**Influence of ambiguity resolution during auditory language
comprehension on executive control processes: a dual-task
paradigm**

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Abstract

In the present preregistered study, we evaluated the impact of linguistic ambiguity processing on non-verbal inhibitory processing in a dual-task paradigm. We assessed whether a shared mechanism is involved during verbal and non-verbal conflict resolution. To do so, we constructed a dual-task paradigm including an auditory language comprehension and a non-verbal Flanker task. The language comprehension stimuli included sentences with French homophones presenting a temporary ambiguity (ambiguous sentences) or not (control sentences). The Flanker task included congruent (low executive control load) and incongruent (high executive control load) trials that were synchronized or not with the homophone in the sentence. We hypothesized that if the homophone meaning selection requires executive control this would interfere with executive control performance of the concomitant Flanker trials. This would be reflected by a performance cost during incongruent Flanker trials for the ambiguous sentences only. Surprisingly, we observed a facilitatory effect during ambiguous sentences on incongruent Flanker trials suggesting better non-verbal inhibitory performances when homophone conflict resolution was simultaneously performed. Exploratory data analysis suggests that this effect is not only related to ambiguity resolution processing but also to the previous ($n-1$) Flanker trial. Indeed, results showed that incongruent $n-1$ Flanker trials led to a facilitation of the incongruent *target* Flanker trials only when ambiguous sentences were conjointly presented. This result, even if it remains to be corroborated in future studies, suggests that the recruitment of executive control mechanisms facilitates subsequent executive control implication during difficult language processing. The present study supports the view of a common executive control mechanism during conflict resolution in verbal and non-verbal tasks.

Introduction

A controversial question is whether language comprehension involves cognitive mechanisms specific for decoding linguistic information or whether language comprehension implies more domain-general cognitive processes. Several authors suggested that language comprehension is performed by language-specific mechanisms only [1–4]., Others authors argue for a more domain-general account of language comprehension with an involvement of the canonical language brain network but also others brain networks (e.g. [5–7]). In line with these assumptions, behavioral and neuroimaging evidence suggest that linguistic information processing could be shared within a larger machinery which encompasses other cognitive functions such as executive control (e.g., [8,9]). It has been also proposed that the recruitment of this domain-general machinery depends upon situation demands. For instance, according to the *Good-Enough* approach [10] cognitive processes at work during language comprehension would depend on the situation requirements. This approach suggests that linguistic inputs are not analyzed in deep in most of language comprehension situation. In several daily live situations only a heuristic analysis is performed as few information is sufficient to have a general idea of what has been said and to be able to communicate. Nevertheless, if the situation requires a deep understand or if the speech is physically or linguistically degraded [11]; or if the linguistic information is complex [12] or ambiguous [13], domain-general mechanism is suggested to be involved and allows a deeper and controlled analysis.

In this debate, the relationship between language processing and executive control has been mostly studied using neuroimaging methods showing an overlap of brain regions recruited during both executive control and language processing tasks

[14–17]. January, Trueswell, and Thompson-Schill [18] showed such an overlap in an fMRI study between bold activity in the posterior left inferior frontal gyrus (LIFG) during high conflict sentence comprehension and incongruent Stroop trials. This overlap suggests that cognitive processes during language resolution and the executive inhibitory processes share the same brain structure, (see [19,20] for reviews). However, it has been argued that this overlap was observed because of the use of a verbal executive control task. According to this view, processes supporting such a verbal conflict resolution would be language-specific and would rely on language-specific brain regions [21,22]. Recently, Hsu, Jaeggi, and Novick [9] showed that the LIFG could be considered as a conflict resolution hub that coordinates with different networks depending on the task (see also [23]). More specifically, authors showed that the LIFG was recruited during language conflict as well as during resolution of proactive inference in memory and executive control. Therefore, it seems that both domain-general and domain-specific processes interact during conflict resolution in language comprehension tasks supporting the view of an involvement of executive control processes during language processing.

