That is, S-V agreement accuracy was reduced for the SPS, SSP and SPP conditions compared to SSS. There was no effect of number mismatch for plural heads.

The results support the previously reported *plural attraction* in production. It appears that the operations for comprehension and production of S-V agreement differ and the discrepancies observed between production and comprehension studies genuinely reflect a *reversed mismatch asymmetry* (i.e., *singular attraction*) in comprehension. Wagers et al. (2009) note that comprehension and production processes must be guided by the same mechanisms, but we disagree. Using the materials previously used in a production study (Franck et al., 2002) in a simpler methodology that would not be challenging on working memory resources we not only *confirmed plural attraction* in production but we also confirmed, with the same materials, *singular attraction* for comprehension (Pearlmutter, 2000). We entertain, in General Discussion in further detail, the idea that in speech production, when there are more features to be encoded in memory such as [+plural], speech planning overlaps for the NPs and the verb; and overlaps in planning cause more interference resulting in *plural attraction* in production. For comprehension data, we concur with Pearlmutter (2000) and maintain that the plural feature of the head NP in existence of singular attractors weakens in a relatively long complex subject with two intervening NPs.

5 Sentence completion task

The last experiment employed a pen-and-paper gap-filling sentence completion task. This task was conducted mainly to examine the participants' general

sensitivity to English S-V agreement rules in an untimed task. But it was also possible that the number feature of the intervening nouns could affect the agreement feature of the verb in an off-line pen-and-paper task. Thus, the data were also analyzed to examine the participants' off-line sensitivity to attraction in S-V agreement in English.

5.1 Materials

The materials were the same as in Experiment 2. The participants' task was to choose the singular or plural form of the verb, which were given as options below the sentence, to complete the sentence.

Since it was an off-line pen-and-paper decision task, the participants could always go back and revise their decisions. Thus, the results were mainly examined with respect to the participants' accuracy. But it is also likely that the participants' decisions could be affected by the number feature of the intervening nouns as in Experiments 1 and 2 as there was no reason for the participants to go back and consciously evaluate their answers unless they preferred to do so. Thus, the participants' sentence completion choices could also be affected by the number feature of the intervening nouns. In that case, the predictions and the results would be similar to those in Experiments 1 or 2. Given the findings in Experiments 1 and 2, it is likely that the participants' sentence completion decisions would be affected more by the syntactically closer noun's number feature and show plural attraction.

The number of experimental sentences and lists were the same as in previous experiments. There were 32 filler sentences including ambiguous constructions in English. There were no practice or warm-up sentences. Each list consisted of 64 sentences in total.

5.2 Data Analysis

The analyses were run on the participants' accuracy in the sentence completion choices. The methods used for the analyses and the random and fixed effects were the same as in Experiment 2.

5.3 Results

The participants had a very high overall accuracy ($M_{overall}$ = 96.8%; singular head noun: M = 94.1%, plural head noun: M = 95.2%). Table 2 shows their accuracy for specific conditions.

Table 2. Mean percent accuracies in the pen-and-paper task.

Conditions	Accuracy	Conditions	Accuracy
SSS	96.9	PPP	95
SSP	96.9	PPS	94.4
SPS	89.4	PSP	96.2
SPP	93.1	PSS	95

Similar model building steps as in Experiments 1 and 2 were administered. In singular head conditions, the SPS condition had lower accuracy than the baseline, $\beta = -2.15$, $SE = .74$, $z = -2.91$, $p < .01$; the other conditions were not significantly different from the baseline, β's ≤ 1.17, SE's $\leq .72$, z's ≤ 1.63, p's $\geq .10$. There was no effect of number mismatch in accuracy for plural head conditions, β's $\leq .53$, SE's $\leq .72$, z's $\leq .73$, p's $\geq .46$.

5.4 Discussion

The participants were highly accurate in their sentence completions. The accuracy decreased when the number feature of the noun that is syntactically closer to the head noun mismatched with the head noun, confirming the results in Experiment 1 and 2. This was only the case for the singular head conditions, as in Experiment 2, confirming the plural attraction in offline measures (Eberhard, 1997).

