The Effects of Non-linguistic Inhibition on Structural Priming

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1. Introduction

Across the literature, it has been shown that in the bilingual processing system, both languages are active even if only one is used (see, e.g., Kroll et al., 2012 for a review). As a result, the non-target language is associated with some degree of activation. Some studies have proposed that this residual degree of activation of the non-target language may lead to cross-linguistic effects from it to the target one (Baroncini & Torregrossa, under review; Serratrice, 2016; Sharwood Smith & Truscott, 2014). Other studies have shown that the activation of the non-target language is responsible for slower lexical retrieval in the target language (Bialystok et al., 2010; Torregrossa et al., 2019). In order to cope with this joint language activation, bilinguals have to suppress the non-target language. Psycholinguistic evidence in favour of this conclusion comes from both language production (e.g., Borragan et al., 2018; Declerck and Koch, 2022) and language comprehension studies (e.g., Blumenfeld & Marian, 2011; Macizo et al., 2010; Durlik et al., 2016).

It is generally assumed that the suppression of the non-target language relies on inhibitory control, which is a central component of executive functions which underlies the ability to suppress prepotent automatic responses and information which is not relevant for achieving a certain goal (e.g., Abutalebi & Green, 2007; Calabria et al., 2018; Declerck & Philipp, 2015; Green, 1998; Kroll et al., 2008). It is an open question whether the same or different inhibitory processes underlie linguistic inhibition – which is involved, for instance, in the suppression of bilinguals' non target language – and non-linguistic inhibition – which is responsible for suppressing automatic responses which are not necessarily linguistic in nature.

In the present study, we address this question by triangulating the results of two structural priming experiments and a non-linguistic inhibition task conducted on a group of 36 Greek-Italian bilingual children ranging in age between 7 and 12 years. Structural priming refers to a speaker's tendency to reuse a morpho-syntactic structure that they previously produced, heard or read (e.g., Pickering & Branigan, 1998; Branigan & Pickering, 2017). When used in a cross-linguistic mode, structural priming serves to examine to what extent speakers reproduce in a language a structure that they previously produced, heard or read in their other

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language. We refer to priming experiments that are conducted in only one language as within-language priming experiments and to cross-linguistic priming experiments as across-language ones.

The foundation of the present study is the hypothesis that participants with better inhibition abilities – as measured through non-linguistic inhibition tasks – resist structural priming to a greater extent than participants with lower inhibition abilities, provided that the same inhibition abilities underlie linguistic and non-linguistic tasks. By investigating this issue, we aim to understand whether inhibitory control is domain-general – being responsible for the inhibition of both linguistic and non-linguistic information – or domain-specific – including a component specialized for linguistic information and a component specialized for non-linguistic information.

2. Structural priming across languages and inhibition

Some studies on cross-linguistic priming draw attention to some possible relations between magnitude of priming and inhibitory control abilities. For instance, Cai et al. (2011) conducted within- and across-language priming experiments with Cantonese-Mandarin bilingual adults using double object and prepositional object datives as target structures. They found that priming effects were stronger in the within-language experiment than in the across-language one. They interpreted their results as showing that the selection of the target language is associated with inhibition of lexical information of the non-target language. Likewise, Hsin et al. (2013) showed that English-Spanish bilingual children ranging in age between 4 and 5 years were primed from English to Spanish in the production of inappropriate adjective-noun phrases. They suggested that the observed priming effect could be attributed to children's inhibitory control abilities. However, neither Cai et al. (2010) nor Hsin et al. (2013) employed a non-linguistic cognitive task in order to determine whether there is a correlation between the ability to inhibit linguistic and non-linguistic material. Wolleb et al. (2018) is the only study so far to consider the relationship between within- and across-language structural priming and non-linguistic inhibitory control in a group of English-Norwegian bilingual children ranging in age between 4;7 and 8;5. The authors used the Dimensional Change Card Sort (DCCS) to assess children's non-linguistic inhibitory control. The results of this study showed that across-language and within-language priming experiments were associated with the same magnitude of priming effects. Furthermore, the magnitude of priming was not affected by children's score in the DCCS. Therefore, these results suggest that there is no unique inhibitory control ability which underlies both linguistic and non-linguistic inhibition.

