**De Vincenzi Fellowship - Final Report**

## 1. Name of the post-doctoral fellow:

Lucia Pozzan

## 2. Title of the project:

Executive Functions and Sentence Processing in Second Language Acquisition

## 3. Time and Location

I was awarded the De Vincenzi Felloship for the academic year 2013-2014. The research funded by the De Vincenzi Fellowship took place at the Institute for Research in Cognitive Science at the University of Pennsylvania (Philadelphia, PA, U.S.A.) between 1/9/2013 and 31/8/2014. This research was conducted under the supervision of Prof. John Trueswell. During this time, I also spent about a month in Beijing, China (visit 1: 11/11/2013-22/11/2013; visit 2: 2/1/2014-13/1/2014), where I collected the data for this project.

## 4. Research Project

As part of the research funded by the De Vincenzi Fellowship, I investigated the existence of a relationship between domain-general executive functions (EF) abilities and sentence processing abilities in child language learners. During this time, I designed, implemented and analyzed a cognitive-intervention study with L1-Mandarin children who are learning Englis has their L2 in a formal setting in Beijing (China)[1]. The results of this work will be presented at BUCLD (oral presentation) and at Psychonomics (poster presentation) in November 2014. I am currently in the process of conducting a number of follow-up analyses on this data in preparation for publication. I expect to be able to submit this work for publication by the end of the calendar year.

During my time as a De Vincenzi post-doctoral fellow, I also supervised data collection and analyses for a correlational study investigating the relationship between executive functions and sentence processing abilities in monolingual English speaking children. The latter project, whose main investigator is Kristina Woodard, had started under John Trueswell's and my supervision before the beginning of the De Vincenzi Fellowship.

Finally, during this time I have worked on the preparation of two manuscripts for publication (they are both currently under revision) and presented the results of related research projects at two international conferences on language processing and development (BUCLD, in November 2013 and CUNY in March 2014).

### 4.1. Experimental Investigation

Learning a foreign language either as a child or an adult is becoming the norm in a world where people and information are crossing borders at rates never seen before in history. The extent of international mobility of migrants, businesses and leisure travelers has given rise to the need—and therefore the market—for effective language teaching. More specifically, for a number of economic and political reasons, people everywhere are learning English at unprecedented rates (Crystal, 2004). In this context, research into the cognitive processes of language acquisition is

[1] The original plan of the study was to test adult second language learners living in the United States. However, thanks to a collaboration with Qooco, an educational company who manages a number of English learning centers in China and Singapore, we had the unique opportunity to work with child L2 learners. We thus adapted the study to this population.

more necessary than ever in order to improve the chances of success of language learners. Because more effective teaching practices depend on a better understanding of the cognitive underpinnings of language processing and acquisition, the social and economic gains that are likely to result from research into the psycholinguistics of second language acquisition are unquestionable: helping learners achieve competence in their new language(s) more successfully and more quickly, so that they can integrate sooner and better into their new communities and be competitive in a rapidly-evolving multilingual global society.

The present project examined the relationship between general cognitive abilities and language processing in child second language learners. The goal of this research was to contribute to furthering our understanding of the relationship between executive function (EF) skills and language performance, with the ultimate goal of building interventions that will transfer across cognitive domains and improve language processing and educational practices in language teaching.

The past fifteen years of psycholinguistic research have seen a growing interest in investigating the mutual effects of executive functions and language performance. A growing body of evidence has shown the existence of a set of shared cognitive resources recruited by different cognitive processes; these executive function skills (e.g., information updating, conflict monitoring and resolution, inhibition, and switching skills) can be enhanced by extensive use (e.g., daily exposure to demanding EF training sessions, a lifetime of switching between two language systems) and transfer across domains (e.g., Chein & Morrison, 2011; Morrison and Chein, 2012; Jaeggi, et al., 2011). These findings have implications for language interventions, in that they suggests that training of domain-general control abilities might have a beneficial effect on learners' language processing skills (see Novick, 2013 for a successful cognitive-intervention study with adult English native speakers).