Additional evidence for such an involvement comes from neuropsychological studies. Vuong and Martin [24] tested two patients with LIFG lesion and a control patient without LIFG lesion on an attentional control task as well as in language comprehension task. Patients with a LIFG lesion exhibited lower attentional control performances and more difficulties to resolve lexical ambiguities. Authors interpreted this result as evidence for a role of attentional control in lexical ambiguity resolution. Novick, Kan, Trueswell and Thompson-Schill [25] also showed such a pattern with LIFG lesion patients during comprehension of syntactically ambiguous sentences. More specifically, patients presented difficulties to inhibit and revise their first

interpretation of syntactically ambiguous sentences supporting the view of an involvement of inhibitory processes during difficult language comprehension situations. Interestingly, a similar pattern of results has been observed among children for whom lower cognitive control abilities in relation with the slow maturation of the frontal cortex was observed [26]. Children around five showed more difficulties to follow temporarily syntactically ambiguous instructions than adults with less abilities to revise and inhibit their first interpretation [27–29].

On a behavioral level, several studies showed correlations between executive control performances and language processing [30,31] suggesting shared cognitive processes between both executive control and language comprehension. In this vein, Brown-Schmidt [32] was able to predict participants' language comprehension performances based on a verbal inhibitory assessment (see also, [33]). Hussey and collaborators [34] showed an improvement in language processing after a cognitive control training through a N-back task in which participants see letters one by one and have to update information in working memory in order to be able to decide whether the presented letter is the same as the one presented 3 letters before. In this study, participants were trained on a N-Back task and were then tested on a language processing task. Participants who performed a high-conflict training reread faster and more easily ambiguous sentences than participants who performed a low-conflict training (see also [35,36] for similar studies). Such training evidence showed a causal effect of domain-general executive control on language processing. Similarly, Rodd, Johnsrude, and Davis [37] showed that reanalysis of ambiguous sentences relied on domain-general processes. In their study, participants listened to sentences containing or not a semantic ambiguity (driven by two homophones) and performed a case-judgment task on a visually presented letter that appeared at different times in the

sentence (at the first homophone, the second, or by the end of the sentence). Authors observed an interference effect only when the letter was presented by the end of ambiguous sentences that required a reanalysis. This result suggests a direct involvement of executive control processes during syntactic reanalysis of ambiguous sentences. Together, these behavioral studies emphasize the view of a direct involvement of executive control processes and more specifically inhibitory and attentional control processes during language comprehension.

The present study aims at evaluating whether common cognitive mechanisms are shared during verbal and non-verbal conflict resolution tasks. More specifically we evaluated whether homophone meaning selection influences a concomitant nonverbal inhibitory control performance. To test this claim, we designed a dual-task paradigm involving: a language comprehension task (auditory sentence comprehension) and a Flanker task that participants performed at the same time. We chose the Flanker task because it is known to assess inhibition control and interference resistance [38], processes that are suggested to be involved during meaning selection [39]. Given that executive control processes are involved in both Flanker and language conflict resolution, we hypothesized a more important interference during difficult Flanker condition concomitantly presented with ambiguous sentences than with unambiguous ones.

Materials and methods

This study has been preregistered on the Open Science Framework website before data collection. The project including protocol and material is available at this link: https://osf.io/65saf/?view_only=7995e9d41aab4d978cbf7f3a72cf24ac

Participants

Eighty students from Université Grenoble Alpes participated in this study (Mean age = 20.8yo, $SD = 3.4$ yo) and received course credits for their participation. All were right handed and native French speakers with a normal or corrected vision and without hearing problem. Previous power calculation for sample size choice (80 participants needed) was computed from PANGAEA's website (Power ANalysis for GEneral Anova designs, v0.2) (see in the preregistered supplementary material). Each participant gave written consent before performing the experiment. This study has been approved by the local ethical committee (CERGA, N°CER Grenoble Alpes-Avis-2020-03-10-02).

Task

Participants were instructed to perform a dual-task paradigm involving: a Flanker task [38] and an auditory language comprehension task. More specifically, participants were instructed to listen to auditory sentences and to perform a Flanker task at the same time (see Fig 1). The Flanker task was designed to measure inhibition control and interference resistance by assessing ability to suppress predominant response. For the Flanker task participants were instructed to decide whether a central arrow in a string of five arrows pointed to the right or to the left. For the auditory language comprehension task, participants were instructed to listen to the auditory delivered sentences and to be able to answer a yes/no question related to these sentences.

