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Villata, Sandra; Franck, Julie

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Similarity-based Interference in Agreement Comprehension and Production: Evidence from Object Agreement

Sandra Villata and Julie Franck

University of Geneva

Author Note

Sandra Villata, Department of Psychology, Laboratory of Psycholinguistics, University of Geneva; Julie Franck, Department of Psychology, Laboratory of Psycholinguistics, University of Geneva.

Sandra Villata is now at Department of Linguistics and Department of Psychology, University of Connecticut.

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Correspondence concerning this article should be addressed to Sandra Villata, Department of Linguistics, University of Connecticut, Storrs, CT 06268.
E-mail: sandravillata@gmail.com

Abstract

Studies on agreement production consistently report an increase in production errors in the presence of an attractor mismatching the agreement feature of the target. In contrast, results from comprehension studies are mixed, ranging from lack of effect to facilitation. We report two forced-choice experiments and two self-paced reading experiments on number and gender object-verb agreement in French in order to systematically explore the effect of a mismatching subject in the production and comprehension of object relatives. Results show that the presence of a mismatching subject penalizes sentence production, in line with reports of attraction, but consistently improves sentence comprehension in off-line comprehension measures, in line with similarity-based interference effects. We discuss the limits of classical models of sentence production and comprehension (Marking and Morphing and ACT-R), and favor a self-organizing sentence processing approach (SOSP), which accounts for both production and comprehension results through a single similarity-based mechanism of structure building.

Keywords: agreement; encoding; cue-based retrieval; comprehension; production; Marking and Morphing, ACT-R; self-organized sentence processing

Similarity-based Interference in Agreement Comprehension and Production: Evidence from Object Agreement

Since the seminal work of Bock and Miller (1991) on agreement production, it has been shown that an intervening element whose features mismatch those of the agreement controller can "attract" agreement, imposing its feature on the verb. These a*ttraction errors* are typically caused by a noun modifying the subject head (e.g., **The key to the cabinets are rusty*), but they may also be caused by a preverbal object (e.g., **The cabinets that the key open are on the second floor*) (see also Franck, Lassi, Frauenfelder, & Rizzi, 2006; Franck, Soare, Frauenfelder, & Rizzi, 2010). Whether and how the presence of an agreement feature mismatching the agreement controller also affects sentence comprehension is less clear. Although an effect is commonly reported in sentences with ungrammatical agreement dependencies, taking the form of an illusion of grammaticality (with faster reaction times for ungrammatical sentences with an attractor matching the number feature of the verb relative to ungrammatical sentences in which neither the attractor nor the controller match the number feature of the verb), most experiments have failed to show attraction effects in grammatical sentences (Dillon, Mishler, Sloggett, & Phillips, 2013; Lago, Shalom, Sigman, Lau, & Phillips, 2015; Shen, Staub, & Sanders, 2013; Tanner, Nicol, & Brehm, 2014; Tucker, Idrissi, & Almeida, 2015; Wagers, Lau, & Phillips, 2009; see Jäger, Engelmann, & Vasishth 2017 for a meta-analysis). Nevertheless, significant effects have occasionally been reported with grammatical sentences in both adults and children (children: Adani, Van der Lely, Forgiarini, & Guasti 2010; Belletti, Friedmann, Brunato, & Rizzi, 2012; adults: Acuña–Fariña, Meseguer, & Carreiras, 2014; Franck, Colonna, & Rizzi, 2015; Nicenboim, Vasishth, Engelmann, & Suckow, 2018; Villata, Tabor, & Franck, 2018). The source of this variability across data sets is unclear; it could be due to differences in the methods, the language, the

populations, the features or the attractor type. Here, we present data on the effect of number and gender mismatch in both sentence comprehension and sentence production of grammatical sentences, collected on the same material and the same participants in order to have a solid empirical basis for theoretical elaboration.

From a theoretical standpoint, attraction effects in production and comprehension have traditionally received different explanations. While attraction effects in production have for the most part been accounted for by the Marking and Morphing model (M&M; e.g., Bock, Eberhard, Cutting, Meyer, & Schriefers, 2001) in terms of feature contamination of the verb by an element that is not the agreement controller, effects of agreement mismatch in comprehension have been conceived as instances of similarity-based interference during the retrieval or encoding of elements in memory, ultimately to be accounted for by models such as ACT-R (e.g., Lewis & Vasishth, 2005). Here, we propose a unified account for attraction effects through a self-organized sentence processing model (SOSP; Smith & Tabor, 2018; Smith, Franck & Tabor, 2018; Tabor & Hutchins, 2004; Villata et al., 2018), which views effects in both production and comprehension as deriving from the continuous interaction and competition of sentential elements during structure building.

The paper is structured as follows. We first briefly summarize the literature on agreement in sentence production and comprehension, and then report four experiments testing attraction in an agreement dependency that has seldom been studied: object-past participle agreement. In French, the past participle agrees in number and gender with the preverbal object, which allowed us to explore the effect of mismatch in these two features on the same agreement dependency. Experiments 1 and 2 explore the role of number and gender mismatch in production using a two-choice response time paradigm, which has been shown to successfully replicate observations collected with the classical sentence completion procedure (Staub, 2009, 2010). Experiments 3 and 4 explore the role of number and gender

in comprehension through a self-paced reading procedure followed by a sentence comprehension task. To anticipate the results, we report evidence for a penalizing effect of mismatch in production, for both gender and number, and a facilitatory effect in comprehension, manifest in off-line accuracy and, to a lesser extent, in online measures of self-paced reading. We argue that the standard agreement production model of Marking and Morphing and the ACT-R approach to sentence comprehension are insufficient to account for the data at hand. In contrast, the self-organized parsing approach provides a natural account for both production and comprehension data through a single mechanism of structure building.

Mismatch Effects in Production and Comprehension

The literature on attraction in sentence production has highlighted three main characteristics. First, attraction is modulated by semantic factors. The most studied semantic influence comes from the notional representation of subject's number (e.g., grammatically singular but notionally plural nouns generate more plural verbs than notionally singular nouns; see Bock, Eberhard, & Cutting, 2004; Eberhard 1999; Haskell & MacDonald, 2003; Vigliocco, Butterworth, & Garrett, 1996). Second, attraction is stronger for plural attractors than for singular ones (e.g., Bock & Miller, 1991; Eberhard 1997; Hartsuiker, Schriefers, Bock, & Kikstra, 2003; Vigliocco, Butterworth, & Semenza, 1995). Third, attraction is modulated by the hierarchical position of the attractor, more than by its linear position. An attractor in sentence-initial position, before the subject and the verb, triggers similar or even stronger attraction than one intervening linearly between the subject and the verb (in questions: Vigliocco & Nicol, 1998; in object relatives: Bock & Miller, 1991; Franck et al., 2006; Franck et al., 2010; Franck et al., 2015). Also, an attractor situated hierarchically closer to the verb prompts more errors than one that is linearly closer to the verb (Franck, Vigliocco & Nicol, 2002).

Attraction effects in production have traditionally been accounted for by the M&M model (e.g., Bock et al., 2001; Eberhard, Cutting, & Bock, 2005). According to this model, number assignment is the result of two processes that apply successively: *Marking*, which is responsible for translating the notional number into a syntactically interpretable feature, and *Morphing*, a morphosyntactic process that reconciles the syntactic feature selected during Marking with the nouns' featural morphosyntactic specifications coming from the lexicon. According to this model, attraction effects are the result of feature contamination (*percolation*) within a complex noun phrase (Eberhard, Cutting, & Bock, 2005; Eberhard, 1997). In M&M, the number values of words are represented on a scale from 1 (unambiguously plural) to -1 (unambiguously singular). All elements in the subject node contribute to the subject's number valuation. On this view, if a local noun in the subject phrase has a number feature mismatching the subject head, this enters into the feature calculation and might shift the subject's number value on a continuum from 1- to 1, leading to attraction errors (see Staub, 2009 for a discussion). Percolation explains why a feature more deeply embedded in the tree has a weaker attraction power than one less deeply embedded, since the percolation path is longer in the former than in the latter case (e.g., Bock & Cutting, 1992; Nicol, Barss, & Barker, 2016; Franck, Vigliocco, & Nicol, 2002), and why plural attractors generate more attraction errors than singular ones, since only marked features have the potential to percolate.

In sentence comprehension, the corresponding effect of attraction effects in production usually manifests as an illusion of grammaticality in ungrammatical sentences: the presence of a mismatching attractor appears to reduce the chance that an agreement error is detected. The effect manifests as reduced reading times at the regions following the critical verb and increased acceptability rates as compared to the condition in which neither the controller nor the target match the number feature of the verb. This effect has been reported

both for simple sentences with a prepositional phrase (PP) modifier (Pearlmutter, Garnsey, & Bock, 1999; Wagers et al., 2009; see Shen et al., 2013 and Tanner et al., 2014 for ERP evidence), for object relative clauses (ORs) (Lago et al., 2015; Tucker et al., 2015; Wagers et al., 2009) and subject relative clauses (SRs) (Dillon et al. 2013) (Jäger et al., 2017 for a meta-analysis). Interestingly, these studies failed to find significant attraction effects in grammatical sentences. Wagers et al. (2009) and much related work have argued that the *grammatical-ungrammatical asymmetry* is due to the involvement of a cue-based retrieval mechanism of agreement checking triggered when an agreement error is detected. If the parser finds an element that matches the number feature on the verb (as it is the case in mismatch conditions), this may occasionally satisfy the agreement checking process, even though that element fails to match other features (like the fact that it does not have the feature [+Head]). This partial match of features between the verb and the attractor noun may thus cause an illusion of grammaticality, allowing the parser to proceed faster than when no element matches the number feature on the verb (as it is the case in match conditions). Hence, attraction effects in comprehension have been traditionally conceived of as the result of similarity-based interference, thus receiving a different explanation from that of attraction errors in production. However, this claim concerning grammatical sentences is surprising given the vast literature showing that retrieval is actually sensitive to similarity-based interference when the target fully matches the retrieval cues. Indeed, all of that literature on cue-based retrieval is based on grammatical sentences (e.g., Gordon, Hendrick, & Johnson, 2001; Gordon, Hendrick, & Levine, 2002; Gordon, Hendrick, & Johnson, 2004; Lewis & Vasishth, 2005; McElree, 2000; McElree, Foraker, & Dyer, 2003; Van Dyke & McElree, 2006, 2011; Van Dyke, 2007). One may thus expect similarity in terms of agreement cues to also generate difficulties in sentence comprehension. Engelmann, Jäger & Vasishth (submitted) suggest that agreement features contrast with the semantic/structural features

manipulated in these other studies in that they fail to provide relevant cues to the retrieval mechanism that is assumed to underlie similarity-based interference effects (see Jäger et al., 2017 for similar conclusions). However, this conclusion does not take into account a variety of sentence-picture matching studies with children attesting to penalty due to agreement feature match in the comprehension of grammatical sentences. For example, Adani et al. (2010) observed that the comprehension of ORs is worse in English and Italian speaking children when the object and the subject match in number or gender. Similarly, Belletti et al. (2012) observed that Hebrew children show poorer comprehension of ORs when the object and the subject match in gender. Interestingly, a few studies on adults also attested to similarity-based interference due to agreement feature match in ORs' processing in French speakers (Franck et al., 2015), as well as English and Italian speakers (Villata et al., 2018; see also Patson & Husband (2016) for evidence of misinterpretation due to attraction in adults in simple sentences involving a PP modifier). What characterizes this set of studies showing significant penalty due to feature match in the comprehension of grammatical sentences is that they all involve offline measures of comprehension accuracy, while studies showing null effects or small effects all involve on-line reading times (to the exception of Franck et al., 2015).

The significant penalty of feature match observed in children' and adults' comprehension of grammatical sentences finds a natural explanation if the parser is making use of agreement cues to build the structure, in line with cue-based approaches to sentence processing (e.g., Van Dyke & Lewis, 2003; Van Dyke & McElree, 2006; Van Dyke, 2007; Van Dyke & McElree, 2011). However, Villata et al. (2018) also highlighted the key role played by encoding interference in the resolution of long-distance dependencies. In two self-paced reading studies accompanied with a sentence comprehension task targeting thematic roles' attribution in Italian and English ORs, the authors manipulated (i) gender in Italian,

which is expressed on both noun phrases but not on the verb (e.g., *Il ballerino-MASC che la cameriera-FEM ha criticato-Ø …* - *The dancer that the waiter has criticized-Ø…*), and (ii) number in English, which is expressed on the noun phrases and on the verb when it is at the present tense form, but not when it is at the past tense form (e.g., *The dancers-PL that the waiter-SG criticizes-SG/has criticized-Ø…*). They reasoned that if similarity-based interference uniquely lies at retrieval, a facilitatory mismatch effect should be observed in the English present tense condition only; if similarity-based interference uniquely lay at encoding, a facilitatory mismatch effect should be observed across the board; if similarity-based interference lay both at encoding and retrieval, a stronger facilitatory mismatch effect should be observed in the English present tense condition as compared to the English past tense condition and Italian. Villata et al. observed higher comprehension accuracy rates for mismatch than match conditions for both the present and the past tense conditions, and weak evidence for such an effect was observed online, as the effect was only detected when longer reading times (up to 8000 ms) were included in the analyses. Since a facilitatory mismatch effect was found independently of the presence of an agreement cue on the verb, this speaks in favor of an interference effect arising at encoding. However, the facilitatory effect of number mismatch was slightly increased when the verb carried an agreement feature (English present tense condition) than when it did not (English past tense condition). The authors concluded that both encoding and retrieval interference are at play in the comprehension of agreement dependencies, although the role of the former seems to be greater than the latter. They argued that encoding interference could be accounted for by two different mechanisms. One mechanism is *activation leveling* in ACT-R, a parsing mechanism that renders the activation of elements sharing a feature more equal. It offers a mechanism for *feature overwriting*, which is assumed to be responsible for encoding interference: two elements sharing a feature enter in a competition and the element losing it results in a degraded

memory representation (Nairne, 1990; Oberauer & Kliegl, 2006). SOSP accounts for encoding interference through an independently motivated mechanism of structure building in which similar elements compete more strongly for attachment, thus leading to longer reading times and lower comprehension accuracy. We will return to these hypotheses in the General Discussion.

Summarizing, there seems to be a striking contrast between results from production studies, showing a mismatch penalty, and those from comprehension studies, showing facilitation due to mismatch. Moreover, results for the comprehension of grammatical sentences are mixed: most of the studies fail to attest to a mismatch effect, contra what is usually observed in non-agreement dependencies, while only a subset of studies report it. At present, it is unclear whether the variability in the data is due to differences in the methods (self-paced reading, maze task, sentence classification, eye-tracking, event-related potential, sentence picture matching, comprehension questions), the language (English, French, Spanish, Hebrew, Italian), the populations (children or adults), the features (number or gender) or the attractor type (subject modifiers or displaced objects). It is thus important to collect maximally comparable data in production and comprehension (i.e., same sentences, same language, same participants) to provide a solid basis for theoretical elaboration.