Finally, in Baroncini & Torregrossa (under review), we tested a group of Greek-Italian bilingual children using across-language and within-language priming experiments, in order to investigate whether a dispreferred structure can be primed in a language (i.e., in Italian, following a prime in Italian) or across-languages (i.e., in Italian, following a prime in Greek). The target structure used in this experiment was the word order verb-subject-object (VSO), which is

dispreferred in Italian, but possible in Greek (see Baroncini & Torregrossa, under review for further details). We also investigated whether VSO could be primed after a prime in Greek which was different from a VSO: a SVO, which is possible in both Greek and Italian. This allowed us to investigate whether the activation of a language in which VSO is possible (Greek) led to the production of VSO, even if this structure was not directly primed. The results showed that VSO were produced both in the Italian-to-Italian task (i.e., after the children were primed with a dispreferred VSO in Italian) and in the Greek-to-Italian task, i.e., following both a Greek SVO and VSO. However, the magnitude of priming was greater in the latter two conditions than in the former one.

Crucially, the children were tested in their non-linguistic inhibitory control abilities, but the results of this tests were not considered in the study by Baroncini & Torregrossa (under review), since the focus of the study was different. The present study aims to investigate whether the likelihood of priming effects varies as an effect of participants' inhibitory control abilities.

3. The present study

In the present study we investigate whether non-linguistic inhibitory control modulates the results of the within-language and across-language priming experiments reported in Baroncini & Torregrossa (under review). We measured inhibitory control abilities by using the flanker task.

Crucially, the priming experiments designed by Baroncini & Torregrossa (under review) comprised three steps. First, the participants heard the prime sentence. The prime sentences were: an ungrammatical VSO in Italian in the Italian-to-Italian task, a grammatical VSO in Greek in the Greek-to-Italian task, a grammatical SVO in both the Italian-to-Italian and the Greek-to-Italian task. Then, they had to repeat the prime sentence. This step required participants to decode the sentence, reconstruct its meaning and reproduce it (Marinis & Armon-Lotem, 2015; Torregrossa et al., 2022). Finally, they had to produce a new sentence (see Section 4.2.1 for further details). Therefore, inhibitory control could play a role in the first step of the experiment, whereby participants with more advanced inhibitory abilities would resist repeating a dispreferred VSO prime in Italian and produce an alternative structure instead. Then, it could affect the second step of the experiment, whereby children with more advanced abilities would resist producing a VSO in Italian. In this study, we will examine the effects of inhibitory control in both steps.

4. Methods

4.1. Participants

We tested 36 Greek-Italian bilingual children (15 females) ranging in age from 7;5 to 11;8 years (M = 9 years and 7 months; SD = 13 months). The children were either simultaneous or sequential bilinguals. Among the sequential bilinguals (N: 16), 12 were first exposed to Italian at the age of 3, 2 at the age of

6 and 4 were first exposed to Greek at the age of 3. All children were living in Athens (Greece) and attending an Italian immersion school at the time of testing. Based on the results of an extensive background questionnaire and a vocabulary test, Baroncini & Torregrossa (under review) showed that the participants were slightly more dominant in Greek than in Italian when considered as a group. However, they also showed that dominance in Greek did not affect the likelihood of production of VSO sentences either in the within-language or in the across-language priming experiment. Therefore, dominance will not be considered as a variable in our study.

4.2. Materials and analysis

Participants' inhibitory control abilities were tested by using a flanker task. Furthermore, the participants were administered two within-language structural priming experiments (Italian-to-Italian and Greek-to-Greek) and one across-language priming one (Greek-to-Italian). In the present study, we do not consider the results of the Greek-to-Greek priming experiment because in this experiment, both SVO and VSO are grammatical. Therefore, inhibitory control abilities should not play any role in the repetition of these sentences or in the production of new ones.