6 General Discussion

Previous research examined S-V agreement mostly in production (e.g., Bock & Miller, 1991; Bock & Cutting, 1992; Bock & Eberhard, 1993; Bock, 1995) but also in comprehension (Pearlmutter, 2000; Wagers et al. 2009). Although there is consensus that the number mismatches in a complex subject NP between the head noun and its PP modifiers affect S-V agreement computation, it has been argued that there is a mismatch asymmetry which is the observation that when the attractors are plural, they cause more S-V agreement errors. One comprehension study, by Pearlmutter (2000), which examined complex subject NPs with PPs showed a reversed mismatch asymmetry, i.e., *singular attraction*. The present study examined whether or not the reversed mismatch asymmetry was a consequence of different comprehension and production processes or was a reflection of design differences across comprehension and production studies (i.e., one or two PPs in complex subject NP). We took sentence preambles from a previous production study (Franck et al., 2002) who reported both plural and singular attraction in production and tested S-V agreement in both production and comprehension using those preambles. Our production task was simpler than

Franck et al.'s such that it would be less demanding on working memory resources. The preambles were like Pearlmutter's in that they contained complex subjects with three NPs such as *the e-mail(s) from the secretary(s) of the manager(s)*. The results confirmed the findings in previous research: there was *plural attraction* in production and *singular attraction* in comprehension. Thus, it appears that *the mismatch asymmetry* and *the reversed mismatch asymmetry* are genuine effects attributable to the mechanisms employed in production and comprehension of S-V agreement but not to the experimental items in the previous studies.

Gillespie and Pearlmutter (2011b) argue that interference from intervening NPs in S-V agreement can be affected by the extent of advance planning in language production. That is, "[i]f the scope of advance planning at a given level is large, multiple items are likely to be simultaneously available, which increases the chance of interference and certain speech errors (Garrett, 1975)" (p. 1615). In their studies Solomon and Pearlmutter (2004) and Gillespie and Pearlmutter (2011a) found that NPs that require semantic integration to the context such as *the pizza with the yummy topping* elicited larger mismatch effects than NPs that did not require semantic integration such as *the pizza with the beverage*. The results, alongside an NP attraction local to the head noun, were taken to support the argument that overlap in planning leads to increased mismatch effects. Local nouns (such as the N2 in the present study) planned overlappingly with the head noun are more likely to interfere with agreement computation. In the case of *plural attraction* in production (as opposed to *singular attraction* in comprehension), it is possible that the cognitive resources necessary to plan for intervening NPs that have a marked [+plural] feature would be higher due to enhanced memory encoding and hence their planning would be more likely to overlap with that of the head noun. But in comprehension, the input is processed as it is received, alongside some prediction for the upcoming items (Altmann & Mirkovic, 2009). Thus, it is possible that the differences across the comprehension and production experiments for singular and plural attraction are due to the processes required for processing or planning for S-V agreement. For singular attraction in comprehension, we concur with Pearlmutter (2000) and maintain that the plural feature of the head NP in existence of singular attractors weakens in a relatively long complex subject with two intervening NPs.

There was an overall effect of the NP syntactically closer to the head noun, in both production and comprehension regardless of the direction of the mismatch asymmetry. Although it is possible to attribute this effect to feature percolation through syntactic hierarchy, given the overall difference between production and comprehension and Wager et al.'s (2009) evidence against feature percolation, we believe that the syntactically closer NP's effect on

agreement attraction is due to its memory retrieval/encoding. That is, it is possible that in comprehension the cues associated with the NP syntactically closer to the head noun (i.e., syntactically less embedded noun) are more readily available to retrieve than those associated with the NP linearly closer to the verb (i.e., syntactically more embedded noun). This would be in line with previous findings showing that syntactic cues may be weighted more heavily than non-syntactic cues in accessing items in memory (e.g., Van Dyke & McElree, 2011). Alternatively, while encoding the number feature of the head noun, the features of the NP that is syntactically and linearly closer to the head (i.e., N2) would be simultaneously active in memory and could therefore have intervened more than the NP that is syntactically and linearly distant to the head (i.e., N3) when S-V agreement is computed (Gillespie & Pearlmutter, 2011b). In production, as Gillespie and Pearlmutter (2011b) argue, agreement attraction could be more likely when there is a mismatching NP local to the head noun (i.e., N2) whose planning overlaps with that of the head noun. Due to the overlap in their planning, both NPs' numbers would be active at the time of the number marking of the subject.