Current Study

The current study aims at systematizing empirical evidence about attraction in production and comprehension. The agreement dependency under study is past participle agreement with the object in object relative clauses in French. In French, when the object moves pre-verbally, as it does under generally accepted analyses of ORs (e.g., Chomsky 1977), the past participle agrees in number and gender with the object (as in (1)), allowing us to explore attraction in both gender and number. This contrasts with SRs, which do not involve object movement. In this case, the past participle remains in its singular, masculine

default form and the auxiliary involves subject-verb number agreement (as in (2)). Although object agreement respects fundamental properties of natural syntax (e.g., it is established in a Spec-Head relation inside an agreement projection; Bošković, 1997; Kayne, 1989; see Belletti, 2006 for a discussion), it is optional in colloquial French, where the past participle is often produced in its default singular, masculine form.

(1) Les danseuses que le serveur a surprises buvaient un cocktail.

The dancers-P,F that the waiter-S,M has-S surprised-P,F drank-P a cocktail

(2) Les serveuses qui ont surpris le danseur buvaient un cocktail.

The waitresses-P,F who have-P surprised-S,M the dancer-S,M drank-P a cocktail

Hence, the test case involves subject interference in an object agreement dependency, following Santesteban, Pickering, & Branigan (2013) who reported significant attraction from the subject in the production of object-verb agreement in Basque. These authors reported both object interference in subject agreement and subject interference in object agreement in canonical SVO sentences and in non-canonical OSV sentences with object topicalization. More errors were generally found in OSV sentences. However, the rate of object-verb agreement errors did not significantly differ from that of subject-verb agreement errors, which led the authors conclude that similar mechanisms were at play in the two dependencies.

We explored the role of feature mismatch in object agreement in both production and comprehension on the same participants and with the same materials, in order to have maximally comparable data sets. Experiments 1 and 2 tested production. Experiment 1 manipulates number mismatch, keeping gender constant (masculine), while Experiment 2 manipulates gender mismatch, keeping number constant (singular). A forced-choice response time paradigm with a Rapid Serial Visual Presentation (RSVP) procedure was used in which sentences are rapidly and automatically presented word by word on a computer

screen and participants are asked to select the verb form that correctly completes the sentence (Staub, 2009, 2010). Although this paradigm involves an initial component of comprehension (which is also present to some extent in the standard elicitation paradigm), this task has been shown to replicate the classical findings obtained with standard production techniques, namely mismatch effects, markedness effects, syntactic position effects and notional effects (Franck et al., 2015; Staub, 2009, 2010).

Experiments 3 and 4 tested comprehension: Experiment 3 manipulated number mismatch and Experiment 4 manipulated gender mismatch. We used a self-paced reading procedure followed by a sentence comprehension task. We restricted our investigation to grammatical sentences only in order to avoid any possible influence from the presence of ungrammatical sentences that could reduce cue reliability (see Acuña–Fariña et al., 2014). The same participants took part in Experiments 1 and 3 and another set of participants took part in Experiments 2 and 4, in order to have maximally comparable data for production and comprehension. The comprehension experiment was always presented first so that it would not be contaminated by the explicit attention drawn to agreement in the production task.

In production, if the same mechanism that underlies subject agreement is at play in object agreement, we expect more attraction errors and slower reaction times in conditions in which the object and the subject mismatch in gender or number than when they match. We will argue that the mechanism of feature percolation assumed by M&M is unable to account for subject interference in object agreement production without positing additional assumptions for when the attractor is outside the controller's node. In comprehension, if parsing is sensitive to similarity-based interference for sentences involving object-past participle number or gender agreement, as in object relative clauses, then we expect match conditions in ORs to generate longer reading times at the critical past participle region and higher error rates in comprehension questions, a distribution that is reversed to the one found

in production. No effect is expected in SRs, since here the object is in its canonical position and therefore no retrieval operation is expected to arise. In the experiment testing for number agreement (Experiment 3), the relative clause's subject and the relative verb agree in number, an agreement configuration that is not avoidable in French (e.g., *Le danseur que* ***les serveurs disaient*** *avoir souvent énervé buvait un cocktail alcoolisé – The dancer-S that* ***the waiters-P claimed-P*** *to have often annoyed-S drank-S a cocktail with alcohol*). However, since the verb is adjacent to the subject, the latter is expected to be in the current focus of attention, thus rendering any retrieval operation unnecessary (see McElree & Dosher, 1989; McElree, 2006). As a result, no similarity-based interference effect is expected to arise at this region.

In recent years, an interesting debate developed about the locus of the similarity-based interference effects reported in the literature. Although it has commonly been assumed that these effects arise during the cue-based retrieval of a distant element, most of the data reported are actually also compatible with the hypothesis that the effects take place during the encoding of the sentence in memory, or both at retrieval and at encoding (see Jäger et al., 2015 and Villata et al., 2018). In order to gain insight about the precise locus of the expected effect, we tested both object and subject relative clauses. In SRs, the object remains in its canonical post-verbal position, and no object retrieval is expected. Therefore, if the expected feature mismatch effect in ORs lies in the cue-based mechanism of object retrieval, no effect is expected to arise in SRs. If similarity-based interference arises at encoding, an effect is expected both in ORs and in SRs, taking the form of longer reading times when the second noun phrase is encountered in match conditions as compared to mismatch ones (see Van Dyke & McElree, 2006). Here also, the standard model, ACT-R, would need additional assumptions to account encoding effects, along the lines suggested by Villata et al. (2018). In the General discussion, we will argue that both attraction errors in production and

similarity-based interference effects in comprehension arise from a single principle of self-organization in structure building.

Experiment 1: Number Agreement in Production

Method

Participants. Sixty-five undergraduates' students at the University of Geneva participated in this experiment for course credits (ages generally in 18-24 years)[1]. Participants were all native French speakers and naïve with regard to the purpose of the experiment. The experiment was approved by the ethics committee of the University of Geneva and informed consent was obtained from all participants.

We estimated a priori the number of participants needed to achieve power of 90% using the power.t.test function in R, following Jäger et al. (2015). Since the same participants who took part in Experiment 1 (production) also took part in Experiment 3 (comprehension), and since we know that match effects are more difficult to detect in comprehension (we studied grammatical sentences), we calculated the sample size needed for the comprehension study. On the basis of the existing literature, we assumed a match effect of 30 ms and a standard deviation of 75 ms.[2] The statistical power test determined that sixty-seven participants were needed. The actual sample size of our study was slightly smaller, resulting in a statistical power of 89%.

Materials and design. Thirty-two sets of four conditions each were used in a 2x2 factorial design, manipulating the number of the object (singular vs. plural) and the number match between the subject and the object (match, i.e., the subject and the object have the same number vs. mismatch, i.e., the subject and the object have a different number). Participants were asked to choose between two past participle forms (singular vs. plural) to complete the sentence. The dependent variables are therefore the proportion of correct responses and the reaction times associated with the response.

Only ORs were tested and they were introduced by a deictic presentative (*voilà*) to make them verb-final. The noun phrases were always animate and masculine. Only nouns forming the plural regularly by adding the morpheme –s were used, which is orthographically present but not realized phonologically. Since in French ORs the auxiliary agrees in number with the subject and the past participle agrees in number (and gender) with the object, we embedded the past participle in an infinitival clause in which the auxiliary was in the infinitive form, in order to avoid influences from the number of the auxiliary. All sentences were reversible, so that the subject and the object were both as likely to be the agent or the patient of the verb (e.g., Caramazza & Zurif, 1976; Garraffa & Grillo, 2008; Stavrakaki, 2001). Reversibility was assessed through informal judgements from three French-speakers who did not take part in the experiment. Example test items are presented in Table 1.

Given that the same participants took part in both the production and the comprehension study and that the comprehension study had 8 conditions (see Experiments 3 and 4), the experimental lists were created based on the comprehension study. Hence, 8 lists were created so that each participant was presented with 16 experimental sentences (one experimental sentence per item) and 24 fillers. Fillers consisted of ORs in which the two response options differed in subtle orthographical errors (e.g., presence or absence of accent, typos, homophony) in order to maximize the chances that participants focus on subtle contrasts as is the case for the experimental contrast.

Procedure. A forced-choice response time paradigm with rapid serial visual presentation procedure (RSVP) was used, following Staub (2009, 2010). Materials were presented on a computer screen using the E-prime software (Schneider, Eschman, & Zuccolotto, 2012). Sentences were presented segment by segment (content word plus a grammatical word when present) at a fast pace. To initiate the trial, the participant pressed the spacebar. Then a fixation cross was presented on the screen for 1 second followed by a

blank screen (150 ms). The segments were then presented one by one at the center of the screen for 250 ms each with a 150 ms inter-stimulus interval. After the final inter-stimulus interval, the two past participle forms were presented on either side of the screen and participants were asked to select the past participle form that would provide the grammatical continuation of the sentence by pressing one of the two allowed keys on the keyboard. For a random half of the items the correct response was on the left side of the screen, and for the other half it was on the right (Staub, 2010). There was no response deadline in order to avoid a possible trade-off between speed and accuracy. Instructions encouraged answering as quickly as possible. Once participants pressed the key, the next trial began. Participants had a one minute break in the middle of the experiment. The whole session lasted about 10 minutes.

Results

Data analyses. A mixed-effects logistic regression was fit to the accuracy data and a linear mixed-effects model to the response times data, with random intercepts for participants and items using the lme4 package in R (R Development Core Team, 2016; Bates, Maechler, Bolker, Walker, Christensen, Singmann, & Grothendieck, 2015). The final model included as fixed factors: the number of the object, the number match between the subject and the object and the interaction between the number of the object and number match. Raw response times greater than 4000 ms or less than 100 ms were removed prior to statistical analyses (affecting less than 2% of the data). No additional outlier removal process was performed. Response times were analyzed on trials for which participants gave a correct answer and then log-transformed to normalize residuals. The random-effects structure always had the same specification as our fixed effects (e.g., if testing for the interaction, the random structure contained the interaction). Correlations between random effects were not estimated since they often cause the model with maximal random slopes to fail to converge.

Our analyses are therefore conservative with respect to the generalizability of the effects of theoretical interest to new participants and items (Barr, Levy, Scheepers, & Tily, 2013). P-values were calculated by way of the Satterthwaites's approximation to degrees of freedom with the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2016). The variable number of the object was coded as 1 if the object was plural, and the number match was coded as 1 if the number of the object and the subject matched. For accuracy analyses, correct responses were coded as 1 and as 0 when incorrect.

Accuracy. Figure 1 illustrates the distribution of accuracy proportions. Results showed a main effect of number match ($\widehat{\beta}$ = 0.793, z = 6.096, p < .001), with higher accuracy for match (M = 0.82) than mismatch conditions (M = 0.62). Results also showed a main effect of the number of the object ($\widehat{\beta}$ = -1.135, z = -6. 865, p < .001), attesting to overall higher accuracy for singular objects (M = 0.86) than for plural objects (M = 0.57). Finally, results showed a significant interaction ($\widehat{\beta}$ = -0.241, z = -2.161, p = 0.031), which revealed that number match has a stronger effect for singular objects ($\widehat{\beta}$ = -0.969, z = -3.781, p < 0.001; M = 0.77 in SP vs. M = 0.95 in SS, which corresponds to a difference in logits of 1. 73) than for plural objects ($\widehat{\beta}$ = -0.697, z = -4.546, p < 0.001; M = 0.46 in PS condition vs. M = 0.68 in PP condition, which corresponds to a difference in logits of .91).[3] The accuracy for fillers was 61%.

Response times. Figure 2 illustrates the distribution of responses times. Analyses revealed a main effect of number match ($\widehat{\beta}$ = -0.123, t = -6.750, p < .001), with longer response times for mismatch conditions (M = 2449 ms) than match conditions (M = 1879 ms). No other significant effect was found. Analyses conducted on incorrect trials revealed no significant effect.

Discussion

Experiment 1 showed that number mismatch negatively affects agreement production accuracy, participants being less accurate in producing past participle agreement in the presence of an intervening subject mismatching the number of the object than in the presence of an intervening subject matching the number of the object. These results replicate, in a new language, the finding of the study in Basque showing attraction effects from the subject on object-verb agreement computation (Santesteban et al., 2013). Subject interference is high: above 20%, as estimated by the difference between match and mismatch conditions. This rate is considerably higher than that reported in Basque for sentences with canonical SOV order (about 0.6%); however, it is closer to the rate of object interference in Basque for sentences with non-canonical OSV order (about 9%) and from the rate previously reported in ORs in French (up to 15%, Franck et al., 2006). Number mismatch also affected response times, as slower times were found in the mismatch condition than in the match condition. This finding replicates previous data collected with the same procedure (Staub, 2009). Finally, we found more attraction from plural than from singular subjects in accuracy. This finding aligns with the classical report that number attraction in subject-verb agreement is stronger for plural attractors (e.g., Bock & Miller, 1991; Bock & Cutting, 1992; Fayol, Largy, & Lemaire, 1994; Vigliocco et al., 1995) and extends it to object-past participle agreement (but see footnote 3). It provides additional evidence that the RSVP procedure is able to replicate results obtained from traditional production paradigms (Staub, 2009, 2010).

Results also attested to globally higher rates of correct agreement for singular object controllers than for plural ones. Considering only sentences with matching features (in which the error can therefore not be due to attraction), whereas an erroneous singular past participle was produced in 32% of the cases, an erroneous plural was virtually never produced. This finding is in line with the tendency to produce the default singular participial form (Corbett, 2000; Greenberg, 1963).

In sum, both accuracy and response times converge in showing attraction from the subject number on past participle agreement with the object, supporting the claim that similar mechanisms underlie object agreement and subject agreement, as proposed by Santesteban et al. (2013). Before describing that mechanism, we present Experiment 2 which explores whether participle agreement is also sensitive to gender attraction.

Experiment 2: Gender Agreement in Production

Method

Participants. Eighty-five undergraduates' students at the University of Geneva participated in this experiment in exchange for course credit (ages generally in 18-24 years). They were all native French speakers and they did not participate in Experiment 1.

Materials and design. We manipulated the gender of the object (masculine vs. feminine) and the gender match between the object and the subject (match vs. mismatch) in a 2x2 factorial design. We used the same experimental sentences as Experiment 1, adapted for the present design. In particular, since in French ORs, the auxiliary never agrees in gender with the subject, we simplified the structure of our relative clauses by removing both the infinitival clause and the adverb. Examples of experimental items are presented in Table 2. Eight lists were created so that each participant was presented with 16 experimental sentences (one experimental sentence per item) and 24 filler sentences identical to those in Experiment 1.

Procedure. The procedure was identical to Experiment 1.