The Flanker visual stimuli were strings of five arrows either all pointing to the same direction (left or right, congruent trials), or the central arrow pointing to the opposite direction of the other four arrows (incongruent trials). A total of 520 trials were presented, half of them for the Control condition (i.e., easy control condition, 260 trials) and the other half for the Incongruent condition (difficult control condition, 260 trials). Strings of arrows were presented in the center of the screen (i.e. grey) with a visual angle of 3.6 degrees (around 4 centimeters on the screen).

Auditory language comprehension task

A set of 130 auditory French sentences were selected from the study of Millotte, René, Wales, and Christophe [40] and included in three different experimental conditions: Ambiguity, Control and Fillers. The Ambiguity condition included 20 pairs of temporary ambiguity sentences (mean duration = 2974 ms; SD = 430 ms). In these sentences, lexical ambiguity was manipulated by the presence of an auditory homophone word that is only desymbolised by the subsequent lexical context for instances: “*Le petit chien mord la laisse dans l’espoir de se libérer*” (The little dog bites the leash hoping to free himself) and “*Le petit chien mort sera enterré demain par ses maîtres*” (The dead little dog will be buried tomorrow by his owners). Thus, the sequence of the first four words are phonologically similar (i.e., / l ə p ə t i j j ɛ̃ m ɔ R /), nevertheless in the first sentence the homophone must be interpreted as a verb (i.e., mord) and in the second sentence as an adjective (i.e., mort). This can be done only when the last part of the sentence is presented. The second condition, the Control condition, also included 20 auditory sentences (mean duration = 3093 ms; SD = 602 ms). The control sentences contained the same homophones as in the Ambiguous conditions but with a different sentence context. In particular, the beginning of the

control sentence leads to only one possible meaning of the homophone (e.g., “*Maintenant qu’il est mort les batailles d’héritages vont commencer*”, Now he is dead the heritage fights are going to start, and “*Parfois on se mord la langue quand on mange trop vite*”, Sometimes we bite our tongue when we eat too fast). The third condition, the Filler condition included 50 auditory sentences (mean duration = 2903; SD = 599 ms) with similar syntactic structure as control and ambiguous sentences. This condition was included in order to make sure participants do not guess experimental manipulation and hypothesis.

All the sentences included in the three conditions, presented a weak prosodic pronunciation (see [40]), in order to reduce the effect of prosody on sentence processing as well as meaning selection. For each sentence, a yes/no comprehension question was recorded by a male speaker and presented at the end of the trial. Participants had 2500 ms to respond after the end of the question.

All stimuli were presented using E-Prime software (v2.0.10.353, E-Prime Psychology Software Tools Inc., Pittsburgh, USA). Auditory stimuli were presented in a headphone with a comfortable sound level set by participants and manual responses were made on a keyboard. Participants gave their manual responses with both hands, right hand for right Flanker target direction and *no* answer to questions and left hand for left Flanker target direction and *yes* answer to questions.

Procedure

Participants were instructed to listen to sentences and at the same time respond to Flanker trials. Sentences and Flanker trials were synchronized in such a way that some Flanker trials started at the same time as a homophone is presented in a

sentence. This manipulation was designed to involve the lexico-semantic selection at the same time as the Flanker trial processing (Fig 1). For filler sentences, the Flanker trial appeared at the same time as a random word in the sentence.

Each trial started with a central rectangle (also used as a visual mask) presented for 300 ms followed by the string of arrows presented for 500 ms. The inter-trial interval was a blank screen varying in presentation duration between 800 ms and 1200 ms. This varying duration was set to avoid participants to anticipate stimulus presentation and rhythmic responses. Sentence type and Flanker type were counterbalanced in order to obtain 20 trials for each condition crossing. Overall, participants performed 130 sentence trials, 97 comprehension questions and 520 Flanker trials.