4.2.1. Flanker Task

We employed the flanker task implemented in "The Psychology Experiment Building Language" (PEBL), a free psychology software available online (https://pebl.sourceforge.net/battery.html). Participants were asked to indicate the direction of arrows appearing at the centre of a computer screen, pressing the right key whenever the arrow was pointing to the right or the left key whenever the arrow was pointing to the left (Figure 1).

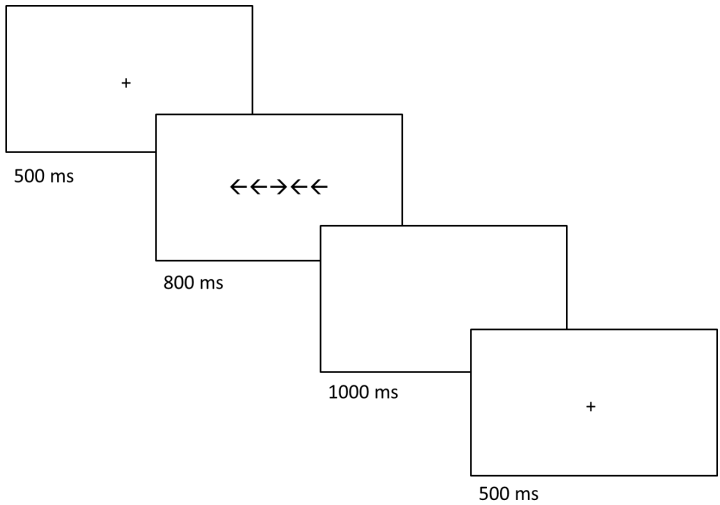

Figure 1: Design of the Flanker Task.

The arrows were presented in four different conditions: congruent, incongruent, neutral and single. In the congruent condition, all arrows pointed in the same direction either to the left (←←←←←) or to the right (→→→→→). In the incongruent condition, the arrow in the middle was flanked by arrows pointing in the opposite direction, such as in (←←→←←) or (→→←→→). In the neutral condition, a single arrow appeared flanked by dashes, such as in (----- → -----) or (----- ← -----). In the single arrow condition, one single arrow appeared in the middle on the screen, pointing either to the right (←) or to the left (→). Each condition was repeated 40 times randomly. Overall, the participants had to identify the direction of the target arrow 160 times. The experiment was preceded by a practice session consisting of 8 trials (2 for each condition).

The program recorded response accuracy and reaction times (RTs). We excluded incorrect trials and RTs which were 1.5 *SD* above or below the mean, considering first all participants together and then each participant individually. Finally, for each participant, we calculated the mean RTs for the incongruent and the congruent condition. The result corresponded to the response conflict, which was our measure of inhibitory control abilities, with a lower response conflict indicating better inhibitory control abilities.

4.2.2. The priming experiments

The priming experiments were designed as picture-description tasks. As mentioned above, children had to listen to a prime sentence, while looking at a picture on the computer screen. Afterwards, they had to repeat the prime sentence out loud. Then, they were asked the question "*And what happens here?*" in Italian.

Finally, they had to describe the new picture appearing on the screen, using the verb provided in the picture (Figure 2).