Results

Data analyses. The same analyses conducted for Experiment 1 were conducted here. The variable gender of the object was coded as 1 if the object was masculine, and the gender match was coded as 1 if the gender of the object and the subject matched.

Accuracy. Figure 3 illustrates the distribution of accuracy proportions. Results attested to a main effect of gender match ($\widehat{\beta}$ = 0.916, z = 5.821, p < .001), with higher accuracy for match (M = 0.87) than mismatch conditions (M = 0.72). The main effect of the gender of the object ($\widehat{\beta}$ = 1.553, z = 7.181, p < .001) attested to higher accuracy for masculine objects (M = 0.93) than feminine objects (M = 0.65). Finally, a marginally significant interaction ($\widehat{\beta}$ = 0.249, z = 1.696, p = .089) revealed that gender match effect tended to be stronger for masculine objects ($\widehat{\beta}$ = -2.098, z = -3.778, p < .001; M = 0.88, vs. M = 0.98, which corresponds to a difference in logits of 1.9) than for feminine objects ($\widehat{\beta}$ = -1.043, z = -4.435, p < .001; M = 0.55 vs. M = 0.75, which corresponds to a difference in logits of 0.9). The accuracy for fillers was 83%.[4]

Response times. Figure 4 illustrates the distribution of responses times. Analyses revealed a main effect of gender match ($\widehat{\beta}$ = -0.08, t = -6.070, p < .001), with slower response times for mismatch (M = 2033 ms) than match conditions (M = 1744 ms). No other significant effect was found. Analyses conducted on incorrect trials revealed no significant effect.

Discussion

Experiment 2 showed that gender mismatch influences both accuracy and response times in the computation of past participle agreement: participants were significantly less accurate and took more time in producing the correct form of the past participle in the presence of a subject attractor mismatching the gender of the object controller. This effect is consistent with results from Experiment 1 on number attraction, and is in line with previous findings showing attraction in gender in other agreement dependencies (e.g., Anton-Méndez, Nicol, & Garrett, 2002; Badeker & Kuminiak, 2007; Malko & Slioussar, 2013; Meyer & Bock, 1999; Vigliocco & Franck 1999, 2001). Again, it suggests that similar mechanisms

underlie attraction in various agreement dependencies like object agreement (present study and Santesteban et al., 2013), predicative adjective agreement (Vigliocco & Franck, 1999, 2001; Vigliocco & Zilli 1999), subject agreement (e.g. Bock & Miller, 1991; Bock & Cutting, 1992; Bock & Eberhard, 1993; Hartsuiker, Antón-Méndez & van Zee, 2001; Thornton & MacDonald, 2003) and pronoun-antecedent agreement (Bock, Nicol, & Cutting, 1999; Bock, Eberhard, & Cutting, 2004; Meyer & Bock, 1999).

We also found a tendency for more attraction from feminine subjects than from masculine ones, in line with previous findings in other languages (e.g., Badeker & Kuminiak, 2007 in Slovak; Malko & Slioussar, 2013 in Russian). This finding is also in line with results from Experiment 1 and the literature on number agreement showing that plural, marked attractors trigger more attraction than unmarked ones (see Discussion of Experiment 1). However, our finding of an asymmetry between marked and unmarked attractors, like that of Experiment 1, needs to be taken with caution given that performance was nearly at ceiling in the masculine, match condition, such that the interaction we found could be spurious.

Finally, results also attested to higher accuracy rates for masculine than for feminine objects, independently of the subject's gender: we found 25% errors consisting in producing the masculine participle in the condition with two feminine nouns while there were virtually no errors consisting in producing the feminine participle in the condition with two masculine nouns. This replicates findings from Experiment 1 in number agreement in keeping with the hypothesis that French speakers have a grammatical option of using the default form of the participle (Corbett, 2000; Greenberg, 1963). Nevertheless, Experiments 1 and 2 show that even though past participle object agreement gives rise to a significant amount of default agreement, speakers consistently produce it and the mechanism underlying its computation appears similar to that underlying subject-verb agreement, as shown by its similar sensitivity to attraction and markedness effects.

What is that mechanism? The standard model of agreement production, M&M (Eberhard et al., 2005), assumes that agreement relies on feature percolation, sensitive to error when the subject phrase contains multiple features: although the head's feature is usually the one that first reaches the mother node, which will then be copied onto the agreement target, other features may occasionally win the competition, generating attraction. However, while this mechanism works well for features that are located on the same branch as the agreement controller, to account for attraction generated by features that are located on another branch, the M&M model should assume that features from any branch can affect the valuation of the controller (e.g., spreading activation, see Eberhard et al. 2005, p. 544). However, as pointed out by Wagers et al. 2009, it is unclear how such an unconstrained percolation approach could account for structural depth effects: the model would minimally need to provide additional constraints on feature percolation very similar to those assumed by the traditional constrained percolation mechanism, which assumes percolation to occur only between structurally related, local elements (e.g., Bock & Eberhard, 1993; Nicol, Forster, & Veres, 1997; Franck et al., 2002). In the General Discussion, we discuss an alternative explanation for attraction in sentence production based on the hypothesis that attraction is the result of the transfer of features onto the verb during the continuous interaction between sentential elements in the process of structure building in a self-organized model. Moreover, we will argue that the very same mechanism is at play in production and comprehension. Before developing our claim, we report two experiments exploring whether attraction arises in the comprehension of grammatical sentences, and which form it takes.

Experiment 3: Number Agreement in Comprehension

Method

Participants. The same 65 participants who took part in Experiment 1 took part in this experiment.

Material and design. The material was the same as Experiment 1, although we added subject relatives, so that the type of relative clause (subject relative vs. object relative) was an additional variable in our 2x2x2 factorial design with the number of the object (singular vs. plural) and the number match between the subject and the object (match vs. mismatch). Examples of experimental items are presented in Table 3. We also added an adverb between the auxiliary and the past participle to increase the distance between the past participle and the finite verb of the relative. Eight lists were created so that each participant was presented with 32 experimental sentences (one experimental sentence per item) and 40 filler sentences. Filler sentences were constituted of complex sentences containing movement and/or subordination, but they did not include relative clauses. Experimental sentences were decomposed into 10 regions, each containing a content word plus a grammatical word, when present. Filler sentences were decomposed in a varying number of windows, depending on their length.

Procedure. The experiment was programmed with E-prime. Sentences were presented on a computer screen as part of a noncumulative self-paced paradigm (Just, Carpenter, & Woolley, 1982). Participants were instructed to read the sentences by pressing the space bar in order to have the segments appear. Each segment was presented in the middle of the screen and disappeared as soon as the participant pressed the space bar. Each trial began with a fixation cross (400 ms) followed by an inter-stimulus blank screen (150 ms). Then, the segment-by-segment presentation started. Participants were told that a yes/no comprehension question would be asked at the end of each sentence. Comprehension questions specifically targeted thematic roles and were all subject questions (e.g., *Did the waiter surprise the dancer?* vs. *Did the dancer surprise the waiter?*) in order to determine whether the correct parse was built. Half the questions required a 'yes' answer. Since our sentences were semantically reversible, no semantic cues were available. An inter-stimulus

blank screen (150 ms) separated the last window of each sentence from the corresponding comprehension question, which appeared at the center of the screen. Instructions encouraged both rapid reading and correctness in answering the question. The items were presented in a random order. Each experimental session began with four practice trials. Three pauses of 1-minute each were administrated during the task. The whole session lasted about 15 minutes.

Results

Data analyses. Responses to comprehension questions were analyzed by way of mixed-effects logistic regression models, and for reading times we used linear mixed-effects regression models using the lme4 package (Bates et al., 2015) in R (R Development Core Team, 2016). The final model included as fixed factors: the relative type, the number of the object, the number match between the subject and the object as well as their interactions. Raw reading times were analyzed as follows. Reading times greater than 3000 ms or less than 100 ms were removed (affecting 2% of the data), which corresponds to approximately 2.5 standard deviations from the mean by region and condition. No additional outlier removal process was performed.

Reading times were analyzed only on trials for which participants gave a correct answer to the comprehension question, since we wanted to investigate the effectiveness of agreement cues in driving the cue-based mechanism of structure building, i.e., when a correct parse is built. Reading times were log-transformed to normalize residuals and then regressed against word length and log list position (Hofmeister, 2011; Hofmeister & Vasishth, 2014), two factors that are known to affect reading times in self-paced reading tasks (i.e., longer words are associated with longer reading times and later list position with faster reading times). The residual log reading time is therefore the dependent variable analyzed here. All our predictive factors were dichotomous and centered by coding one level of the factor as -1 and the other as 1. The random-effects structure always had the same specification as our

fixed effects. No correlations between random effects were estimated. When the initial models failed to reach convergence, we progressively simplified our statistical models but in no case did the model simplification result in a model with no random slopes. P-values were calculated using Satterthwaites's approximation to degrees of freedom with the lmerTest package (Kuznetsova et al., 2016). The variable relative type was coded as 1 if the structure was a subject relative clause, the number of the object was coded as 1 if the object was plural, and the number match was coded as 1 if the number of the object and the subject matched.

We performed four analyses of reading times. In order to assess the relative clause effect, we analyzed the reading times at the past participle region (*annoyed*), which is our critical region of interest for ORs, and at the matrix verb region (*drank*), which represents the point at which both the subject and the object have been integrated in both SRs and ORs (King & Just, 1991; Gordon et al., 2001). Since our critical predictions concerns ORs and SRs separately, rather than their interaction, we also performed two separate analyses for the two structures at the past participle region and the matrix verb region. We also analyzed the verb region (*claimed*) in ORs, in order to investigate if subject-verb number agreement generates retrieval interference effects. Finally, in order to investigate if encoding interference effects manifest at the point of encoding, we also analyzed the second noun phrase region in both sentence types (Van Dyke & McElree, 2006).

Comprehension question accuracy. The distribution of mean accuracy proportions for comprehension questions is shown in Figure 5. Analyses revealed a significant effect of relative type ($\widehat{\beta}$ = 0.587, z = 9.870, $p < .001$), attesting to higher accuracy for SRs (M = 0.85) than for ORs (M = 0.68), and a significant effect of number match ($\widehat{\beta}$ = -0.152, z = -2.593, p =.009), attesting to higher accuracy for mismatch conditions (M = 0.79) than for match conditions (M = 0.74) in both structure types. All other effects were non-significant. The accuracy for fillers was 92%.

Reading times. The distribution of reading times across the different experimental conditions for both subject and object relatives is reported in Figure 6.

Past Participle (region 6 for SRs and 7 for ORs). A significant effect of relative type was found ($\widehat{\beta}$ = -0.091, t = -5.207, p < .001), with slower reading times for ORs (M = 529 ms) than for SRs (M = 383 ms). No other significant effect was found. No significant effect was attested in the separate analyses.

Matrix verb (region 8). No significant effect was found.

Relative verb (region 4, ORs). No significant effect was found.

Second noun phrase region (region 7 SRs, region 3 ORs). No significant effect was found.

Discussion

Experiment 3 replicates the well-attested relative type effect, with ORs being harder to understand and slower to process at the critical relative past participle region than SRs, in line with the vast cross-linguistic literature showing that ORs involve greater processing cost than SRs (see, among others, Frauenfelder, Segui, & Mehler, 1980; Gordon et al., 2001, 2004; Just & Carpenter, 1992; King & Just, 1991; Mak, Vonk, & Schriefers, 2002; 2006; Traxler, Morris, & Seely, 2002). Importantly, we found that ORs were comprehended better when the object and the subject mismatched in number than when they matched. This finding aligns with the recent finding of Villata et al. (2018) on the comprehension of ORs by Italian and English-speaking adults. The authors reported higher accuracy scores when the object and the subject mismatched in number in English, and when they mismatched in gender in Italian. These results also align with findings on children, showing improved comprehension of ORs in English, Italian and Hebrew in cases of agreement feature mismatch between the subject and the object (Adani et al., 2010; Belletti et al., 2012).

In contrast, no effect of number mismatch was detected in online reading times, in line with most comprehension studies conducted to date (Dillon et al., 2013; Lago et al., 2015; Tucker et al., 2015; Wagers et al., 2009; see Jäger et al., 2017 for a meta-analysis). However, it is interesting to note that a few studies have shown mismatch effects in on-line measures (in French: Franck et al., 2015; in English: Experiment 5 in Wagers et al., 2009 in later regions of the sentence; in Spanish: Experiment 3A in Lago et al., 2015).

Finally, we also observed a mismatch effect in the comprehension accuracy of SRs. Under the hypothesis that mismatch effects reflect similarity-based interference in the process responsible for retrieving a long-distance element, no effect was expected in SRs since in these sentences, the object is in its canonical, post verbal position, and the sentence involves no long-distant element to be retrieved. Although the object has not yet been encountered by the parser at the relative verb region, the mismatch effect discussed here was observed on comprehension accuracy; hence, for that hypothesis to hold, one would need to assume that the parser does not necessarily immediately engage in subject retrieval at the verb, and may trigger retrieval operations further along as the sentence is still unfolding. Another possibility is that the subject was distant from the matrix verb (*buvait/buvaient*) and that at that point retrieval was contaminated by interference from the object of the relative verb. It is therefore possible that the mismatch effect found in SRs reflects the involvement of a cue-based mechanism responsible for retrieving the subject (Van Dyke & McElree, 2011). In any case, if the hypothesis that the number mismatch effect reported here arises at the level of subject retrieval is correct, then no facilitation should be observed for gender mismatch, since gender is not a feature of the target verb in French. In Experiment 4, we test this prediction, and on the basis of the results, discuss the possible mechanism underlying mismatch effects in SRs.

Experiment 4: Gender Agreement in Comprehension

Method

Participants. The same 85 participants who took part in Experiment 2 took part in Experiment 4.

Materials and design. We manipulated the type of relative clause (subject vs. object), the gender of the object (masculine vs. feminine) and the gender match between the object and the subject (match vs. mismatch) in a 2x2x2 factorial design. The materials were the same as in Experiment 2, although here SRs were also tested. Since the gender agreement on the past participle is sometimes audible in French, for half of our verbs it was audible while for the other half it was not, although it was always orthographically realized through the final –e morpheme. Examples of experimental items are presented in Table 4. Eight lists were created so that each participant was presented with 32 experimental sentences (one experimental sentence per item) and 40 filler sentences. The same fillers used in Experiment 3 were employed here. Experimental sentences were decomposed into 8 regions, each containing a content word plus a grammatical word, when present. Filler sentences were decomposed into various numbers of reading windows, depending on their length.

Procedure. The same self-paced reading procedure used in Experiment 3 was adopted.

Results

Data analyses. The same data analyses conducted for Experiment 3 were conducted here. The variable relative type was coded as 1 if the structure was a subject relative clause, the gender of the object was coded as 1 if the object was masculine, and the gender match was coded as 1 if the gender of the object and the subject matched.