Finally, in order to make sure participants were involved in the two tasks, an auditory yes/no comprehension question was asked in 75% of sentence trials. Participants responded to the Flanker trials and to the question with two keyboard buttons. A short training session was proposed for the Flanker task; including 16 trials (eight congruent and eight incongruent trials). Reaction times and accuracy on all of the Flanker trial and language comprehension questions were recorded.

Data Analyses

Statistical analyses were conducted using R version 4.0.3 (R Core Team, 2018), and lme4 [41] and lmerTest [42] packages.

Before performing statistical analysis assessing the study hypothesis, we performed verification analysis evaluating: 1) accuracy of each task and 2) the effective involvement in the dual task paradigm. First of all, and in order to be sure that participants perform the language task, we checked participants' performances on the

comprehension task by the evaluation of the behavioral responses to the final-trial comprehension questions (see Fig 1 for the experimental paradigm presentation). For each participant in which the comprehension questions have been performed below 75% of accuracy was considered as a deviant and excluded from the subsequent analysis. Second, we evaluated the behavioral performances for the Flanker task for each participant and participants with less than 80% of correct responses were considered as a deviant and were excluded from the subsequent analysis. Finally, we statistically compared performances during Flanker trials on task condition (i.e., Flanker trial synchronized with the language trial) and Flanker trials alone (i.e. Flanker trial without language trial).

Confirmatory (preregistered) analyses

The main goal of this study was to evaluate whether common cognitive mechanisms are shared during conflict resolution of verbal and nonverbal tasks. More specifically, we evaluated the impact of language conflict resolution, as manipulated by homophone meaning selection during auditory sentences presentation, on the behavioral performances for a nonverbal conflict resolution induced by a Flanker task.

Regarding our hypothesis, we expected to observe an interaction between language comprehension and Flanker tasks during conflict resolution trials. According to our paradigm we expected less efficient responses (less accuracy and longer reaction times) on incongruent Flanker condition when presented simultaneously with the ambiguous sentence condition than with the control sentence condition. In other words, we expected a cognitive cost during trials involving both Flanker and language conflict resolution conditions (i.e. incongruent condition and ambiguous sentences, respectively) but not for other condition combinations. We expected a significant main

effect of Flanker type, with slower reaction times for incongruent than for congruent Flanker condition as well as a main effect of sentence type reflected by slower reaction times during ambiguous sentence condition than during control sentence condition.

To statistically evaluate our hypotheses in terms of reaction times, we computed a mixed effect model with sentence type, Flanker type and their interaction as fixed effects and sentence's intercept, subject's intercept, and subject's random slope for Flanker type as random effects. In order to reduce the weight of extreme data reaction times were *log* transformed. Regarding accuracy, we computed a logistic mixed effect model with sentence type, Flanker type and their interaction as fixed effects and stimuli's intercept, subject's intercept, and subject's random slope for Flanker type as random effects. Participants deviating from more than two standard deviations from the mean on the dependent variable were excluded from this analysis. A total of three participants were removed from reaction time analyses in addition to three participants that did not reach a threshold of 80% of correct responses for the Flanker task.

Exploratory (non-preregistered) analyses

Previous studies have shown a pre-activation effect of cognitive control on language processing using a cross-task paradigm [13]. Hsu and Novick showed that increase in executive control load through incongruent Stroop trials led to a better subsequent syntactic ambiguity resolution. These results suggest that incongruent Stroop trials pre-activated inhibitory and attentional control processes that were then at work during the syntactic ambiguity resolution, leading to faster ambiguity resolutions than when no pre-activation appeared (congruent Stroop trials) (see also [43]). More specifically, they showed that a *n-1* incongruent trial induce a conflict language resolution facilitation on a *n-target* trial. In line with these results it is possible

that, in our paradigm, the previous Flanker ($n-1$) trial has an effect on the *target* Flanker trial (i.e. Flanker trial synchronized with the language trial). We tested this hypothesis by adding one new factor in our mixed effect model, the Flanker type of the $n-1$ Flanker trial (congruent or incongruent).