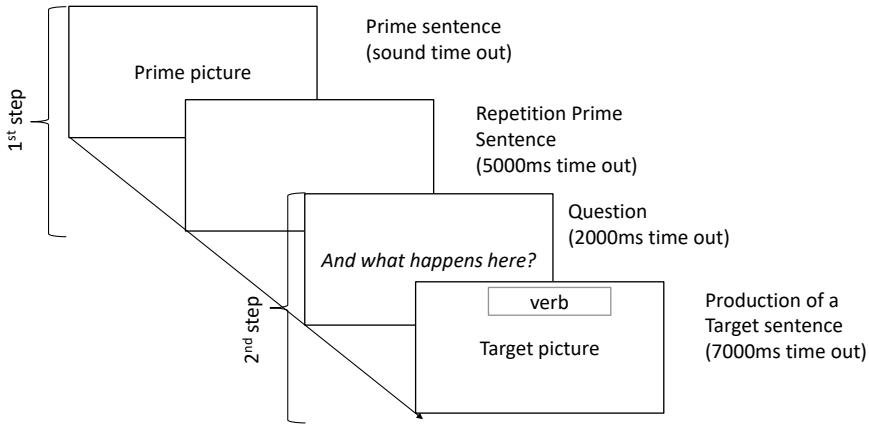

Figure 2: Design of the priming experiments.

In the Italian-to-Italian priming task, the primes were in Italian, whereas in the Greek-to-Italian priming task, they were in Greek. In both tasks, participants were expected to answer in Italian. The primes were either a VSO or a SVO sentence containing a transitive verb. In each task, children had to repeat 40 primes, 20 VSO primes and 20 SVO primes, and produce 40 target sentences.

We transcribed all repetitions of the prime and all sentences produced to describe the target picture (see Figure 1). For the analysis of the tasks, we considered two measures. First, we counted the number of correct repetitions of the prime (i.e., repetition of a VSO following a VSO and of a SVO following a SVO). With 'correct repetition', we refer also to the repetition of a dispreferred structure (i.e., a VSO in Italian). Second, we considered the number of VSO vs. SVO sentences produced, after excluding all target sentences produced after an incorrect repetition of the prime or no repetition. This was done in order to make sure that the children listened correctly to the prime.

5. Results

5.1. Flanker task

The percentage of correct responses for the flanker task was 76.74% for the congruent condition (*M* = 30.69; *SD* = 8.17), 65.56% (*M* = 26.22; *SD* = 9.73) for the incongruent condition, 73.06% (*M* = 29.22; *SD* = 8.80) for the neuter condition, 80.21% (*M* = 32.08; *SD* = 7.83 SD) for the single arrow condition. The overall accuracy was 73.89% (*M* = 118.22; *SD* = 32.78). The mean RTs for each condition was: 529.90 *ms* (*SD* = 88.86) for the congruent condition, 546.62 *ms* (*SD* = 84.64) for the incongruent condition, 526.61 *ms* (*SD* = 88.74) for the neuter

condition and 509.48 *ms* (*SD* = 87.20) for the single arrow condition. The mean RTs for the response conflict was 16.72 *ms* (*SD* = 45.65).

5.2. Repetition of the prime

Table 1 reports the number of incorrect repetitions of the prime in the Italian-to-Italian task and the Greek-to-Italian task, respectively. In the Italian-to-Italian task, they provided 81 incorrect repetitions of VSO structures. Sixty-four of these incorrect repetitions consisted in the production of a SVO. Furthermore, they provided 10 incorrect repetitions of SVO structures, but never produced a VSO in these cases. In the Greek-to-Italian task, they provided 26 incorrect repetitions of VSO structures. Eighteen of these incorrect repetitions consisted in the production of a SVO. Furthermore, they provided 9 incorrect repetitions of SVO structures but never produced a VSO in these cases, as in the case of the Italian-to-Italian task. It should be reminded that the incorrect repetition of a VSO in the Italian-to-Italian task corresponds to the lack of repetition of a dispreferred structure.

Table 1: Occurrences, means (M) and standard deviations (*SD*) related to incorrect repetitions of the prime in the Italian-to-Italian and the Greek-to-Italian task.