Comprehension question accuracy. The distribution of mean accuracy scores in the four experimental conditions is illustrated in Figure 7. Generalized linear mixed effect analysis revealed a significant effect of relative type ($\widehat{\beta}$ = 0.619, z = 10.997, p < .001), with

higher accuracy scores for SRs (M = 0.878) than for ORs (M = 0.715). Results also attested to a main effect of gender mismatch ($\widehat{\beta}$ = -0.309, z = -5.570, p < .001), with higher accuracy for mismatch (M = 0.84) than match conditions (M = 0.75) and no interaction between gender mismatch and relative type, showing that gender mismatch similarly affects ORs and SRs. Results also revealed a two-way interaction between gender mismatch and the gender of the object ($\widehat{\beta}$ = 0.133, z = 2.396, p = .016), which attested to a stronger effect of gender match when the object is feminine (M = 0. 71 in FF vs. M = 0.84 in FM; $\widehat{\beta}$ = 0.449, z = 5.758, p < .001) than when it is masculine (M = 0.79 in MM vs. M = 0.83 in MF; $\widehat{\beta}$ = 0.156, z = 1. 955, p = .051). Remaining effects were not significant (t_s < 2). The accuracy for fillers was 93%.

Reading Times. The distribution of reading times across the different experimental conditions for both subject and object relatives is reported in Figure 8.

Past Participle (region 4 for SRs and 5 for ORs). A significant effect of relative type was found ($\widehat{\beta}$ = 0.054, t = 3.653, p < .001), with slower reading times for ORs (M = 538 ms) than for SRs (M = 399 ms), and a significant effect of the gender of the object ($\widehat{\beta}$ = -0.02, t = -2.765, p = .009), with slower reading times for feminine (M = 474 ms) than for masculine objects (M = 447 ms). Results also attested to a significant three-way interaction ($\widehat{\beta}$ = -0.025, t = -2.776, p = .010).

For ORs, results attested to a significant effect of the gender of the object ($\widehat{\beta}$ = -0.032, t = -2. 477, p = .013), with slower reading times for feminine objects (M = 561ms) than for masculine objects (M = 516 ms). A significant interaction between the gender of the object and gender mismatch was also found ($\widehat{\beta}$ = -0.036, t = -2.273, p = .031), revealing an effect of match when the object is feminine ($\widehat{\beta}$ = -0.048, t = -2.598, p = .009), with faster reading times in the gender mismatch condition (FM; M = 516 ms) than in the gender match condition (FF; M = 619 ms), but no effect of mismatch when the object is masculine ($\widehat{\beta}$ =

0.027, t = 1.512, p = .132) (M = 490 ms in MM vs. M = 541 ms in MF). No other test was significant.

As for SRs, no significant effect was found.

Matrix verb (region 6). No significant effect was attested.

Second noun phrase region (region 5 SRs, region 3 ORs). No significant effect was found when SRs and ORs were analyzed together. However, since our critical prediction concerns ORs and SRs separately, we also performed two additional separate analyses for ORs and SRs. For ORs, results revealed a significant main effect of gender mismatch ($\widehat{\beta}$ = 0.048, t = 2.034, p = .045), attesting to longer reading times for mismatch (M = 646 ms) than match conditions (M = 444 ms), an effect that appears to be driven by the MF condition (M = 488 ms), which is significantly longer than the MM condition (M = 427 ms) ($\widehat{\beta}$ = 0.080, t = 2.531, p = .011), while the FF and FM conditions do not significantly differ ($\widehat{\beta}$ = 0.015, t = 0.465, p = .641). For SRs, a significant effect of the gender of the object was found ($\widehat{\beta}$ = -0.087, t = -3.023, p = .004), with longer reading times for feminine objects (M = 549 ms) than for masculine ones (M = 484 ms).

Discussion

Results from Experiment 4 replicated the well-known advantage found for SRs compared to ORs cross-linguistically and also found in Experiment 3, and this both in comprehension accuracy and in reading times at the past participle region. More importantly, comprehension accuracy was significantly higher in conditions where the gender of the subject mismatched that of the object. This finding converges with previous findings on Italian speaking adults (Villata et al., 2018) and on Hebrew speaking children (Belletti et al., 2012). On-line measures also revealed a facilitatory effect of gender mismatch at the level of the agreement target, although this effect only reached significance when the object was feminine. Finally, results also revealed an effect of gender mismatch at the second noun

phrase region for ORs, attesting to longer reading times for mismatch than match conditions. This *prima facie* surprising result appears to be driven by the condition in which the first noun phrase is masculine and the second one is feminine, attesting to increased difficulties for the processing a feminine noun phrase rather than for a more general penalizing effect of mismatch (otherwise the same effect should have been found in the mismatch condition involving a first feminine noun and a second masculine one).

All in all, results from Experiment 4 basically align with those from Experiment 3 on number, with a greater sample size (yielding a statistical power of 95%), showing a clear facilitation in mismatch conditions on accuracy measures, and a milder effect in on-line measures.

In contrast to Experiment 3, where the effect of mismatch was stronger for unmarked, masculine objects, a stronger mismatch effect was observed here for marked, feminine objects. The source of this difference between gender and number is unclear; further investigation is required to understand it. For now, we will capitalize on the main finding that the data from Experiments 3 and 4 converge in showing that feature mismatch facilitates sentence comprehension, which was the focus of our study.

In line with Experiment 3 on number mismatch, gender mismatch was found to facilitate the comprehension of SRs. This finding casts doubt on the hypothesis that the number mismatch facilitation in SRs found in Experiment 3 was due to the fact that verb number was used as a retrieval cue for the subject at the main verb, since gender was not a retrieval cue in Experiment 4. It therefore seems plausible to conclude that those similarity-based interference effects lie at encoding, rather than retrieval. We discuss the possible mechanisms of encoding interference in the next section.

General Discussion

We reported four studies on number and gender object-verb agreement in French investigating the effect of feature mismatch between the agreement target, i.e., the object, and the intervening subject in the production and comprehension of complex structures involving relativization. Results showed a consistent pattern of mismatch penalization in the production of agreement in object relatives, both on production accuracy and on reading times at the level of the agreement target (Experiments 1 and 2). These findings revealed a type of attraction that had previously only been reported in Basque (Santesteban et al., 2013): subject attraction. It brings support to the hypothesis that the same mechanism underlies attraction across various types of agreement dependencies (object-verb, subject-verb, subject-predicative adjective, pronoun-antecedent agreement) and across various agreement features (number and gender). Results from the comprehension studies (Experiments 3 and 4) showed a reverse pattern manifest in terms of mismatch facilitation observable in comprehension accuracy and, to a lesser extent, in on-line reading times at the past participle. Unexpectedly, the effect of mismatch facilitation in comprehension was not only observed in ORs, but also in SRs. Even though SRs also involved a long-distance dependency between the subject and the verb, the report that feature mismatch affects comprehension independently of whether the mismatching feature is represented on the verb (as in Experiment 3) or not (as in Experiment 4) suggests that mismatch effects do not lie in the process of retrieving, at the verb, an argument that was distant from it.

In the following sections, we discuss how models of sentence production and comprehension can account for these results. At present, separate models have been proposed for production and comprehension: we briefly describe how M&M (Eberhard et al., 2005) could account for production data, and then how ACT-R (Lewis & Vasishth, 2005) could account for the comprehension data, and argue that both models would need adjustments to capture all the data at hand. We then turn to a model based on self-organizing

sentence processing (SOSP), which has the benefit of accounting for both production and comprehension data through a single, independently-motivated mechanism (e.g., Smith & Tabor, 2018; Smith, Franck & Tabor, 2018; Tabor & Hutchins, 2004; Villata et al., 2018).

A Two-Models Account of Interference Effects in Production and Comprehension

Under the M&M model of agreement production (Bock et al., 2001; Eberhard et al., 2005), attraction errors in sentences containing a prepositional phrase (PP) modifier arise during the stage of Morphing: the morphosyntactic properties of a distracting element in the subject phrase sometimes percolate up the tree to the subject root, contaminating the feature of the subject head. Critically, however, in an object relative clause, the distracting element (the object) is not part of the subject phrase. As discussed in Wagers et al. (2009), a possible theoretical adjustment to account for attraction errors in both sentences with a PP modifier and in ORs is to relax the assumptions concerning how features percolate in the syntactic tree, by assuming that attractors in any syntactic position can overwrite the features of the verb. This move, however, has the disadvantage of not accounting for structural depth effects (i.e., elements that are more deeply embedded in the syntactic tree cause less attraction than less embedded ones, e.g. Franck et al., 2002). Feature percolation would have to be allowed or not allowed as a function of the shape of syntactic structure in order to account for the various types of effects reported in the literature.

Another possibility, initially proposed by Bock & Miller (1991), is that attraction in ORs arises from a fundamentally different mechanism than attraction from PP modifiers. Errors in ORs would be due to a difficulty in syntactic role assignment and, more precisely, to the incorrect assignment of the subject role to the object. In support of their hypothesis that different mechanisms underlie object and PP attraction, the authors reported an effect of animacy in ORs, with more attraction when the object was animate and therefore a plausible agent for the verb, but not in PP sentences (see also Barker, Nicol, & Garrett, 2001). They

also found that when the object was animate, participants sometimes produced completions suggesting that they indeed treated the first noun phrase as the subject of the verb. Further evidence comes from experiments conducted with the forced-choice response time paradigm. Staub (2009) showed that while in sentences containing a PP modifier response times did not vary with the correctness of the response, they did so in ORs, with slower response times for incorrect than correct productions. Moreover, Staub (2010) observed that whereas the effect of a number mismatching PP was distributed across trials, whether or not an agreement error was made, the effect of a mismatching object was restricted to a few trials, on many of which an agreement error was made. Although it is plausible that two different mechanisms underlie PP and object attraction, it is desirable to have an explanation relying on a single mechanism. Such a possibility is offered by the SOSP model, which we develop in the next section.

The ACT-R model (Lewis & Vasishth 2005; see also Engelmann, Jäger & Vasishth, submitted; Lewis, Vasishth, & Van Dyke, 2006) has been argued to account for a variety of sentence comprehension data showing sensitivity to similarity-based interference (e.g., McElree, 2000; Van Dyke & Lewis, 2003; Van Dyke 2007; Van Dyke & McElree, 2006, 2011). The mismatch facilitation effect reported in ORs in Experiments 3 and 4 here may be generated under ACT-R via similarity-based interference under the assumption that the parser makes use of agreement cues at the past participle to retrieve the long-distance object. In ACT-R, elements are retrieved based on their activation level: more active elements in memory are retrieved faster and earlier than less active ones. Because the activation level of an element increases when it is the only element containing the retrieval cue (*fan effect*), mismatch conditions are processed faster and more accurately than match conditions. ACT-R may also account for the facilitatory mismatch effect observed in comprehension accuracy results because correct online retrieval increases the chances that the structure will be

properly built. However, ACT-R fails to predict the fact that the mismatch facilitation effect was detected to a comparable extent in the comprehension accuracy of SRs even when no agreement cue was represented on the verb, as it was the case for gender, and can therefore not serve as a cue.

To account for mismatch effects that cannot arise at retrieval, Villata et al. (2018) proposed to extend the fan effect to all features that are shared across elements, including features that are not retrieval cues. In this augmented version of ACT-R, elements sharing a feature become more equal in their activation level (through a mechanism of *activation leveling*), thus increasing competition during structure building. If activation leveling is included, ACT-R can account for both retrieval and encoding interference with two separate mechanisms: fan and activation leveling. Hence, here again two mechanisms would be needed for the augmented version of ACT-R to account for the data. We will now turn to see how, in the SOSP model, these effects follow from a single independently motivated mechanism of structure building, which provides a unitary framework for both production and comprehension data.

A Unitary Framework for Interference Effects in Production and Comprehension: SOSP

In self-organized sentence processing (SOSP; Cho, Goldrick, & Smolensky, 2017; Kempen & Vosse, 1989; Smith & Tabor 2018; Smith et al., 2018; Stevenson, 1994; Tabor & Hutchins, 2004; van der Velde & de Kamps, 2006; Villata et al., 2018; Vosse & Kempen, 2000, 2009), each word activates a treelet (i.e., a piece of syntactic structure stored in memory). Each treelet comes with a feature vector encoding the syntactic and semantic properties of its mother node, as well as of each of its possible daughters. Treelets continuously interact in all possible ways to form the global structure, creating competition for attachment. Links among treelets with a good feature match strengthen more quickly than

those with a poorer feature match, therefore generally outcompeting the former. However, due to noise in the system, when treelets with a similar featural configuration compete for the same attachment, sometimes a poorer match wins so, across instances, the system generates a distribution over optimal and semi-optimal structures. SOSP also assumes a mechanism of *re-self-organization*, which activates whenever the structure has to be re-built after some time has elapsed since its first generation. This mechanism has been first introduced to account for errors in sentence repetition as well as for the loss of syntax-specific memory over time (see Fodor, Bever, & Garrett, 1974). Re-self-organization is in all respects similar to the self-organization mechanism at play during the initial parse of the sentence, except that during re-self-organization all constituents participate simultaneously in structure-building, given that this mechanism does not proceed incrementally as all the sentential elements are already available in memory.

How does SOSP account for attraction in sentence production? During the continuous interaction among treelets, the features of a treelet are transferred to the treelets to which it is trying to attach, through bidirectional feature passing. The gradual transfer of features among treelets is responsible for attraction errors. Consider the well-known example from Bock & Miller (1991):

(2) The key [+SG] to the cabinets [+PL] …

When the first noun phrase is encountered, a treelet is activated by "key". The mother of this treelet bears features including [+NP, +SG]. This treelet activates a verb treelet, because treelets project into the future, i.e., they predict future treelets to combine with, based on the grammatical constraints they impose, even if the lexical anchor has not been encountered yet. At this point, the "key" treelet begins to attach to the subject slot of the verb. Since "key" is specified as singular, this leads the verb's subject, as well as the verb daughter itself, to gradually converge towards a singular value. When the second noun

phrase, “cabinets” kicks in, a new treelet with the plural feature is activated. Due to the continuous interaction between treelets, “cabinets” also tries to establish a link with the subject slot of the verb. In most of the cases, it will not win the competition, since the first noun has a lead in forming this attachment. However, the temporary bond between “cabinets” and the verb treelet can (due to noise in the activations) cause the verb to gravitate to [+PL], producing an attraction effect. Hence, attraction results from the fact that the modifier is momentarily linked to the verb.