At present, however, little is still known about the precise relationship between conflict-monitoring skills and language processing in language learners. The proposed project aimed at exploring this topic by addressing two interconnected lines of research:

(1) Examine the extent to which individual differences in EF skills account for differences in sentence processing and, in particular, the extent to which they account for differences in learners' ability to inhibit preferred (but, at times, unsuccessful) processing strategies during online sentence processing. To do this, we investigated whether individual differences in EF functions correlate with differences in comprehension accuracy for simple and complex sentences in child L2-learners (**Pre-Training**).

(2) Examine the extent to which gains in domain-general cognitive abilities might transfer to language processing skills. To do this, learners underwent EF practice regimens; gains between pre- and post-training in sentence processing performance were compared and correlated with gains in EF skills (**Post-Training**).

#### ***4.1.1. Pre-Training:*** *Cognitive Predictors of Second Language Processing*

Individuals differ from each other in terms of both their general cognitive skills and their language processing capacities; behavioral and neuroimaging evidence shows the existence of a reliable positive relation between EF skills (e.g., working memory, updating, conflict monitoring, inhibition, switching) and language processing abilities. In this experiment, we examined the extent to which individual differences in EF skills account for differences in learners' ability to process simple and complex sentences, which might require revision of initial interpretations.

Methods: Participants, Materials and Procedure

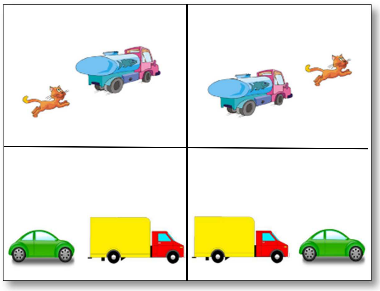
Child participants (N=62) were recruited from Qooco, a private English school in Beijing, China. Participants were child L2-learners of English (age range: 5-12, mean: 8.68, SD: 1.51) whose native language was Mandarin. Participants were randomly assigned to an experimental and a control group (see below).

During the two weeks before the experimental session, children took an oral English proficiency exam (*Versant Junior English*, Pearson 2010). The exam was completed in 15-20 minutes and was self-administered via a computer. On average, children scored 25/50 on this test (range: 10-50, SD: 11.24). The experimental and the control groups did not differ in terms of their scores ($t$ (60) = .94, $p$ = .35).

***Language Processing Tasks***

During the experimental session, two language processing tasks were administered:

**(1)** A picture selection task containing both sentences that are hypothesized to involve inhibition of preferred processing strategies (e.g., temporarily ambiguous sentences, passives, sentences containing negation, object relative clauses, see (**(i) a**) and sentences that are not (e.g., unambiguous sentences, actives, simple affirmative sentences, subject relative clauses, see **(i) b,** and **Table 1**)



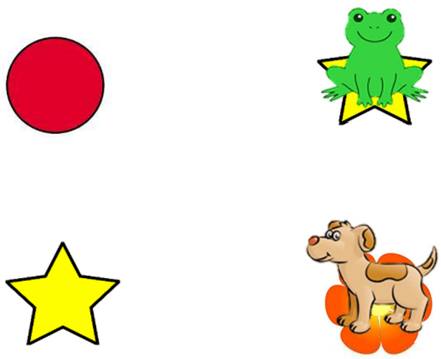
**(i) a:** The cat is followed by the truck

**(i) b:** The cat followed the truck

**Table 1: Picture Selection Task: Complex and Simple Sentence Types**

| Complex | Simple |
|---|---|
| 1: The cat was followed by the truck | 8. The cat followed the truck |
| 2: The girl the man is pointing to is laughing | 9. The man is pointing to the girl that is laughing |
| 3: The pen is not only red but also long | 10. The pen is red and also long |
| 4: Click on the girl with no flowers | 11. Click on the girl with flowers |
| 5: Bill will put the cookies in the jar onto the plate | 12. Bill will put the cookies that are in the jar onto the plate |

**(2)** An act-out task in which children will heard temporarily unambiguous or ambiguous instructions to move objects around on a computer screen (see **(ii) a** and **(ii) b**, respectively)



**(ii) a:** Put the frog that's on the star onto the circle

**(ii) b:** Put the frog on the star onto the circle

***Cognitive Tasks***

During the experimental session, children were also administered a number of online computer games from the Lumosity suite that they would then be asked to play daily for the next 45 days.