	Italian-to-Italian	Greek-to-Italian
Incorrect repetitions of VSO primes	81/720 *M* = 2.25; *SD* = 5.25	26/720 *M* = 0.72; *SD* = 3.18
Incorrect repetitions of SVO primes	10/720 *M* = 0.26; *SD* = 0.57	9/720 *M* = 0.22; *SD* = 0.5

We fit a generalized-linear mixed effects model using the correct vs. incorrect repetition of the prime (coded as 0 and 1, respectively) as dependent variable and the interaction between type of prime (SVO vs. VSO) and type of task (Italian-to-Italian and Greek-to-Italian) as predictor. We used sum contrast coding (-.50/+.50) for both factors (type of prime and type of task). We specified random intercept for participants.[1]

The results of the glmer-analysis reported in Table 2 show that there was a significant effect of type of prime, indicating that participants were more likely to produce a different repetition of the prime following a VSO-prime. We did not find any effect of type of task, but we found a significant interaction between type of prime and type of task, indicating that the difference in the probability of producing an incorrect repetition after a SVO vs. a VSO prime is lower in the Greek-to-Italian task than in the Italian-to-Italian task (see Figure 3).

[1] The resulting model was: m1 <- glmer (repetition ~ 1 + prime * task + (1|ID), data = priming, family=binomial(link="logit"), glmerControl(optimizer = "bobyqa")). We did not specify random slopes because the model failed to converge.

Table 2: Parameters of the generalized linear mixed-effects analysis concerning the likelihood of producing an incorrect repetition according to type of prime (SVO vs. VSO) and type of task (Italian-to-Italian and Greek-to-Italian).

Fixed effects	*Estimate*	*SE*	*Z*	*P*
Intercept	-7.66	.78	-9.81	<.001
type of prime (VSO)	4.41	.66	6.63	<.001
type of task (Italian-to-Italian)	.56	.60	.92	.35
type of prime (VSO) * type of task (Italian-to-Italian)	4.54	1.21	3.73	<.001

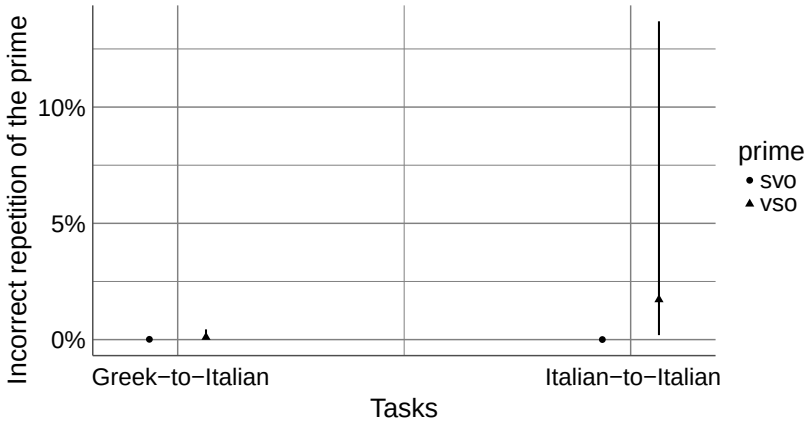

Figure 3: Predicted probability of an incorrect repetition of the prime (SVO vs. VSO) in the Greek-to-Italian and the Italian-to-Italian task.

Based on the results shown in Table 2 and Figure 3, participants seemed to resist repeating a VSO to a greater extent in the Italian-to-Italian task than in the Greek-to-Italian task. This is an expected result, given that VSO is possible in Greek but not in Italian.

The analysis in the next Section examines how far participants' inhibition abilities affected the incorrect repetition of prime sentences across the two tasks. We expect to find an effect of inhibition only in association with VSO-sentences in the Italian-to-Italian task, given that these sentences represent a dispreferred option (contrary to SVO sentences in Italian and Greek and VSO sentences in Italian).