Turning to our data on ORs in production (e.g., *The dancers that the waiter has surprised…*), when the first NP is encountered (the object), the parser activates a verb treelet that it links to as a subject, and the features of the NP are gradually transferred to the verb. When the relativizer is reached, this brings information that the initial NP is actually an extracted element. It signals that a constituent will need to be associated with a gap coming later, and the features of that constituent are placed on the first mother node of the branch where the gap is expected (for an NP constituent, this is typically written as an annotation to the side of the mother node's label in the form "/NP"). The "/NP" should be thought of as a vector of features specifying all the relevant properties of the moved NP. Then, this slash feature bundle is passed from treelet to treelet down the tree through *slash propagation* as each additional treelet is added attempting to attach to any open attachment sites that come along (Gazdar, 1981). When the second NP of the sentence is reached (the subject), it also generates a slash feature bundle, this time including a feature [+SUBJ], indicating that the second NP should play the subject role in the upcoming verb (this feature is originally generated at the relative clause attachment site on the first NP and passed down to the mother node of the relative clause subject). When the auxiliary occurs, the two NPs compete to occupy the subject slot of the auxiliary. The actual subject is most likely to win because the verb subject slot bears the feature [+SUBJ], which makes the actual subject a better match,

but because of the noise, the object feature bundle can also get attached (either temporarily or permanently) as the subject of the auxiliary, causing object interference with subject agreement as has been observed in other studies (Bock & Miller, 1991; Franck et al., 2006; 2010; Staub, 2009). The auxiliary then projects a past participle treelet which has an optional object attachment site. This site, which bears the feature [-SUBJ] is looking for a NP to attach and the object slash bundle is the best match. However, the subject feature bundle also competes to attach to the object slot of the participle (despite mismatch on the [-SUBJ] feature, for this can be overcome by noise), thus potentially causing subject interference in object agreement, as observed in our current results. The dynamics of feature passing also account for the faster reaction times in match conditions. This is again because, when the structure is still in the process of forming, features flow at the same time from both noun phrases ("waiter" and "dancer") to the verb. When both noun phrases are specified with a singular feature, the verb grows singular more quickly, even if the structure has not completely stabilized yet, thus allowing speakers to decide between the two agreement forms of the verb faster than in mismatch conditions. Crucially, in match conditions the parser can select the correct form of the verb before an attachment decision has been made or even if the wrong attachment has been formed. SOSP, unlike M&M, predicts that agreement errors in production can result from incorrect feature passing but also from incorrect structure building, such that the attractor occupies the controller's position in the tree. Preliminary evidence supporting this claim has been collected in an experiment involving an RSVP production task *plus* a comprehension question task administrated right after, which allows us to assess for structure building. Results provide preliminary evidence that agreement errors also arise as a result of incorrect structure building, in line with SOSP (see Schmid et al., 2018).

How does SOSP account for mismatch effects in sentence comprehension? SOSP generates these through another consequence of feature transfer: once an initial NP has transferred its features onto the verb, the presence of these features on the verb will tend to attract an NP with the same features more than one with different features. That is, the more the second NP's feature bundle overlaps with that of the first, the more strongly the verb strives to attach to both of them, producing slowdown due to competition. This mechanism of feature-based competitive bonding underlies similarity-based slow-down effects reported in the literature (e.g. Gordon et al., 2001, 2004; Lewis et al., 2003; McElree, 2000), including the agreement feature mismatch effects reported here which is another instance of similarity-based interference.

The inverse relationship between production and comprehension stems from the fact that stronger competition in sentences with feature match is 'invisible' in production; indeed, although the features of the attractor are more likely to be erroneously transferred to the agreement target in the match condition, the presence of these features on the agreement target is invisible given that they match those of the agreement controller. In contrast, in comprehension, the measured behaviour is not the verb feature that participants select but their overall understanding of the sentence, and this is predominantly determined by which bonds have stabilized during the initial structure-building. This measure thus reflects the erroneous bonds that the parser has occasionally stabilized on, which are more frequent when the two NPs match in agreement features than when they mismatch.

Why is the match effect most clear in off-line data, and only occasionally observed on-line (Franck et al., 2015; Villata et al., 2018)? In SOSP, this stems from the gradual nature of feature passing: the differentiation of subject and object under mismatch grows stronger with the passage of time. The mismatch effect is thus more often significant in comprehension accuracy measures than in online processing, for comprehension is a later

measure and involves a second building of the tree, which tends to reinforce any erroneous tendencies that occurred during the initial building (see Villata et al., 2018).

The mismatch effect attested in comprehension question accuracy is equally observed in SRs and ORs. This is because this effect arises at the point of re-self-organization prompted by the comprehension question. When the comprehension question is asked, the system finds itself in a new state in which, first, the comprehension question has to be parsed, and, second, the sentence previously built has to be re-generated with the purpose of question answering. This re-generation is achieved through re-self-organization. Since in re-self-organization all the NPs in the sentence participate simultaneously in structure-building (all the sentential elements are already available in memory), interference between subjects and objects is expected for both SRs and ORs, since both structures involve two NPs that must be attached to the verb. The greater ease of processing SRs as compared to ORs is expected due to the fact that initial structure building for sentences with fewer slash-propagated arguments (i.e., fewer extracted constituents) is easier to stabilize on. In SRs, only one NP is available when the verb is perceived. It can therefore easily occupy the subject slot of the verb without having to compete with other candidates stored in memory.

How does SOSP account for markedness effects? Marked elements take longer to process than unmarked ones (Experiment 4 of the current study; Wagers et al., 2009) and attraction errors are more frequent when the attractor is marked than when it is unmarked (Experiments 1 and 2 of the current study and Eberhard, 1995). In SOSP, there is boundary in the activation space that separates the initial states that lead to the marked outcome from those that lead to the unmarked outcome. This boundary is not symmetrically positioned: instead, it is located close to the convergence point for the unmarked state (singular) and far from it for the marked state (plural).[4] The input places the system close to this boundary with a slight deflection to one side or the other, depending on which outcome the context specifies.

Since the system has to travel farther to converge on the marked outcome, the model takes longer to process marked elements, consistent with empirical results. Moreover, once the system has gravitated to the marked state, it is harder for the noise to knock it back over the boundary because the boundary is far away in that case, so marked cases are more stable and greater attraction is expected when the correct state is unmarked (e.g., *the key to the cabinets*) than when it is marked (e.g., *the keys to the cabinet*) (see Franck, 2017 for a discussion of the possibility that markedness effects primarily lie in the markedness of the head, and not in that of the attractor as commonly assumed in the attraction literature).

How does SOSP account for the fact that mismatch effects systematically arise in ungrammatical sentences, and much less so in grammatical ones (e.g., Wagers et al., 2009)? In SOSP, convergence on the stable structure occurs more rapidly in grammatical sentences than in ungrammatical ones: interfering elements only have a weak effect in perturbing the formation of the structure in grammatical sentences because of the presence of an element that fully matches the requirements of the verb, which easily outcompetes distracting elements. In ungrammatical sentences, no element fully matches the feature of the verb, since the agreement controller mismatches it. Moreover, in mismatch conditions, the distractor matches the agreement features of the verb: this unavoidable tension in ungrammatical sentences slows processing and amplifies the difference between match and mismatch conditions (see also Smith, Franck, & Tabor, 2016; Villata et al., 2018).

It is at present unclear why mismatch effects sometimes arise on-line in grammatical sentences and sometimes not. One possibility is that the materials in studies reporting significant effects are particularly challenging for the parser. For example, in Franck et al. (2015), participants had to switch from ORs (e.g., *Jérome speaks to the prisoner-SG that the guard-SG takes-SG out sometimes in the yard*) to superficially very similar complement clause structures (e.g., *Jérome tells to the prisoner-SG that the guard-SG goes-SG out*

sometimes in the yard), which may have contributed to increase the difficulty of the structure building process. Further research is needed to understand the conditions under which effects of feature match appear on-line in sentence comprehension.

Conclusion

On the basis of four experiments on which we investigated the production and comprehension of sentences containing object-past participle number and gender agreement in French, we reached the following conclusions. Results from production showed that a subject mismatching the object penalizes production by reducing accuracy and increasing response times. This finding extends previous reports of attraction to a new agreement dependency in which the subject is the attracting element. Results from comprehension, in contrast, showed that a mismatching attractor increases off-line comprehension accuracy and decreases reading times at the critical past participle region, although the on-line effect appears to lie in the tail of the long reading times. This mismatch effect was found to impact, in a similar way, object relatives and subject relatives in which no long-distance dependency was involved. We have argued that while M&M and ACT-R may be able to explain our results, they need to be augmented with a variety of novel mechanisms to do so. We then described how a self-organized sentence processing model, SOSP, can handle both production and comprehension results with a single computational mechanism of competition for attachment between sentential elements during structure building. The advantage of SOSP, beyond its parsimony, lies in the fact that competition is an independently motivated mechanism of structure formation. In this view, attraction arises due to the erroneous bonds established between the verb and its arguments, although structure-building errors may only be temporary, such that an attraction error may arise even though the structure is ultimately correctly built. An important consequence of this hypothesis is that although attraction errors are actually observed in conditions in which the agreement controller and the distractor

mismatch in their agreement features, attraction is actually assumed to be stronger, although not detectable, in conditions in which their features match. One valuable next step for researchers could be to identify experimental tools to test this challenging prediction.

Supplementary data

In this section, we report analyses for reading times for the two self-paced reading experiments without excluding incorrectly-answered trials. Results globally replicate those obtained when reading times for correct trials only were analyzed.

Experiment 3

Reading times. The distribution of reading times across the different experimental conditions for both subject and object relatives is reported in Figure 9.

Past Participle (region 6 for SRs and 7 for ORs). A significant effect of relative type was found ($\widehat{\beta}$ = -0.079, t = -5.146, p < .001), with slower reading times for ORs (M = 529 ms) than for SRs (M = 383 ms). No other significant effect was found.

Matrix verb (region 8). No significant effect was found.

Relative verb (region 4, ORs). No significant effect was found.

Second noun phrase region (region 7 SRs, region 3 ORs). No significant effect was found.

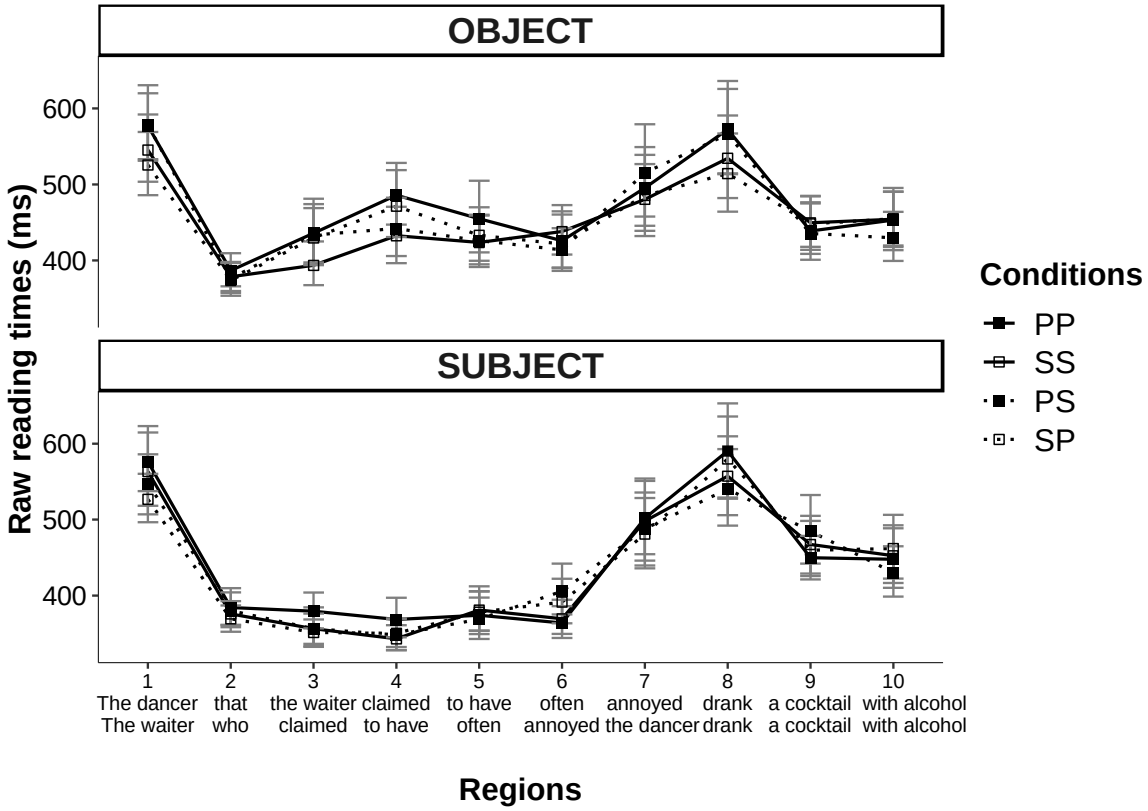

Figure 9. Distribution of reading times (in ms) in the eight experimental conditions for the different regions of Experiment 3 (all trials). Error bars represent standard errors by subject means.

Experiment 4

Reading Times. The distribution of reading times across the different experimental conditions for both subject and object relatives is reported in Figure 10.

Past Participle (region 4 for SRs and 5 for ORs). A significant effect of relative type was found ($\widehat{\beta}$ = 0.054, t = 4.026, p < .001), with slower reading times for ORs (M = 542 ms) than for SRs (M = 398 ms), and a significant effect of the gender of the object ($\widehat{\beta}$ = -0.01, t = -2.229, p = .026), with slower reading times for feminine (M = 478 ms) than for masculine objects (M = 460 ms). Results also attested to a marginally significant three-way interaction ($\widehat{\beta}$ = -0.02, t = -2.018, p = .052).

For ORs, results attested to a numerical tendency for an interaction between the gender of the object and gender mismatch ($\widehat{\beta}$ = -0.025, t = -1.913, p = .067), revealing an effect of match when the object is feminine ($\widehat{\beta}$ = -0.037, t = -2.389, p = .018), with faster reading times in the gender mismatch condition (FM; M = 515 ms) than in the gender match condition (FF; M = 590 ms), but no effect of mismatch when the object is masculine ($\widehat{\beta}$ = 0.011, t = 0.713, p = .476) (M = 525 ms in MM vs. M = 538 ms in MF). No other test was significant. As for SRs, no significant effect was found.

Matrix verb (region 6). No significant effect was attested.

Second noun phrase region (region 5 SRs, region 3 ORs). No significant effect was found.