In this experiment, control sentences were seen as unambiguous because of previous context in the sentence driving lexical interpretation toward only one specific meaning of the homophone. However, processing a homophone might still involve different processing mechanisms than non-homophone words. Regarding the control sentences, context might favor one interpretation of the homophone but does probably not totally remove activation of other interpretations [44,45]. In order to compare ambiguous sentences with sentences that does not require such selection between several meanings we included filler sentences in the sentence type variable of the statistical model evaluating the interaction between Flanker type on *target* Flanker trials and sentence type. Thus we were able to compare ambiguous sentences to control ones but also to filler sentences and their interaction with Flanker type.

Results

As previously suggested to ensure that all participants correctly perform the dual-task paradigm we check accuracy in both Flanker and language comprehension tasks. We showed that all the participants performed correctly the language comprehension task with rates higher than 80% (mean proportion of correct answers = 0.92; SD = 0.27). We also evaluated the dual-task implication of participants by the comparison between Flanker trials performed alone (i.e. Flanker trial without language trial) and Flanker trials performed in dual-task situation (i.e., Flanker trial synchronized with the language trial) performances. This analysis revealed a significant classical

main effect of Flanker type ($t = 55.70$, $p < .001$) with participants being slower for incongruent (mean RT = 515ms; SD = 111ms) trials compared to congruent ones (mean RT = 441ms; SD = 104ms). Importantly, we observed a main effect of task situation ($t = 24.46$, $p < .001$). Participants were slower for Flanker trials on dual-task situation (mean RT = 516ms; SD = 128ms) than for Flanker trials alone (mean RT = 455ms; SD = 100ms). This main effect is observed for both congruent and incongruent Flanker conditions (Fig 2) and suggests a cognitive cost of doing two tasks at the same time in this paradigm. We also observed a significant interaction between task situation and Flanker type ($t = -11.02$, $p < .001$) showing a larger difference between congruent and incongruent trials during the Flanker task alone than in a dual-task situation.

Fig 2. Reaction times to Flanker trials as a function of task situation and Flanker Type conditions.

322 Note. *** $p < .001$.

323 **Confirmatory results**

324 In terms of accuracy, analysis revealed a significant effect of Flanker type ($Z =$
325 $-5.21, p < .001$) showing that participants responded more correctly for congruent (M
326 $= 0.99$; $SD = 0.12$) than for incongruent ($M = 0.93$; $SD = 0.26$) Flanker trials. We
327 observed an absence of significant effect of sentence type ($Z = 1.37, p = 0.17$) as well
328 as of the interaction effect between Flanker type and sentence type ($Z = -0.75, p =$
329 0.46).

330 In terms of reaction times, the computed model showed a significant main effect
331 of Flanker type ($t = 11.29, p < .001$). Participants were slower for the incongruent
332 Flanker condition (mean RT = 539ms; $SD = 119$ ms) than for the congruent condition
333 (mean RT = 482ms; $SD = 111$ ms). A marginal significant main effect of Sentence
334 type ($t = -1.91, p = 0.059$) was observed in which participants seem to be faster to
335 Flanker trials while listening to ambiguous sentences (mean RT = 505ms; $SD = 119$ ms)
336 than while listening to control sentences (mean RT = 516ms; $SD = 121$ ms). Finally, an
337 absence of significant interaction between Flanker type and Sentence type was
338 observed ($t = 0.92, p = 0.36$). This absence of the interaction effect prevents us from
339 concluding on a modulated influence of the sentence type by Flanker type on Flanker
340 trials (Fig 3).

Fig 3. Mean reaction times for each experimental Sentence type as a function of target Flanker type.

Note. $p < .06$. *** $p < .001$.

Exploratory results

The mixed model including $n-1$ Flanker type, *target* Flanker type and Language ambiguity as fixed effects revealed a significant main effect of *target* Flanker type ($t = 3.73$, $p < .001$). As observed in the first model (confirmatory results), participants were faster for congruent Flanker trials than for incongruent ones. Analysis revealed a marginally significant interaction effect between *target* Flanker type and Sentence type ($t = 1.92$, $p = 0.058$), showing that the difference in reaction time between congruent and incongruent Flanker trials was slightly larger for ambiguous sentences than for control ones. Finally, we

observed a marginally significant interaction between *n-1* Flanker type, *target* Flanker type, and Sentence type ($t = -1.94$, $p = 0.056$) as shown in Fig 4. This effect suggests a different pattern of interaction between the *target* Flanker type and Sentence type when the *n-1* Flanker trial was congruent or incongruent. Since we observed such an interaction effect between these three variables, we analyzed the interaction effect between *n-1* and *target* Flanker trials for ambiguous and control sentences separately.