The experimental games consisted of a number of tasks aimed at measuring and training EF functions (i.e., a Stroop task, a flanker task, a switching task, an n-back task, and a spatial working memory task.

The control tasks were aimed at improving children's knowledge of English vocabulary and world geography. The control games were also administered online, using the website freerice.com.

**Coding & Analyses:**

Predictor Variables: Five composite predictor measures were created based on individual children's z-scores on the EF tasks[2]: (1) a composite **accuracy** measure calculated averaging across all games, (2) a composite speed measure calculated averaging RTs across all games, (3) an Inhibition-Accuracy measure, calculated by taking the average accuracy difference between congruent and incongruent trials, in the Stroop, flanker, and switching tasks, (4) an inhibition-speed measure, calculated by taking the average RT difference between congruent and incongruent trials on the same tasks, and an EF composite measures, calculated averaging across all previous measures.

Outcome variables: Overall accuracy in the two language processing tasks was the outcome variable. Overall accuracy scores (expressed as z-scores), as well as separate accuracy scores for unambiguous/simple and ambiguous/complex sentences were calculated for each child.

The effects of age and proficiency were statistically removed from both predictor and outcome variables.

**Predictions:**

Recent work from our research group has found that monolingual English-speaking children's ability to revise initial interpretative commitments is correlated with children's ability to inhibit irrelevant information and focus on relevant information, as measured by children's RT difference between congruent and incongruent trials in a flanker task (Woodard, Pozzan, & Trueswell, in prep.). We expected to replicate and extend these findings to a different population (i.e., children learning English as a second language), and a set of novel sentence structures (i.e., passives, sentence with negation, and object relative clauses).

### *4.1.2. **Post-Training**:* *Effects of Cognitive Training on Second Language Processing*

A growing body of research suggests that cognitive skills may be more malleable than previously thought, in that they can be enhanced by extensive practice, resulting in long-term cognitive benefits. Moreover, some recent evidence indicates that training of non-verbal cognitive skills—and conflict-monitoring skills, in particular—may generalize to untrained language processing skills in adult native speakers of English (Novick et al. 2013).

The goal of this study was to further explore this hypothesis and extend this research to second language learning and processing. We hypothesized that language processing in this group of speakers might particularly benefit from cognitive training. In fact, a number of studies have shown that second language processing might tax cognitive resources to a greater extent than native language processing (e.g., Abutalebi, 2008). These cognitive resources might thus become overloaded during second language processing, resulting in slow and error-prone sentence comprehension (Pozzan & Trueswell, 2013). Our hypothesis was that increased

[2] For ease of presentation, higher z-scores always indicate better performance.

practice with challenging tasks that exert working memory, conflict resolution, cognitive flexibility, switching and information updating, might enhance language learners' cognitive skills and free up their cognitive resources, resulting in more efficient language processing.

Methods: Participants, Materials and Procedure

A subset of children who participated in the pre-training and training phases (N=36) were tested again about 2 months after the first experimental session.

During the week before the post-training session, children were administered the oral English proficiency exam (*Versant Junior English*, Pearson 2010) a second time. Children's average proficiency score at post-training was 26.9 (range: SD: 11.60). The experimental and control groups did not differ in term of their standard proficiency scores as measured by this test at post-training ($t$ (34) = 1.4, $p$ = .18).

***Language Processing Tasks & Cognitive Tasks***

The same tasks from the pre-training phase were administered in this phase.

**Coding & Analyses:**

Predictor Variables: Improvement scores for the five composite predictor measures were calculated by subtracting pre-training from post-training scores.

Outcome variables: Improvement scores for the two language processing tasks were calculated by subtracting pre-training from post-training scores. Overall improvement scores, as well as separate scores for unambiguous/simple and ambiguous/complex sentences were calculated.

Before calculating improvement scores, the effects of age and proficiency were statistically removed from both predictor and outcome variables at pre- and post-training.