5.3. Incorrect repetition and inhibition

We fit a second model, using the correct vs. incorrect repetition of the prime (coded as 0 and 1, respectively) as dependent variable and the interaction between

type of prime (SVO vs. VSO), type of task (Italian-to-Italian and Greek-to-Italian) and response conflict (in RTs) as predictor. We used sum contrast coding (-.50/+.50) for the factors (type of prime and type of task) and we centered the response conflict variable. We specified random intercept for participants.[2]

The results of the glmer-analysis reported in Table 3 showed an effect of type of prime and a significant interaction between type of prime and type of task, which confirms the pattern observed in Table 2. We also found an effect of response conflict. The children with better inhibitory control abilities (i.e., lower response conflict scores) tended to produce more incorrect repetitions (i.e., not to repeat the prime sentence). However, we did not find any two-way interaction between response conflict scores and type of task or response conflict and type of prime. We also did not find any three-way interaction between the three fixed effects.

Table 3: Parameters of the generalized linear mixed-effects analysis concerning the likelihood of producing an incorrect repetition according to type of prime (SVO vs. VSO), type of task (Italian-to-Italian and Greek-to-Italian) and response conflict.

Fixed effects	*Estimate*	*SE*	*Z*	*p*
Intercept	-7.63	.78	-9.72	<001
type of prime (VSO)	3.57	.91	3.92	<001
type of task (Italian-to-Italian)	1.12	.90	1.25	.21
response conflict	-1.24	.55	-2.26	.02
type of prime (VSO) * type of task (Italian-to-Italian)	5.31	1.80	2.94	.003
type of prime (VSO) * response conflict	-.49	.57	-.85	.39
type of task (Italian-to-Italian) * response conflict	.59	.55	1.08	.28
type of prime (VSO) * type of task (Italian-to-Italian) * response conflict	.95	1.10	.86	.39

Figure 4 plots the predicted probabilities of a different repetition of the prime as an effect of inhibitory control ability. Children who performed better in the inhibition task (lower response conflict scores on the left) were more likely to produce an incorrect repetition. This tendency seems to be more evident in association with VSO-primes and in the Italian-to-Italian task, although we observed no interaction between type of task and response conflict scores or between type of prime and response conflict score.

[2] The resulting model was: m2 <- glmer (repetition ~ 1 + prime * task * response_conflict + (1|ID), data = priming, family=binomial(link="logit"), glmerControl(optimizer = "bobyqa")). We did not specify random slopes because the model failed to converge.

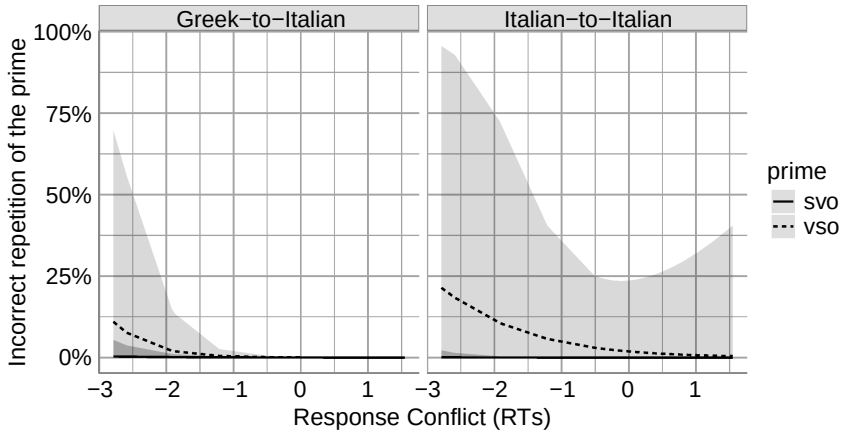

Figure 4: Predicted probability of an incorrect repetition of the prime as a function of the response conflict score in the Greek-to-Italian task (on the left) and the Italian-to-Italian task (on the right). The shaded lines indicate a 95% confidence interval. The predicted probabilities have been derived by using the ggpredict() function in the 'ggeffects' package (Lüdecke, 2018).