Finally, the attraction effects occurred in grammatical sentences in our study. This is in line with most previous studies (e.g., Nicol et al., 1997; Pearlmutter et al., 1999; Pearlmutter, 2000; Häussler & Bader, 2009) except for the findings in some studies such as Wagers et al. (2009 see Hammerly, et al., 2019 for a review). Wagers et al. found attraction effects in ungrammatical sentences but not in grammatical sentences. They argue that this is due to the incorrect retrievals of target items from memory either in initial stage or during reanalysis. They suggest that in the initial stage a partially matching NP is (almost) never retrieved if a fully matching NP is present as the fully matching NP would out-compete partially matching NPs (p. 230). Or the system would rule out weak cues such as [Category: NP] and rely on stronger cues such as number. In the reanalysis stage, in ungrammatical sentences, the mechanism might erroneously retrieve partially matching NPs. This would not be the case in grammatical sentences as there would be no need for rechecking. Number attraction effects were observed in grammatical sentences in the present study. This can be taken as evidence that a partially matching NP, i.e., the attractor, can be retrieved as a potential subject upon processing the verb, even in the presence of a fully matching NP. This is predicted in the cue-based memory retrieval account (Lewis & Vasishth, 2005; Lewis et al., 2006), specifically under the notion of inhibitory interference. This would be predicted in the cue-based memory retrieval account (Lewis & Vasishth, 2005; Lewis et al., 2006) if misretrievals of feature-matching attractors are assumed (Jäger et al., 2015). This would also account for the slow-down in RTs in mismatching conditions or the speed-up in RTs in the matching conditions where misretrievals would

be faster than correct retrievals. It is also possible that attraction in grammatical sentences is due to a graded or continuous encoding of the number feature of the head noun in mismatch conditions (Hammerly, et al., 2019).

7 Conclusion

This study investigated the comprehension and production of S-V agreement by English speakers. A self-paced reading study, a read-aloud task and a sentence completion task employed complex subjects with three NPs such as *the email from the secretary of the manager*. The results showed evidence for a mismatch asymmetry in English S-V agreement in production and a reversed mismatch asymmetry in comprehension. That is, whereas plural attractor nouns were more likely to cause agreement errors in production, singular attractors led to processing difficulty in comprehension. This may be due to the weakening of the plural number feature of head nouns in comprehension and a higher cognitive demand with plural attractors in planning production. In both production and comprehension, agreement attraction was due to attractor nouns syntactically closer to the head noun. We attribute this to the syntactically closer noun's features being more readily available during memory retrieval/encoding.

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Ethical Approval/Participant Consent: All procedures were in accordance with the ethical standards of the Institutional Review Board in Social Sciences and Humanities

(INAREK) at Boğaziçi University, Istanbul, Turkey (protocol number: 2014/65). Informed consent was obtained from all individual participants included in the study.
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APPENDIX

Experimental stimuli (in SSS conditions) in Experiment 1, adapted from Franck et al. (2002)

1. The e-mail from the secretary of the manager was confidential.
2. The announcement by the director of the foundation was important.
3. The article by the writer for the magazine was informative.
4. The author of the speech about the city was famous.
5. The computer with the program for the experiment was new.
6. The contract for the actor in the film was detailed.
7. The discussion about the topic of the paper was subjective.
8. The dog on the path around the lake was playful.
9. The friend of the editor of the magazine was friendly.
10. The gift for the daughter of the visitor was expensive.
11. The helicopter for the flight over the canyon was big.
12. The lesson about the government of the country was boring.
13. The letter from the friend of my cousin was short.
14. The manual by the developer of the machine was detailed.
15. The mast on the deck of the yacht was damaged.
16. The meal for the guest of the inn-keeper was delicious.
17. The museum with the picture of the poet was interesting.
18. The design for the engine of the plane was new.
19. The payment for the service to the school was late.
20. The photo of the girl with the baby was beautiful.
21. The post in the support for the platform was long.
22. The prescription by the doctor from the clinic was lost.
23. The producer of the movie about the artist was famous.
24. The publisher of the book about the king was well-known.
25. The setting for the movie about the astronomer was impressive.
26. The statue in the garden near the mansion was fascinating.
27. The switch for the light on the stairway was rusty.
28. The telegram to the friend of the soldier was short.
29. The threat to the president of the company was serious.
30. The tour of the museum near the monument was long.
31. The train to the city near the lake was comfortable.
32. The truck on the bridge over the stream was old.