Fig 4. Mean reaction times to *target* Flanker trials as a function of *target* and *n-1* Flanker type and Sentence type. (A) shows a significant main effect of *target* Flanker type for control sentences while (B) shows significant main effects of *n-1* and *target* Flanker type as well as a significant interaction effect between the two variables for ambiguous sentences.

Note. * $p < .05$. ** $p < .01$. *** $p < .001$.

Regarding ambiguous sentences, we observed a significant effect of *n-1* Flanker type ($t = 2.69$, $p = .01$), suggesting an influence of *n-1* Flanker trials on *target* ones. More specifically, participants were slower after an incongruent *n-1* Flanker trial (mean RT = 521;

SD = 122) than after congruent ones (mean RT = 490; SD = 117) when presented with an ambiguous sentence. We also observed a significant effect of *target* Flanker type ($t = 6.9$, $p < .001$), showing that participants were faster for congruent *target* Flanker trials (mean RT = 477; SD = 111) than for incongruent ones (mean RT = 535; SD = 123) when presented with ambiguous sentences. Finally, we observed a significant interaction effect between *n-1* and *target* Flanker type presented with ambiguous sentences ($t = -3.18$, $p = .003$). This results suggests that the difference in reaction times between congruent and incongruent *target* Flanker trials is smaller (mean difference = 42ms; SD = 54ms) after incongruent *n-1* Flanker trials than after congruent ones (mean difference = 73ms; SD = 70ms) when presented with ambiguous sentences (Fig 4B). Regarding, control sentences, we only observed a significant effect of *target* Flanker type ($t = 3.47$, $p = .001$) showing that participants were faster for congruent *target* Flanker trials (mean RT = 490; SD = 119) than for incongruent ones (mean RT = 540; SD = 121) without specific influence of *n-1* Flanker type (Fig 4A).

The analysis including filler sentences revealed a significant difference between ambiguous sentences and filler ones ($t = 2.69$, $p = .019$). This effect suggests that participants were slower for Flanker trials while listening to fillers sentences (mean RT = 526ms; SD = 125ms) than while listening to ambiguous sentence (mean RT = 505ms; SD = 119ms) (see S1 Fig A). Moreover, when we took filler sentences into consideration in our model, the difference between ambiguous sentences and control ones did not reach significance level suggesting that this effect was small compared to the one of filler sentences.

396 Discussion

397 The main goal of this study was to evaluate whether common executive control
398 process is shared during conflict resolution of verbal and non-verbal tasks. Specifically,
399 we evaluated the effect of homophone meaning selection on a non-verbal conflict
400 resolution task. We have for this purpose designed an experimental paradigm in which
401 participants performed a Flanker task synchronized or not with a verbal conflict
402 resolution (i.e., homophone meaning selection) during an auditory sentence
403 comprehension. Participants were instructed to be involved in these two tasks at the
404 same time (i.e., a dual-task paradigm). We hypothesized that if the homophone
405 meaning selection requires executive control this would interfere with executive control
406 performances assessed in the concomitant Flanker trials. This would be reflected by a
407 performance cost during incongruent Flanker trial for the ambiguous sentences only.
408 In order to evaluate the study hypothesis, we analyzed the Flanker task performances
409 and also ensure that the language task was correctly performed by including language
410 comprehension questions after 75% of trials.