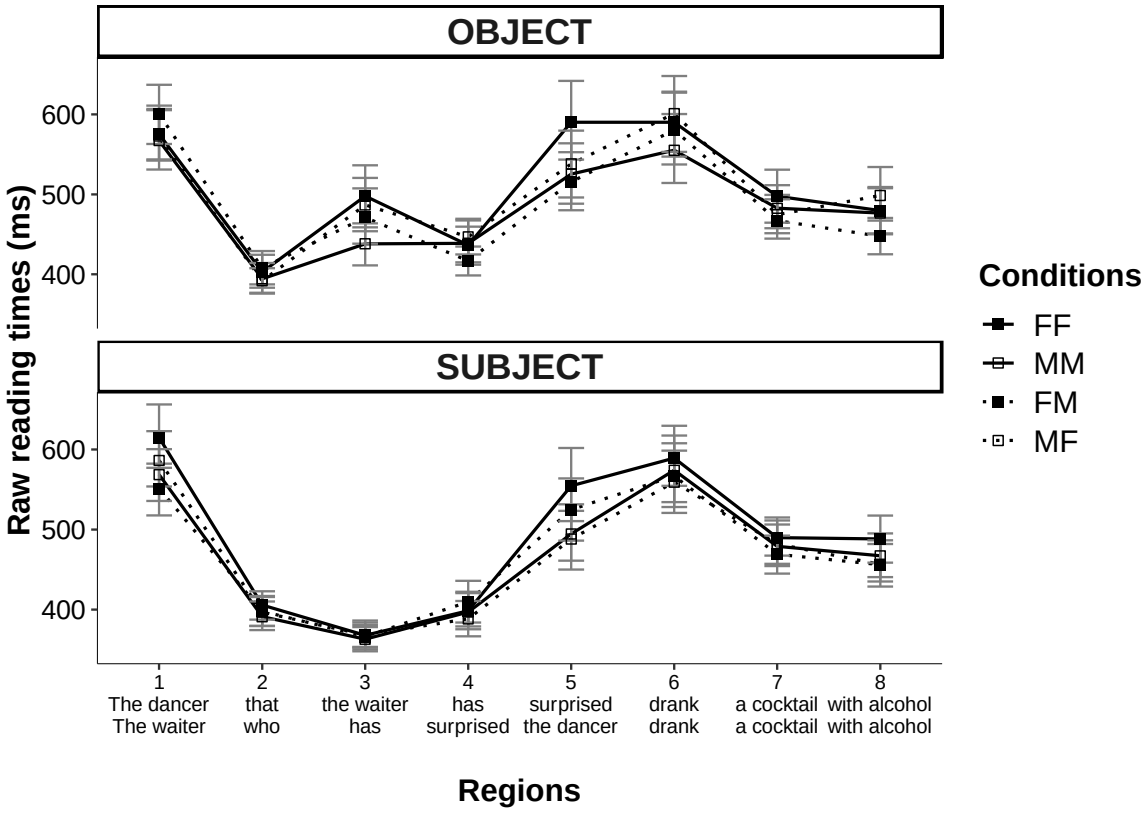

Figure 10. Distribution of reading times (in ms) in the eight experimental conditions for the different regions of Experiment 4 (all trials). Error bars represent standard errors by subject means.

References

Acuña-Fariña, J. C., Meseguer, E., and Carreiras, M. (2014). Gender and number agreement in comprehension in Spanish. *Lingua*, *143*, 108-128.

Adani, F., Van der Lely, H. K., Forgiarini, M., and Guasti, M. T. (2010). Grammatical feature dissimilarities make relative clauses easier: A comprehension study with Italian children. *Lingua*, *120*(9), 2148-2166.

Antón-Méndez, I., Nicol, J. L., and Garrett, M. F. (2002). The relation between gender and number agreement processing. *Syntax*, *5*(1), 1-25.

Badecker, W., and Kuminiak, F. (2007). Morphology, agreement and working memory retrieval in sentence production: Evidence from gender and case in Slovak. *Journal of Memory and Language*, *56*(1), 65-85.

Barker, J., Nicol, J., and Garrett, M. (2001). Semantic factors in the production of number agreement. *Journal of Psycholinguistic Research*, *30*(1), 91-114.

Barr, D. J., Levy, R., Scheepers, C., and Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of memory and language*, *68*(3), 255-278.

Belletti, A. (2006). (Past) participle agreement. *The Blackwell companion to syntax*, 493-521.

Belletti, A., Friedmann, N., Brunato, D., and Rizzi, L. (2012). Does gender make a difference? Comparing the effect of gender on children's comprehension of relative clauses in Hebrew and Italian. *Lingua*, *122*(10), 1053-1069.

Bock, K., and Miller, C. A. (1991). Broken agreement. *Cognitive psychology*, *23*(1), 45-93.

Bock, K., and Cutting, J. C. (1992). Regulating mental energy: Performance units in language production. *Journal of memory and language*, *31*(1), 99-127.

Bock, K., and Eberhard, K. M. (1993). Meaning, sound and syntax in English number agreement. *Language and Cognitive Processes*, *8*(1), 57-99.

Bock, K., Nicol, J., and Cutting, J. C. (1999). The ties that bind: Creating number agreement in speech. *Journal of Memory and Language*, *40*(3), 330-346.

Bock, K., Eberhard, K. M., Cutting, J. C., Meyer, A. S., and Schriefers, H. (2001). Some attractions of verb agreement. *Cognitive Psychology*, *43*(2), 83-128.

Bock, K., Eberhard, K. M., and Cutting, J. C. (2004). Producing number agreement: How pronouns equal verbs. *Journal of Memory and Language*, *51*(2), 251-278.

Boskovic, Z. (1997). On certain violations of the Superiority Condition, AgrO, and the economy of derivation. *Journal of Linguistics* 33. 227-254.

Caramazza, A., and Zurif, E. B. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia. *Brain and language*, *3*(4), 572-582.

Cho, P. W., Goldrick, M., and Smolensky, P. (2017). Incremental parsing in a continuous dynamical system: Sentence processing in Gradient Symbolic Computation. *Linguistics Vanguard, 3*.

Chomsky, N. (1977). On wh-movement. In *Formal syntax*, ed. Peter Culicover, Thomas Wasow, and Adrian Akmajian, 71–132. New York: Academic Press.

Corbett, G. (2000). Number. Cambridge, England: Cambridge University Press.

Dillon, B., Mishler, A., Sloggett, S., and Phillips, C. (2013). Contrasting intrusion profiles for agreement and anaphora: experimental and modeling evidence. *Journal of Memory and Language*, *69*(2), 85-103.

Eberhard, K. M. (1997). The marked effect of number on subject–verb agreement. *Journal of Memory and language*, *36*(2), 147-164.

Eberhard, K. M. (1999). The accessibility of conceptual number to the processes of subject–verb agreement in English. *Journal of Memory and Language*, *41*(4), 560-578.

Eberhard, K. M., Cutting, J. C., and Bock, K. (2005). Making syntax of sense: number agreement in sentence production. *Psychological Review, 112*(3), 531.

Engelmann, F., & Jäger, L. A., and Vasishth, S. (submitted for publication). The determinants of retrieval interference in dependency resolution: Review and computational modeling.

Fayol, M., & Got, C. (1991). Automatisme and contrôle dans la production écrite: les erreurs d'accord sujet verbe chez l'enfant et l'adulte. L'année psychologique, 91(2), 187-205.

Fayol, M., Largy, P., and Lemaire, P. (1994). Cognitive overload and orthographic errors: When cognitive overload enhances subject–verb agreement errors. A study in French written language. *The Quarterly Journal of Experimental Psychology*, *47*(2), 437-464.

Fodor, J., Bever, A., & Garrett, T. G. (1974). The psychology of language: An introduction to psycholinguistics and generative grammar. New York: McGraw-Hill.

Franck, J., Vigliocco, G., and Nicol, J. (2002). Subject-verb agreement errors in French and English: The role of syntactic hierarchy. *Language and cognitive processes*, *17*(4), 371-404.

Franck, J., Cronel-Ohayon, S., Chillier, L., Frauenfelder, U. H., Hamann, C., Rizzi, L., & Zesiger, P. (2004). Normal and pathological development of subject–verb agreement in speech production: A study on French children. *Journal of Neurolinguistics*, *17*(2), 147-180.

Franck, J., Lassi, G., Frauenfelder, U. H., and Rizzi, L. (2006). Agreement and movement: A syntactic analysis of attraction. *Cognition*, *101*(1), 173-216.

Franck, J., Vigliocco, G., Antón-Méndez, I., Collina, S., & Frauenfelder, U. H. (2008). The interplay of syntax and form in sentence production: A cross-linguistic study of form effects on agreement. *Language and Cognitive Processes*, *23*(3), 329-374.

Franck, J., Soare, G., Frauenfelder, U. H., and Rizzi, L. (2010). Object interference in subject–verb agreement: The role of intermediate traces of movement. *Journal of Memory and Language*, *62*(2), 166-182.

Franck, J., Colonna, S., and Rizzi, L. (2015). Task-dependency and structure-dependency in number interference effects in sentence comprehension. *Frontiers in psychology*, *6*, 349.

Franck, J. (2017). Syntactic encoding: Novel insights into the relationship between grammar and processing. In E. Fernandez and H. Cairns (Eds.) The handbook of psycholinguistics. Wiley :NJ.

Frauenfelder, U., Segui, J., and Mehler, J. (1980). Monitoring around the relative clause. *Journal of Verbal Learning and Verbal Behavior*, *19*(3), 328-337.

Garraffa, M., and Grillo, N. (2008). Canonicity effects as grammatical phenomena. *Journal of Neurolinguistics*, *21*(2), 177-197.

Gazdar, Gerald. (1981). Unbounded dependencies and coordinate structure. *Linguistic Inquiry, 12*, 155–184.

Gennari, S. P., and MacDonald, M. C. (2008). Semantic indeterminacy in object relative clauses. *Journal of memory and language*, *58*(2), 161-187.

Gordon, P. C., Hendrick, R., and Johnson, M. (2001). Memory interference during language processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*(6), 1411.

Gordon, P. C., Hendrick, R., and Levine, W. H. (2002). Memory-load interference in syntactic processing. *Psychological science*, *13*(5), 425-430.

Gordon, P. C., Hendrick, R., and Johnson, M. (2004). Effects of noun phrase type on sentence complexity. *Journal of Memory and Language*, *51*(1), 97-114.

Greenberg, J. H. (1963). Some universals of grammar with particular reference to the order of meaningful elements. *Universals of language*, *2*, 73-113.

Hartsuiker, R. J., Antón-Méndez, I., and van Zee, M. (2001). Object attraction in subject-verb agreement construction. *Journal of Memory and Language*, *45*(4), 546-572.

Hartsuiker, R. J., Schriefers, H. J., Bock, K., and Kikstra, G. M. (2003). Morphophonological influences on the construction of subject-verb agreement. *Memory and Cognition*, *31*(8), 1316-1326.

Haskell, T. R., and MacDonald, M. C. (2003). Conflicting cues and competition in subject–verb agreement. *Journal of Memory and Language*, *48*(4), 760-778.

Hofmeister, P. (2011). Representational complexity and memory retrieval in language comprehension. *Language and cognitive processes*, *26*(3), 376-405.

Hofmeister, P., and Vasishth, S. (2014). Distinctiveness and encoding effects in online sentence comprehension. *Frontiers in psychology*, *5*.

Hupet, M., Schelstraete, M. A., Demaeght, N., & Fayol, M. (1996). Les erreurs d'accord sujet-verbe en production écrite. *L'année psychologique*, *96*(4), 587-610.

Hupet, M., Fayol, M., & Schelstraete, M. A. (1998). Effects of semantic variables on the subject—verb agreement processes in writing. *British journal of psychology*, *89*(1), 59-75.

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of memory and language*, *59*(4), 434-446.

Jäger, L. A., Benz, L., Roeser, J., Dillon, B. W., and Vasishth, S. (2015). Teasing apart retrieval and encoding interference in the processing of anaphors. *Frontiers in psychology*, *6*.

Jäger, L. A., Engelmann, F., and Vasishth, S. (2017). Similarity-based interference in sentence comprehension: literature review and Bayesian meta-analysis. J. Mem. Lang. 94, 316–339. doi: 10. 1016/j. jml. 2017. 01. 004

Just, M. A., Carpenter, P. A., and Woolley, J. D. (1982). Paradigms and processes in reading comprehension. *Journal of experimental psychology: General*, *111*(2), 228.

Just, M. A., and Carpenter, P. A. (1992). A capacity theory of comprehension: individual differences in working memory. *Psychological review*, *99*(1), 122.

Kayne, R. (1989). Facets of Romance past participle agreement. *Dialect variation and the theory of grammar*, 85-103.

King, J., and Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of memory and language*, *30*(5), 580-602.

Kuznetsova, A., Brockhoff, P. B., and Christensen, R. H. B. (2015). Package 'lmerTest'. *R package version*, 2-0.

Lago, S., Shalom, D. E., Sigman, M., Lau, E. F., and Phillips, C. (2015). Agreement attraction in Spanish comprehension. *Journal of Memory and Language*, *82*, 133-149.

Lewis, R. L., and Vasishth, S. (2005). An activation-based model of sentence processing as skilled memory retrieval. *Cognitive science*, *29*(3), 375-419.

Lewis, R. L., Vasishth, S., and Van Dyke, J. A. (2006). Computational principles of working memory in sentence comprehension. *Trends in cognitive sciences*, *10*(10), 447-454.

Mak, W. M., Vonk, W., and Schriefers, H. (2002). The influence of animacy on relative clause processing. *Journal of Memory and Language*, *47*(1), 50-68.

Mak, W. M., Vonk, W., and Schriefers, H. (2006). Animacy in processing relative clauses: The hikers that rocks crush. *Journal of Memory and Language*, *54*(4), 466-490.

Malko, A., and Slioussar, N. (2013). Attraction Errors in Gender Agreement: Evidence from Russian. In *Proceedings of FASL* (Vol. 21, 162-175).

McElree, B., & Dosher, B. A. (1989). Serial position and set size in short-term memory: the time course of recognition. Journal of Experimental Psychology: General, 118(4), 346.

McElree, B. (2000). Sentence comprehension is mediated by content-addressable memory structures. Journal of psycholinguistic research, 29(2), 111-123.

McElree, B., Foraker, S., and Dyer, L. (2003). Memory structures that subserve sentence comprehension. Journal of Memory and Language, 48(1), 67-91.

McElree, B. (2006). Accessing recent events. Psychology of learning and motivation, 46, 155-200.

Meyer, A. S., and Bock, K. (1999). Representations and processes in the production of pronouns: Some perspectives from Dutch. *Journal of Memory and Language, 41*(2), 281-301.

Nairne, J. S. (1990). A feature model of immediate memory. *Memory and Cognition*, *18*(3), 251-269.

Nicenboim, B., Vasishth, S., Engelmann, F., and Suckow, K. (2018). Exploratory and confirmatory analyses in sentence processing: A case study of number interference in German. *Cognitive science*.

Nicol, J. L. Forster, K. I., & Veres, C. (1997). Subject-verb agreement processes in comprehension. Journal of Memory and Language, 36(4), 569-587.

Nicol, J. L., Barss, A., and Barker, J. E. (2016). Minimal interference from possessor phrases in the production of subject-verb agreement. *Frontiers in psychology*, *7*.

Oberauer, K., and Kliegl, R. (2006). A formal model of capacity limits in working memory. *Journal of Memory and Language*, *55*(4), 601-626.