**Predictions:**

We predicted that the experimental group would improve more than the control group on the language processing measures, and that this benefit would be more substantial for sentences that are hypothesized to require inhibition of preferred processing strategies. Since there is considerable inter-individual variation in the amount of improvement that can be obtained on EF measures through practice, which in turn might obfuscate the training effects on language processing, we also planned to conduct a correlation analysis within the experimental group: within this group, we expected a positive correlation between improvement scores on the EF and the language processing measures.

### *4.1.3.* Results

#### *4.1.3.1. Pre-Training*

As can be seen in Figures 1-2, at pre-training, the control and the experimental group did not differ in their accuracy in either the picture selection or the act-out tasks (all ps. >.05). Moreover, while, as expected, in the picture selection task complex sentences that might require inhibition of preferred processing strategies were associated with significantly lower accuracy rates than simple sentences, there was no significant difference between unambiguous and ambiguous sentences in the act-out task.

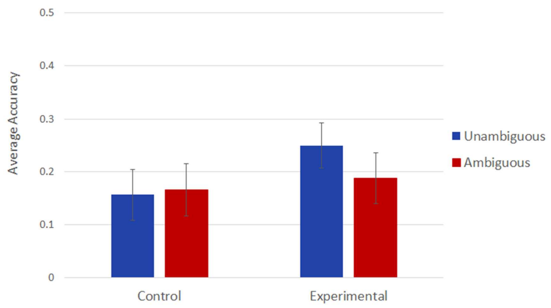



Figure 1

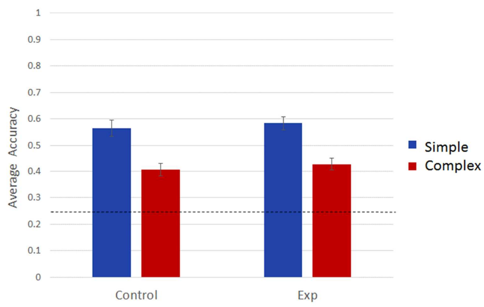



Figure 2

The results of a stepwise multiple regression in which the five EF measures were used to predict accuracy rates for ambiguous/complex and unambiguous/simple sentences in the experimental group indicate that children's ability to successfully process temporarily ambiguous sentences is positively correlated with overall EF performance on the five EF tasks (EF composite, r=.45, p=.04, Figure 2); their ability to successfully process complex sentences positively correlated with their Inhibition Speed scores (r=.75, p<.001, Figure 3).

In contrast, there were no correlations between EF measures and processing performance for unambiguous and simple sentences (all *ps* >.05).

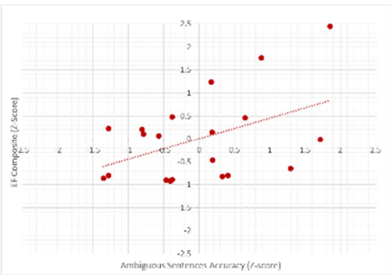



Figure 3

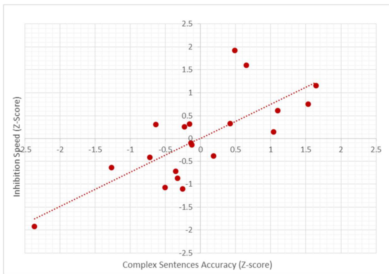



Figure 4

#### *4.1.3.2. Post-Training*

As shown in Figure 5, where average gains for the control and the experimental groups in the act-out task are plotted, processing performance did not significantly improve between pre- and post-training on this task (t (35) = .94, p = .35) and there was no effect of group (t (35) = .09, p = .93). In the picture selection task, processing performance did not significantly improve between pre- and post-training on this task (t (35) = .80, p = .42) and there was no effect of group (t (35) = 1.43, p = .16). However, as can be seen in Figure 6, the experimental group did show an improvement between pre- and post-training (t (20) = 2.10, p = .04) as shown in Figure 6, indicating a weak effect of training on this task.