5.4. Production of VSO target sentences

We summarize briefly the results shown in Baroncini & Torregrossa (under review) related to the likelihood of producing a VSO as an effect of type of prime and type of task, focusing on the Italian-to-Italian and Greek-to-Italian tasks. We found: (i) a significant effect of VSO-prime, indicating that VSO-primes enhanced the likelihood of producing a VSO target sentence compared to SVO-primes; (ii) a significant effect of type of task, whereby participants tended to produce more VSO sentences in the Greek-to-Italian task compared to the Italian-to-Italian task; and (iii) no interaction between type of prime and type of task, showing that the effect of VSO-prime did not vary across the tasks. Figure 5 shows the proportion of VSO-sentences following a VSO vs. SVO prime in the Italian-to-Italian and Greek-to-Italian task, respectively: 0.006 (*SD* = 0.079) following a SVO and 0.024 following a VSO in the Italian-to-Italian task, and 0.045 (*SD* = 0.207) following a SVO and 0.077 (*SD* = 0.267) following a VSO in the Greek-to-Italian task. The data are taken from Baroncini & Torregrossa (under review). We refer to Baroncini & Torregrossa (under review) for the number of sentences included in the analysis. In the present paper, we aim to understand to what extent the production of VSO sentences was affected by inhibitory control abilities. We expect to observe an effect of inhibition in the production of VSO in both tasks, since the production of VSO in Italian represents a dispreferred option.

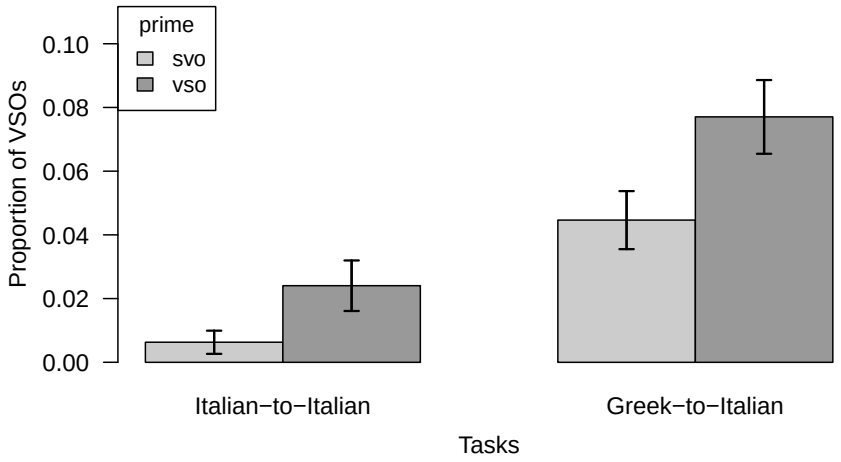

Figure 5: Proportion and standard errors (+/- 1.5) of produced VSO sentences across primes (SVO vs. VSO) and tasks (Italian-to-Italian and Greek-to-Italian). The figure is taken from Baroncini & Torregrossa (under review), without considering the Greek-to-Greek task.

5.5. Production of VSO target sentences and inhibition

We fit a generalized linear mixed effects model using the production of SVO vs. VSO as dependent variable (coded as 0 and 1, respectively) and the interaction between type of prime (SVO vs. VSO), type of task (Italian-to-Italian and Greek-to-Italian) and response conflict (in RTs) as predictor, choosing SVO and the Italian-to-Italian task as reference levels. We specified random intercept for participants and items.[3]

The results of the glmer-analysis reported in Table 4 revealed that there was an effect of type of prime (VSO): children produced more VSO target sentences after a VSO prime than after an SVO prime in Italian-to-Italian. We also found an effect of type of task (Greek-to-Italian): children produced more VSOs in the Greek-to-Italian task than in the Italian-to-Italian task after a SVO. Furthermore, there was no significant interaction between type of prime and type of task. These results confirm the ones obtained in Baroncini & Torregrossa (under review), as were summarized above. However, the response conflict scores were not associated with any significant effect either when considered as a fixed effect or in interaction with type of prime and type of task.