Patson, N. D., & Husband, E. M. (2016). Misinterpretations in agreement and agreement attraction. *The Quarterly Journal of Experimental Psychology*, *69*(5), 950-971.

Pearlmutter, N. J., Garnsey, S. M., and Bock, K. (1999). Agreement processes in sentence comprehension. *Journal of Memory and language*, *41*(3), 427-456.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www. R-project. org/.

Santesteban, M., Pickering, M. J., and Branigan, H. P. (2013). The effects of word order on subject–verb and object–verb agreement: Evidence from Basque. *Journal of Memory and Language*, *68*(2), 160-179.

Schmid, S., Villata, S., Tabor, W., and Franck, J. (2018). Two mechanism underlying agreement errors. Poster presented at Cuny, Uc Davis.

Schneider, W., Eschman, A., and Zuccolotto, A. (2012). E-Prime User's Guide. Pittsburgh: Psychology Software Tools, Inc.

Shen, E. Y., Staub, A., and Sanders, L. D. (2013). Event-related brain potential evidence that local nouns affect subject–verb agreement processing. *Language and Cognitive Processes*, *28*(4), 498-524.

Smith, G., Franck, J., and Tabor, W. (2016). An asymmetry of agreement attraction provides evidence for self-organized parsing. Poster presented at the *29th CUNY Conference on Human Sentence Processing*.

Smith, G., Franck, J., and Tabor, W. (2018). A Self-Organizing Approach to Subject-Verb Number Agreement. *Cognitive Science, 42*(S4), 1043-1074.

Smith, G., and Tabor, W. (2018). Toward a theory of timing effects in self-organized sentence processing. *Proceedings of the 16th Annual Meeting of the International Conference on Cognitive Modeling.*

Staub, A. (2009). On the interpretation of the number attraction effect: Response time evidence. *Journal of Memory and Language*, *60*(2), 308-327.

Staub, A. (2010). Response time distributional evidence for distinct varieties of number attraction. *Cognition*, *114*(3), 447-454.

Stavrakaki, S. (2001). Comprehension of reversible relative clauses in specifically language impaired and normally developing Greek children. *Brain and language*, *77*(3), 419-431.

Stevenson, S. (1994). Competition and recency in a hybrid network model of syntactic disambiguation. Journal of Psycholinguistic Research, 23(4), 295–322.

Tabor, W., and Hutchins, S. (2004). Evidence for self-organized sentence processing: digging in effects. J. Exp. Psychol. Learn. Mem. Cogn. 30, 431–450. doi: 10. 1037/0278-7393. 30. 2. 431

Tanner, D., Nicol, J., and Brehm, L. (2014). The time-course of feature interference in agreement comprehension: Multiple mechanisms and asymmetrical attraction. *Journal of memory and language*, *76*, 195-215.

Thornton, R., and MacDonald, M. C. (2003). Plausibility and grammatical agreement. *Journal of Memory and Language*, *48*(4), 740-759.

Traxler, M. J., Morris, R. K., and Seely, R. E. (2002). Processing subject and object relative clauses: Evidence from eye movements. *Journal of Memory and Language*, *47*(1), 69-90.

Tucker, M. A., Idrissi, A., and Almeida, D. (2015). Representing number in the real-time processing of agreement: self-paced reading evidence from Arabic. *Frontiers in psychology*, *6*, 347.

Van der Velde, F., & De Kamps, M. (2006). Neural blackboard architectures of combinatorial structures in cognition. *Behavioral and Brain Sciences*, *29*(1), 37-70.

Van Dyke, J. A. (2007). Interference effects from grammatically unavailable constituents during sentence processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(2), 407.

Van Dyke, J. A., and Lewis, R. L. (2003). Distinguishing effects of structure and decay on attachment and repair: A cue-based parsing account of recovery from misanalyzed ambiguities. *Journal of Memory and Language*, *49*(3), 285-316.

Van Dyke, J. A., and McElree, B. (2006). Retrieval interference in sentence comprehension. *Journal of Memory and Language*, *55*(2), 157-166.

Van Dyke, J. A. (2007). Interference effects from grammatically unavailable constituents during sentence processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(2), 407.

Van Dyke, J. A., and McElree, B. (2011). Cue-dependent interference in comprehension. *Journal of memory and language*, *65*(3), 247-263.

Vigliocco, G., Butterworth, B., and Semenza, C. (1995). Constructing subject-verb agreement in speech: The role of semantic and morphological factors. *Journal of Memory and Language*, *34*(2), 186.

Vigliocco, G., Butterworth, B., and Garrett, M. F. (1996). Subject-verb agreement in Spanish and English: Differences in the role of conceptual constraints. *Cognition*, *61*(3), 261-298.

Vigliocco, G., and Franck, J. (1999). When sex and syntax go hand in hand: Gender agreement in language production. *Journal of Memory and Language*, *40*(4), 455-478.

Vigliocco, G., and Zilli, T. (1999). Syntactic accuracy in sentence production: The case of gender disagreement in Italian language-impaired and unimpaired speakers. *Journal of Psycholinguistic Research*, *28*(6), 623-648.

Vigliocco, G., and Franck, J. (2001). When sex affects syntax: Contextual influences in sentence production. *Journal of Memory and Language*, *45*(3), 368-390.

Villata, S., Tabor, W., & Franck, J. (2018). Encoding and retrieval interference in sentence comprehension: Evidence from agreement. *Frontiers in psychology*, *9*, 2.

Vosse, T., and Kempen, G. (2000). Syntactic structure assembly in human parsing: a computational model based on competitive inhibition and a lexicalist grammar. Cognition 75, 105–143.

Wagers, M. W., Lau, E. F., and Phillips, C. (2009). Agreement attraction in comprehension: Representations and processes. *Journal of Memory and Language*, *61*(2), 206-237.

List of Tables

Table 1

Example of item in the four experimental conditions of Experiment 1.

Singular object	
Match (SS)	Voilà/le danseur/que/le serveur/disait/avoir/énervé-*énervés *Here's/the dancer-SG/that/the waiter-SG/claimed/to have/surprised-SG-*surprised-PL*
Mismatch (SP)	Voilà/le danseur/que/les serveurs/disaient/avoir/énervé-*énervés *Here's/the dancer-SG/that/the waiters-PL/claimed/to have/surprised-SG-*surprised-PL*
Plural object	
Match (PP)	Voilà/les danseurs/que/les serveurs/disaient/avoir/énervés-(*)énervé *Here's/the dancers-PL/that/the waiters-PL/claimed/to have/surprised-PL-*surprised-SG*
Mismatch (PS)	Voilà/les danseurs/que/le serveur/disait/avoir/énervés-(*)énervé *Here's/the dancers-PL/that/the waiter-SG/claimed/to have/surprised-PL-*surprised-SG*

Note. The two past participles in the examples indicate the options among which participants were asked to make a choice. The asterisk in brackets indicates that the singular agreement is not truly ungrammatical, due to the optionality of the object-past participle agreement in colloquial French. This contrasts with the plural agreement with a singular object, which is truly ungrammatical.

Table 2

Example of item in the eight experimental conditions of Experiment 2.

Masculine object	
Match (MM)	Voilà / le danseur/que/le serveur/a/surpris-*surprise *Here's/the dancer-MASC/that/the waiter-MASC/has/surprised-MASC-*surprised-FEM*
Mismatch (MF)	Voilà / le danseur/que/la serveuse/a surpris-*surprise *Here's/ the dancer-MASC/that/the waiter-FEM/has surprised-MASC-*surprised-FEM*
Feminine object	
Match (FF)	Voilà/la danseuse/que/la serveuse/a/surprise-(*)surpris *Here's / the dancer-FEM/that/the waiter-FEM/has/surprised-FEM-surprised-MASC*
Mismatch (FM)	Voilà/la danseuse /que/le serveur/a/surprise-(*)surpris *Here's /the dancer-FEM/that/the waiter-MASC/has/surprised-FEM-surprised-MASC*

Table 3

Example of item in the eight experimental conditions of Experiment 3.

	Object relative
Singular object	
Match (SS)	Le danseur/que/le serveur/disait/avoir/souvent/énervé/buvait/un cocktail/alcoolisé. *The dancer-SG/that/the waiter-SG/claimed-SG/to have/often/annoyed-SG/drank-SG/a cocktail/with alcohol.*
Mismatch (SP)	Le danseur/que/les serveurs/disaient/avoir/souvent/énervé/buvait/un cocktail/alcoolisé. *The dancer-SG/that/the waiters-PL/claimed-PL/to have/often/annoyed-SG/drank-SG/a cocktail/with alcohol.*

Plural object	
Match (PP)	Les danseurs/que/les serveurs/disaient/avoir/souvent/énervés/buvaient/un cocktail/alcoolisé. *The dancers-PL/that/the waiters-PL/claimed-PL/to have/often/annoyed-PL/drank-PL/a cocktail/with alcohol.*
Mismatch (PS)	Les danseurs/que/le serveur/disait/avoir/souvent/énervés/buvaient/un cocktail/alcoolisé. *The dancers-PL/that/the waiter-SG/claimed-SG/to have/often/annoyed-PL/drank-PL/a cocktail/with alcohol.*
	Subject relative
Singular object	
Match (SS)	Le serveur/qui/disait/avoir/souvent/énervé/le danseur/buvait/un cocktail/alcoolisé. *The waiter-SG/who/claimed-SG/to have/often/annoyed-SG/the dancer-SG/drank/a cocktail/with alcohol.*
Mismatch (PS)	Les serveurs/qui/disaient/avoir/souvent/énervé/le danseur/buvaient/un cocktail/alcoolisé. *The waiters-PL/who/claimed-PL/to have/often/annoyed-SG/the dancer-SG/drank-PL/a cocktail/with alcohol.*
Plural object	
Match (PP)	Les serveurs/qui/disaient/avoir/souvent/énervé/les danseurs/buvaient/un cocktail/alcoolisé. *The waiters-PL/who/claimed-PL/to have/often/annoyed-SG/the dancers-PL/drank-PL/a cocktail/with alcohol.*
Mismatch (SP)	Le serveur/qui/disait/avoir/souvent/énervé/les danseurs/buvait/un cocktail/alcoolisé. *The waiter-SG/who/claimed-SG/to have/often/annoyed-SG/the dancers-PL/drank-SG/a cocktail/with alcohol.*

Table 4

Example of item in the eight experimental conditions of Experiment 4.

	Object relative
Masculine object	
Match (MM)	Le danseur/que/le serveur/a/surpris/buvait/un cocktail/alcoolisé. *The dancer-MASC/that/the waiter-MASC/has/surprised-MASC/ drank/a cocktail/with alcohol.*
Mismatch (MF)	Le danseur/que/la serveuse/a/surpris/buvait/un cocktail/alcoolisé. *The dancer-MASC/that/the waiter-FEM/has/surprised-MASC/ drank/a cocktail/with alcohol.*
Feminine object	
Match (FF)	La danseuse/que/la serveuse/a/surprise/buvait/un cocktail/alcoolisé. *The dancer-FEM/that/the waiter-FEM/has/surprised-FEM/ drank/a cocktail/with alcohol.*
Mismatch (FM)	La danseuse /que/le serveur/a/surprise/buvait/un cocktail/alcoolisé. *The dancer-FEM/that/the waiter-MASC/has/surprised-FEM/ drank/a cocktail/with alcohol.*
	Subject relative
Masculine object	
Match (MM)	Le serveur/qui/a/surpris/le danseur/buvait/un cocktail/alcoolisé. *The waiter-MASC/who/has/surprised-MASC/the dancer-MASC/drank/a cocktail/with alcohol.*
Mismatch (FM)	La serveuse/qui/a/surpris/le danseur/buvait/un cocktail/alcoolisé. *The waiter-FEM/who/has/surprised-MASC/the dancer-MASC/drank/a cocktail/with alcohol.*
Feminine object	
Match (FF)	La serveuse/qui/a/surpris/la danseuse/buvait/un cocktail/alcoolisé. *The waiter-FEM/who/has/surprised-MASC/the dancer-FEM/drank/a cocktail/with alcohol.*

Mismatch (MF)	Le serveur/qui/a/surpris/ la danseuse/buvait/un cocktail/alcoolisé. *The waiter-MASC/who/has/surprised-MASC/the dancer-FEM/drank/a cocktail/with alcohol.*

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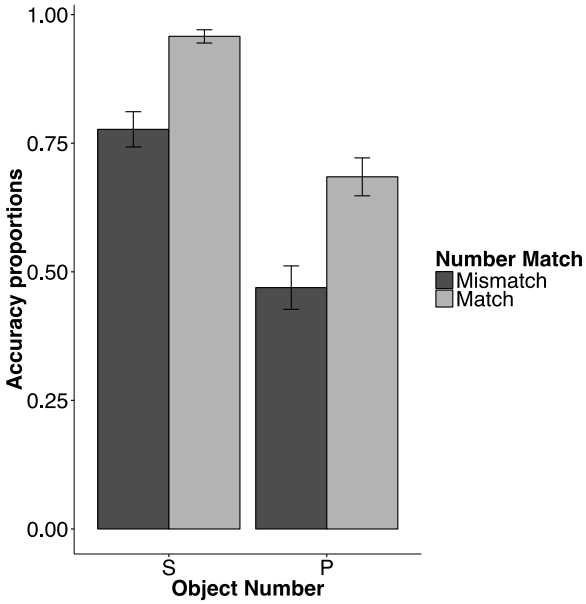

Figure 1. Accuracy proportion in Experiment 1. Error bars represent standard errors by subject means.

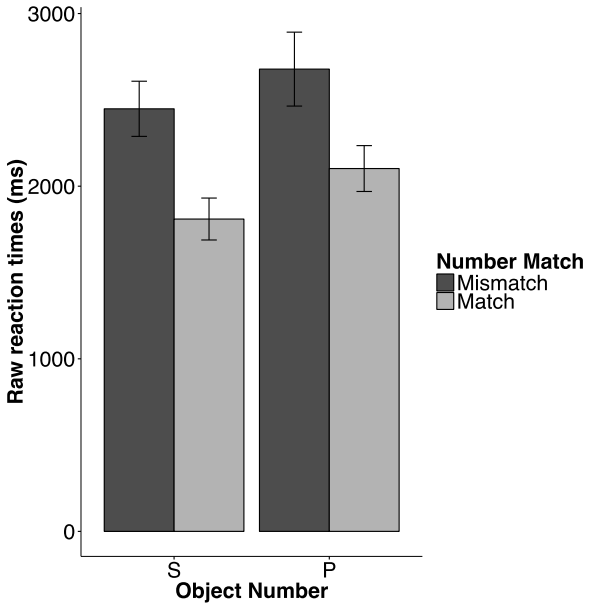

Figure 2. Distribution of responses times (in ms) in Experiment 1. Error bars represent standard errors by subject means.