411 First, the test of task situation showed a significant cost of doing two tasks at
412 the same time. In fact, participants were slower to respond to Flanker trials when they
413 were also listening to sentences. Overall, participants took around 70 more
414 milliseconds to respond when in dual-task situation compared to when in the Flanker
415 task alone, and if we look at Fig 2, we can see that participants had similar
416 performances to incongruent Flanker trials when performed alone as congruent trials
417 when performed in dual-task situation. This result confirms that the synchronization
418 with language stimulation induces a cognitive cost and also that participants were

involved in the dual-task. In line with this point, we also showed that language comprehension performances were correct as suggested by the final trial questions performances rates (higher than 75%). Results also showed a classical Flanker effect as reflected by participant faster reaction times for congruent than for incongruent Flanker trials as well as by increasing errors rate for incongruent than for congruent trials. This well-known effect is presented in both Flanker dual-task trials (i.e., with language synchronization) and Flanker alone trials (i.e., without language synchronization) suggesting an effective recruitment of executive processing. More specifically, this result reflects a recruitment of an inhibitory processing for incongruent trials as participants are required to inhibit predominant information in order to correctly perform the task. Regarding the interaction effect observed between task situation and Flanker type, it is important noting that Flanker trials alone preceded the synchronized dual-task Flanker trials. Thus, the interaction effect could arise from this temporal sequence (this point will be discussed later).

Confirmatory results show a marginal effect of sentence type on the non-verbal Flanker task. It is important to note that given the paradigm used in the present study, in which the dependent variable measured was the reaction time to the Flanker task, this main effect of sentence type shows that linguistic processing influences executive control processes at work during Flanker trials. In others words, this effect suggests an influence of the language processing on non-verbal inhibitory processes. Nevertheless, this sentence type effect on Flanker performances is reversed with respect to our expectations. Indeed, we expected as a classical dual-task paradigm that a shared common cognitive control mechanism induces behavioral performances cost in the main task (here Flanker), specifically: we expected a Flanker stronger cost during homophone conflict resolution (ambiguous sentence condition) than during the

control sentence condition. Instead, data showed that participants respond faster to Flanker trials when presented with an ambiguous homophone than with a control one. This pattern of results is in line with a pre-activation effect of cognitive control during language conflict resolution as previously suggested in the literature [12,13,43]. Indeed, it is possible that the selection between activated meanings of the homophone might rely on inhibitory processes as participants need to inhibit the inappropriate meanings in order to process only the correct one. Hence, it is probable that the meaning conflict resolution pre-activates inhibitory processes needed for the Flanker task, leading to faster reaction times. In others words, data could reflect that an inhibitory processing from homophone meaning selection induces a pre-activation of similar inhibitory processing needed during Flanker task resolution and thus reduces reaction time during Flanker trials. We will return on this interpretation bellow as all of the observed data that are related to this proposition.

Results also showed an absence of significant interaction between Flanker type and sentence type. One explanation for the absence of such interaction is the use of context during control sentences. In fact, in this study control sentences contained the same homophone as the ambiguous sentences but previous context of control sentences carried information that drove homophone processing toward the correct interpretation of the homophone meaning. Based on previous studies showing early use of context during sentence processing [40,46,47] we considered control sentences as unambiguous but we cannot totally rule out the possibility that context is used only after the homophone meaning selection. Hence, this late context use could explain the absence of interaction effect. Another explanation can be the strength of the conflict driven by homophone meaning selection. In fact, it is possible that the conflict arising

from meaning selection in our study is too small compared to the strong Flanker conflict.

Another factor that might be involved in the modulation of inhibitory processes is the sequence of Flanker trials as suggested by Hsu and Novick [13]. Indeed, previous studies suggested that conflict detection initiates sustained cognitive control which attenuates the cost of processing subsequent conflict [48,49] like a pre-activation effect of the cognitive control process. This is the reason why we carried out our exploratory analyses including the *n-1* Flanker trials in our model. This way, we were able to test the effect of a previous increase in executive control load on participants' reaction times. This exploratory analysis was also supported by the interaction effect observed between the Flanker type and the dual-task situation (dual-task –synchronized with language– or Flanker alone –not synchronized with language–) in which we observed reduced Flanker type effect during dual-task situation compared to Flanker alone situation (see Fig 2). Regarding the first exploratory analysis, the observed marginal interaction effect between the *n-1* Flanker type, the *target* Flanker type, and sentence type reveals that the difference in reaction time between incongruent and congruent *target* Flanker trials is modulated both by *n-1* Flanker type and sentence type conditions. The observed interaction effect between *n-1* and *target* Flanker type when presented with ambiguous sentences and the absence of such interaction when presented with control sentences suggests an involvement of common executive control mechanisms during homophone meaning selection and inhibitory non-verbal processing. Indeed, the fact that the interaction effect appears only for ambiguous sentences supports the hypothesis of a recruitment of executive processes, and in our case of inhibitory processing, during language