[3] The resulting model was: m3<- glmer (target ~ 1 + prime * task * response_conflict + (1|ID) + (1|item), data = priming, family=binomial(link="logit"), glmerControl(optimizer = "bobyqa")). In this case, we used treatment coding of the factors, in order to allow for comparability with Baroncini & Torregrossa (under review).

Table 4: Parameters of the generalized linear mixed-effects analysis concerning the likelihood of producing a VSO target sentence according to type of prime (SVO vs. VSO), type of task (Italian-to-Italian and Greek-to-Italian) and response conflict.

Fixed effects	*Estimate*	*SE*	*Z*	*p*
Intercept	-13.88	2.10	-6.60	<001
type of prime (VSO)	1.64	.80	2.04	.04
type of task (Greek-to-Italian)	3.19	.74	4.33	<001
response conflict	-1.22	1.96	-.62	.53
type of prime (VSO) * type of task (Greek-to-Italian)	-.29	.93	-.32	.75
type of prime (VSO) * response conflict	-1.09	1.77	-.62	.54
type of task (Greek -to-Italian) * response conflict	.64	1.77	.36	.71
type of prime (VSO) * type of task (Greek-to-Italian) * response conflict	3.14	2.04	1.54	.12

6. Discussion and conclusion

The foundation of the present study was the hypothesis that bilingual children with better inhibitory control abilities would be less likely to be primed with a dispreferred structure both in within-language experiments and in across-language ones. The study confirmed this hypothesis only partially.

The first result emerging from our study was that non-linguistic inhibitory control affected the correct repetition of the prime: Participants with better inhibitory control abilities tended to produce fewer repetitions of the prime.

When considering VSO primes in Italian, this observation is in line with our hypothesis: Participants with better inhibitory control abilities resisted repeating a dispreferred VSO in Italian to a greater extent than participants with lower inhibitory control. This result has several implications for the understanding of the relation between linguistic and non-linguistic inhibition. On the one hand, it is consistent with the concept that non-linguistic inhibition operates on linguistic material. This supports the hypothesis that there is a unique inhibition ability underlying linguistic and non-linguistic inhibition. On the other hand, it suggests that inhibition interacts with grammatical knowledge, given that the participants did not reproduce dispreferred structures.

However, we also observed no interaction between type of task and inhibitory control abilities in the likelihood of incorrect repetition of VSO sentences. This shows that participants resisted repeating VSO also in the Greek-to-Italian task, although VSO is possible in Greek in this case. This leads us to put into perspective our previous conclusions. It seems that higher inhibitory control abilities led participants to resist repeating a prime sentence independently of its grammaticality (dispreferred VSOs in Italian and possible VSOs in Greek).

Therefore, our results show that inhibition operates on linguistic material, although its effects are not modulated by the grammaticality of the prime sentence. As a final remark, it should be noticed that Figure 4 indicates that the likelihood to produce incorrect repetitions was greater in association with VSO primes in the Italian-to-Italian task, which seems to suggest an effect of grammaticality. However, the effect did not reach significance.

The results of this study seem to be in line with the idea that inhibition is a domain-general ability, involving both linguistic and non-linguistic material, and to contradict the results emerging from the study by Wolleb et al. (2018). However, it should be noticed that there is a fundamental methodological distinction between our study and the study by Wolleb et al. (2018). Whereas in the present study, we asked participants to repeat the prime, Wolleb et al. (2018) did not. Therefore, the effect of inhibition was visible when the prime sentence is decoded, its meaning is reconstructed and the sentence is eventually repeated, but not when a new sentence was produced based on activated syntactic structures. Crucially, we did not observe any effect of inhibitory control abilities on the production of VSO sentences, thus replicating the findings by Wolleb et al. (2018). Further research is needed to understand why the interaction between inhibition and linguistic material is restricted only to certain functions (i.e., repetition of stimuli, but not production of new sentences).

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