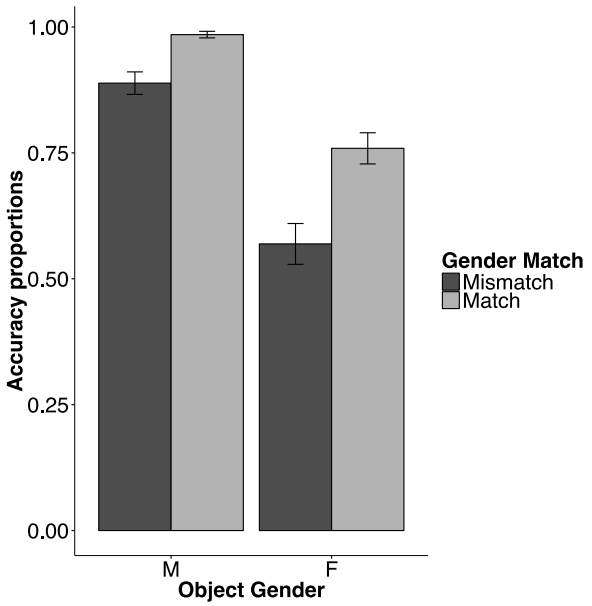

Figure 3. Accuracy proportions in Experiment 2. Error bars represent standard errors by subject means.

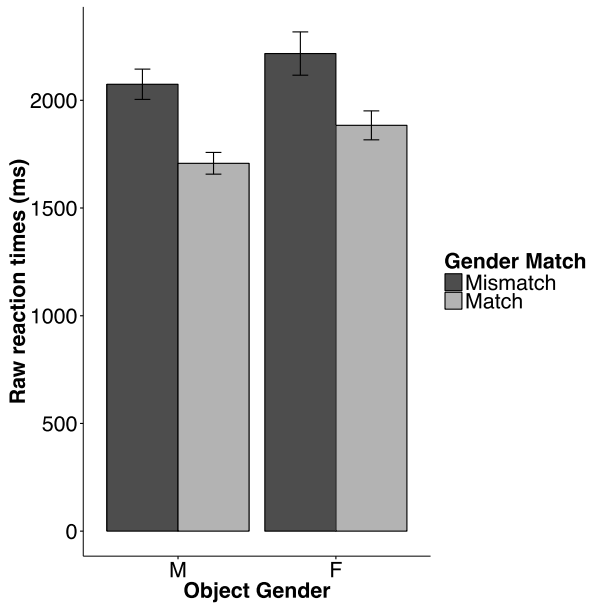

Figure 4. Distribution of responses times (in ms) in Experiment 2. Error bars represent standard errors by subject means.

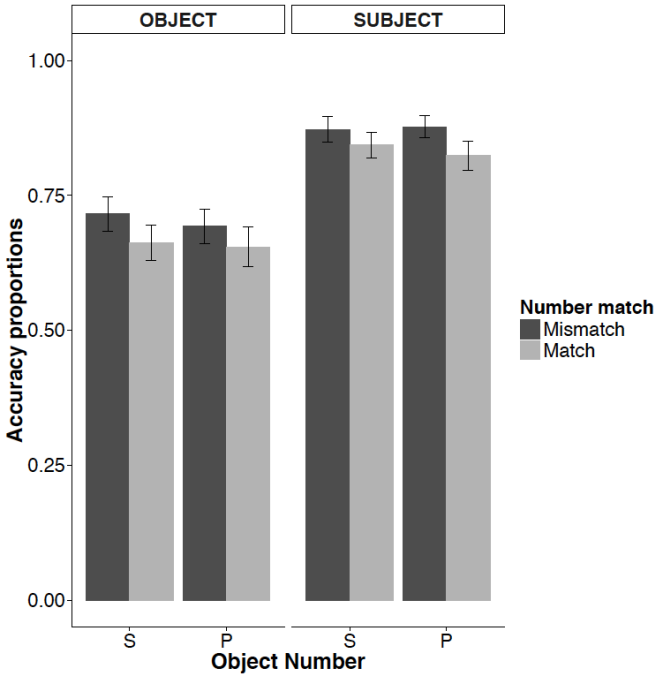

Figure 5. Distribution of accuracy proportions to comprehension questions in Experiment 3. Error bars represent standard errors by subject means.

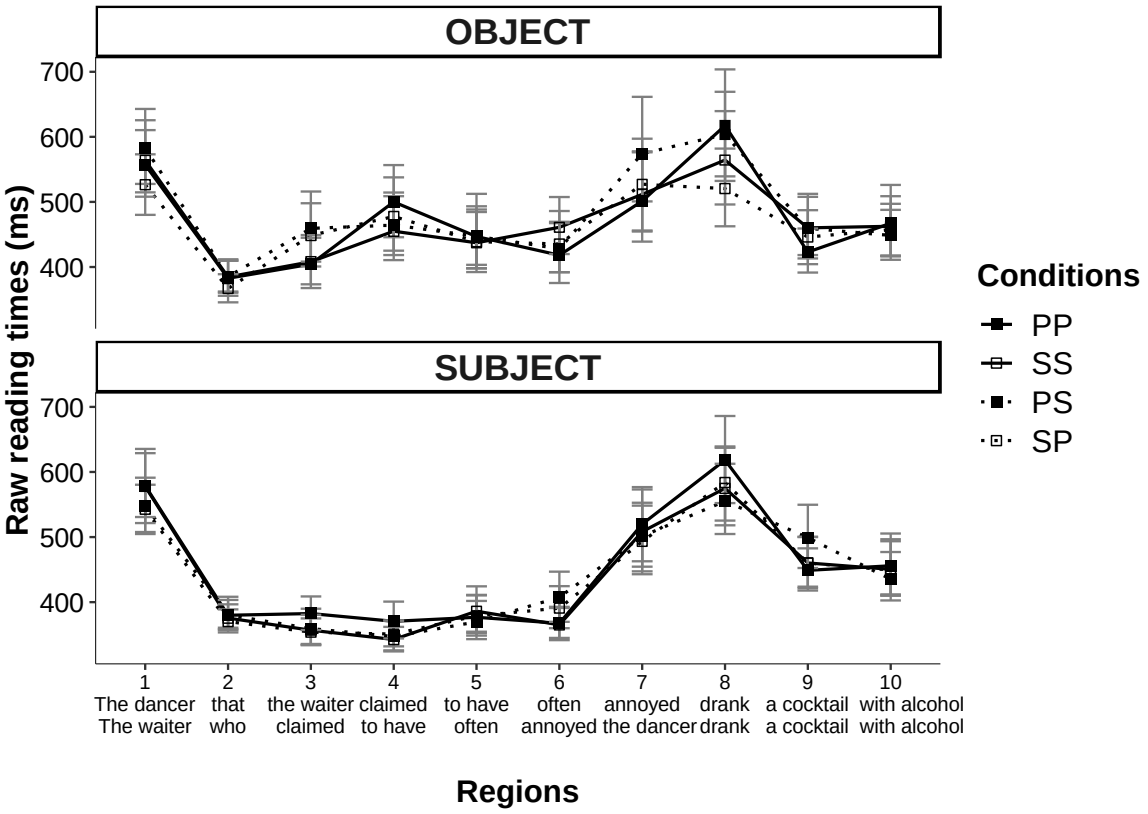

Figure 6. Distribution of reading times (in ms) in the eight experimental conditions of the different regions of Experiment 3 (correct trials only). We plot raw reading times in ms for the sake of readability, but statistical analyses were performed on residual log reading times. Error bars represent standard errors by subject means.

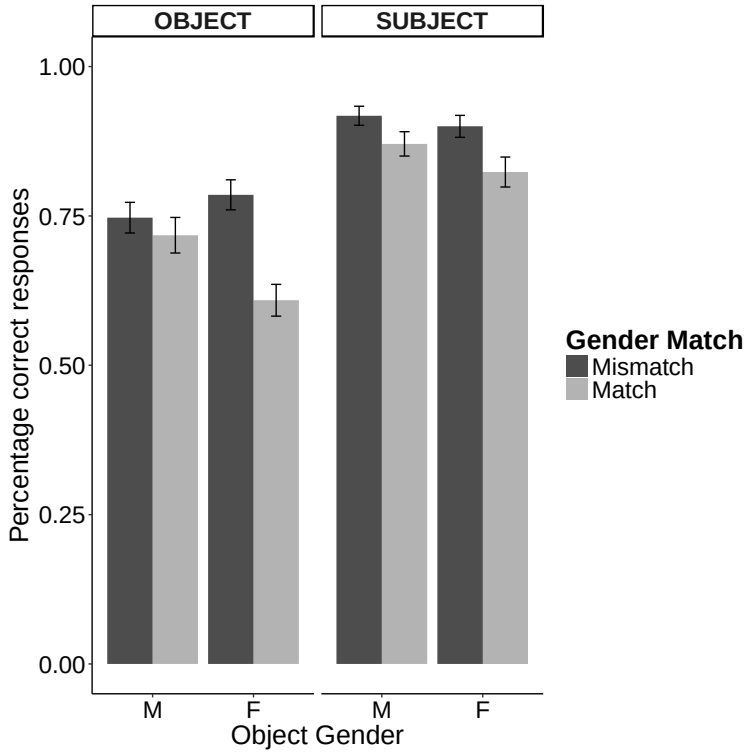

Figure 7. Accuracy proportion in the comprehension question of Experiment 4. Error bars represent standard errors by subject means.

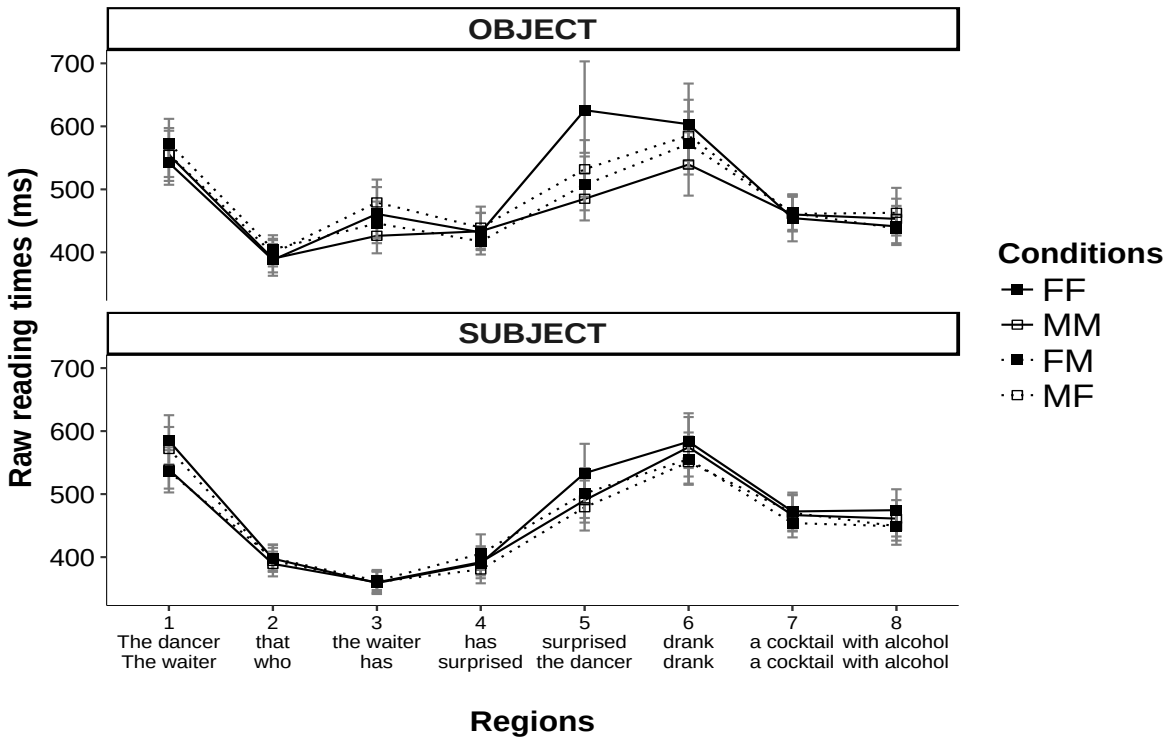

Figure 8. Distribution of reading times (in ms) in the eight experimental conditions for the different regions of Experiment 4 (correct trials only). Error bars represent standard errors by subject means.

Footnotes

[1] Since all the reported experiments were carried out at the University and only undergraduates' students took part in them, we did not collect more fine-grained information about participants' ages.

[2] Since we only tested grammatical sentences, unlike most studies in the literature, we based our power analysis on Experiment 1 in Franck et al. (2015), who tested for attraction errors in the comprehension of grammatical French ORs, and Villata et al. (2018), who tested for attraction errors in the comprehension of Italian (Experiment 1) and English (Experiment 2) grammatical ORs. Franck et al. reported a match effect of 72 ms at the critical verb region and a standard deviation of 61.5 ms. Villata et al. found a match effect of 119 ms with a standard deviation of 130 ms in Italian at the critical verb region, and a match effect of 74 ms and a standard deviation of 79 ms at the spillover region in English. However, Villata et al.'s effects were significant only when longer reading times (up to 8000 ms) were included in the analyses, which is likely to account for the high standard deviation observed in the Italian study. However, since most of the studies in the literature failed to find an effect of match in grammatical sentences, in the power analysis we assumed a smaller effect (30 ms), in order to remain more conservative in our power estimation. The standard deviation (75 ms) was close to the one in Franck et al. and Villata et al. (Experiment 2), and also matched the one reported in the power analysis in Jäger et al. (2015).

[3] The direction of the interaction is opposite to that suggested by Figure 1, as shown by the parameter estimate, which is larger for singular (β = -0.969) than for plural (β = -0.697). This is because when proportions are transformed to logits, differences in the part of the scale near 0 or 1 are magnified (Jaeger, 2008). This means that we cannot exclude that the observed interaction might be spurious. It is worth noting, however, that empirical evidence shows that markedness effects in French are absent or even reverted, with stronger attraction from singular attractors than plural ones (e.g., Fayol & Got, 1991; Fayol et al., 1994; Hupet et

al., 1996; Hupet et al., 1998; Franck et al., 2004). French differs from English in that singular verbs are morphologically simpler than plural ones in French, while the opposite is true for English (see Franck et al., 2008). It has been argued that two factors are at play in markedness effects: one has to do with the markedness of the local noun, the other has to do with the morphological complexity of the verb. Whereas the markedness of the local noun pushes the system to produce an erroneous plural verb, in all languages, the morphological complexity of the verb pushes French speakers to produce a singular verb, but English speakers to produce a plural verb. As a result, whereas the two factors converge to produce erroneous plural verbs in English, the effect of the two factors diverges in French.

[4] In Dynamical Systems Theory, these convergence points are called "attractors". An attractor, in this sense, is a point to which the system converges from an open set of surrounding points. We avoid this terminology here to avoid confusion with the different use of the term in the context of agreement "attraction".