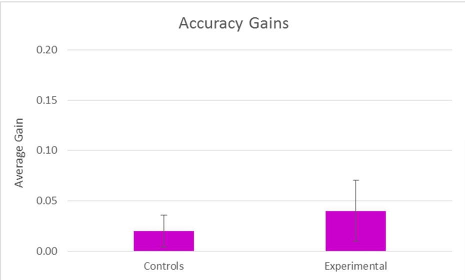



Figure 5

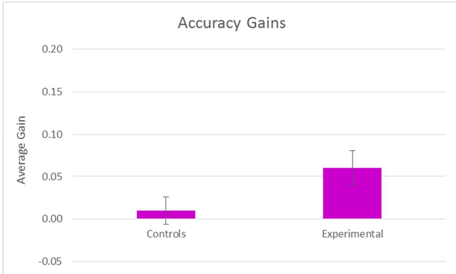



Figure 6

While the latter result is suggestive, at the group level, we failed to find conclusive evidence in support of the hypothesis that EF training has a positive effect on processing abilities. This is in line with results from Novick et al. (2013), and might be due to the fact that individuals benefit to different degrees from EF training. For this reason, we then examined the extent to which improvements in EF-training correlated with language processing improvements at the individual level within the experimental group.

The results of a multiple regression analysis show that individual improvements in Inhibition-Accuracy predicted improvements in processing ambiguous sentences (r=.60, p=.005, Figure 3), and improvements in Inhibition-Speed predicted improvements in processing complex sentences (r=.5, p=.03, Figure 4). Improvements in EF measures did not predict improvements in processing unambiguous or simple sentences (all *ps* >.05)

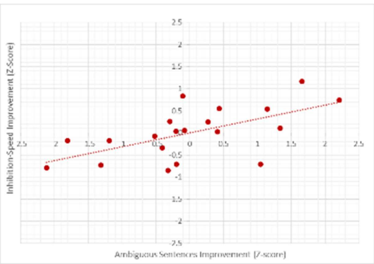


*Figure 3*

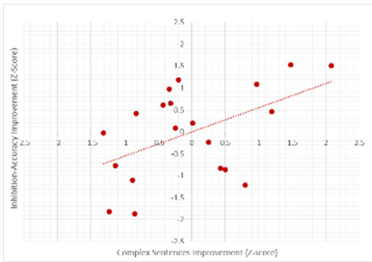


*Figure 4*

### *4.1.4.* Discussion and Concluding Remarks

The results of the current study confirm our findings with monolingual English-speaking children (Woodard, Pozzan & Trueswell, in prep.) and extend them to a novel population (child L2 learners); taken together, the results of these studies indicate that individual differences in domain-general EF skills support the processing of complex sentences that require suppression or revision of interpretation biases (**Pre-Training**). Children's ability to successfully process temporarily ambiguous sentences and sentences that require conflict monitoring positively correlates with their performance on a number of tasks aimed at measuring EF abilities. Moreover, the present study documented, for the first time in a group of language learners, the existence of a causal link between verbal and non-verbal abilities (**Post-Training**): more pronounced improvements in EF skills translated into greater language processing benefits in the group of children who underwent cognitive training. These findings could have important and far-reaching implications for second language acquisition: increased practice with challenging cognitive tasks that exert skills involved in information updating, conflict-monitoring, inhibition, and switching, might enhance language learners' cognitive resources and thus enhance second language performance for structures that are notoriously difficult to process and acquire.

## 5. Collaborations and Additional Funding Sources

The research conducted as part of this project was done in collaboration with three private companies: Qooco, Lumosity and Pearson. Qooco is an ed-tech company whose aim is to improve language learning though both live human interaction and human-computer interactions. Qooco allowed us to recruit and test children in two of their English language learning centers in Beijing and gave us access to children's proficiency scores as measured by their iTest exam. Lumosity offers a cognitive-training program consisting of more than 40 online computer games in the areas of memory, attention, flexibility, inhibition, speed of processing, and problem solving. Lumosity provided us access to their cognitive-training program, individual reports detailing children's daily usage of the games, as well as scientific and technical support at no cost to us. Finally, Pearson, an international education company and publisher, provided us access to the *Versant Junior English*, a standardized proficiency test for children acquiring English as a foreign language that can be self-administered either on the phone or on the computer.

Funding for the research conducted in China (airfare, accommodation, meals, etc.) and for purchasing the *Versant Junior English* test was provided by the Research Foundation of the University of Pennsylvania.

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