conflict resolution. Thus, incongruent *n-1* Flanker trials seem to reduce reaction time differences between congruent and incongruent *target* Flanker trials for ambiguous sentences but do not influence control ones.

This exploratory result is in line with findings of Hsu and Novick [13] who observed, in an EyeTracking paradigm, a facilitatory effect of a previous increase in executive control load (through incongruent Stroop trials) on syntactic resolution. Recently, Thothathiri, Asaro, Hsu and Novick [12] used the same EyeTracking paradigm with active and passive sentences and also showed a facilitatory effect of previous high executive control load on passive sentence processing. These studies show a direct link between executive control processing arising from Stroop conflict and syntactic ambiguity resolution or complex sentence processing. What is important noting is that these studies use a verbal Stroop task as an executive control task. This way, the executive control effect observed in these studies could be considered as a language processing distinct from non-verbal executive control processes. In our study, we used a non-verbal executive control process in order to argue against this language specific hypothesis. Thus our findings add evidence to the domain-general cognitive control account and suggest an involvement of non-verbal inhibitory control processes during word meaning selection.

The model including filler sentences revealed a significant difference between reaction times to Flanker trials while listening to fillers sentences and ambiguous ones, with participants being slower for filler sentences. This result is in line with the marginal effect observed in the confirmatory analysis comparing ambiguous and control language conditions. In fact, it seems here that when there is no specific selection demand during sentence processing (i.e., filler condition) participants are slower than

when there is a strong need to selection between several meanings (i.e., ambiguous condition). In other words, the facilitatory effect observed when comparing the ambiguous condition to the control one also appears when comparing the ambiguous to the filler one. Thus, it seems that the more processing and selection participants needed during language processing the more facilitated they were for the concomitant inhibitory conflict resolution (see S1 Fig 1 in supporting information). This exploratory results add evidence to the claim that non-verbal executive control processes are at work during language processing and more specifically that inhibitory processes are involved during meaning selection.

Further research is needed to investigate which executive control processes are at work during language comprehension. In a study with semantic aphasic patients, Hoffman, Rogers and Lambon Ralph [50] showed that selection between several semantic meanings of words rely on control processes. In fact, authors showed that semantic aphasic patients, who are known to have difficulties inhibiting semantics associations [51], exhibited a frequency effect on a synonym judgment test only when semantic diversity of words (i.e., how many meanings and semantic associations words can have) was taken into account. This study brings evidence for an involvement of inhibitory processes during lexical selection as more diverse words have more related meaning and more semantic associations that need to be inhibited in order to correctly perform the task. In a recent study with two semantic aphasic patients, Nozari [52] was able to segregate activation and inhibition processes involved in meaning selection during language production (see also [53] for an interesting review on access deficits). Such a distinction between activation and inhibition during meaning selection

might also appear in language comprehension and could be important to better rehabilitate patients with language deficits.

Conclusion

In this study, we evaluated the influence of homophone meaning selection on a concomitant Flanker task. Results showed a facilitatory effect of homophone meaning selection on Flanker processing. Thus, this study brings evidence for an involvement of inhibitory control processes during homophone meaning selection independent of the modality (verbal and nonverbal). Moreover, analysis taking into account $n-1$ Flanker trials suggests an interaction between cognitive processes at work during Flanker trials and meaning selection reflecting the complex interplay between domain-general and domain-specific language processing.

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Supporting Information

S1 Fig 1. Reaction times to Flanker trials as a function of Flanker type and Sentence type.

Note. * $p < .05$. *** $p < .001$.