Executive Function and Language Learning: Differentiating Vocabulary and Morpho-Syntax

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Abstract

In recent years, the debate around the relationship between executive control and bilingual language proficiency has extended to the investigation of the role of the former in second language learning. The present study is based on data collected from 20 native and near-native adult speakers of English and investigated the relationship between the learning of Brocanto2, an artificial language with a complex morpho-syntax, and two measures of executive function - cognitive flexibility and inhibitory control. Although the result of the present study did not support the existence of a significant relationship between executive function and the acquisition of L2 morpho-syntax, they confirmed the role of vocabulary learning as a factor possibly driving the correlations between language learning and executive function found in previous studies.

Keywords: Executive function, artificial language learning, vocabulary learning

[1] Harriet Stone contributed to sections 2, 3 and 4 re-elaborating materials from her BA dissertation, and Diana Pili-Moss contributed to the Introduction and sections 1, 4 and 5.

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1. Introduction

Executive function (EF) is a label used to denote a number of different high-order cognitive functions localised in the brain's prefrontal cortex (Funahashi & Andreau, 2013; Fuster, 2010). These include among others, working memory, inhibitory control, attentional monitoring and cognitive flexibility. In the last ten years a large body of literature has discussed and provided evidence for the existence of cognitive advantages for bilingual speakers in executive function performance, in both children (Bialystok & Martin, 2004; Yoshida, Tran, Benitez, & Kuwabara, 2011) and adults (Bialystok, Craik, & Luk, 2008; Prior & MacWhinney, 2010). In spite of this evidence, the close relationship between bilingualism and the presence of enhanced executive control is still debated and a number of studies comparing bilinguals and monolinguals have found no significant differences in inhibitory control and switching tasks (Duñabeitia, Hernandez, Anton, Macizo, Estevez et al., 2013; Kousaie & Phillips, 2012; Paap & Greenberg, 2013). Additionally, it is possible that the age of the participants constitutes a modulating factor, as evidence of a positive relationship between bilingualism and executive function performance emerged more clearly in studies with young children or older adults than in studies with younger adults (Bartolotti, Marian, Schroeder, & Shook, 2011).

Extending the scope of the enquiry from bilingualism to first language acquisition and SLA, recent research has investigated the question of how executive function performance relates to L1 proficiency on the one side and to natural and artificial L2 learning on the other. We turn to the review of a selection of these studies in the following section.

2. Executive function and language proficiency

In a recent paper Ibbotson and Kearvell (2015) tested inhibitory control in 81 L1- English five-year olds. Focusing on the relationship between inhibitory control and L1 performance, they administered a child-friendly version of the Stroop task and correlated its outcomes to the children's ability to correctly produce irregular past tense forms, as opposed to a tendency to overgeneralise the production of past forms with the suffix *–ed* . They found that unlike age or vocabulary size, inhibitory control as measured by the Stroop task significantly predicted past tense accuracy.

In general, studies that looked at the relationship between executive function and language performance have either been interested in identifying specific learning advantages in individuals with higher executive control abilities; or have sought to measure executive control enhancements emerging as a consequence of L2 learning. Sullivan, Janus, Moreno, Astheimer and Bialystok (2014) investigated the short-term effects of L2 learning on executive control in a group of L1-English adults learning beginner level Spanish. Adopting a pretest/posttest design, they measured verbal fluency in English using performance on a grammaticality judgement test (GJT), and measured performance on a flanker task before and after 6 months of L2 training. During the GJT and the flanker task they also recorded event-related potential performances (ERP), analysing N400 and P600 effects. Although no differences between the experimental and a control group were found on any of the behavioural measures; analysis of the ERPs in the experimental group revealed a significant decrease in the mean amplitude of P600 waveforms relative to syntactic violations in the GJT, a pattern similar to the one observed in studies where bilingual participant have been compared to monolinguals. Moreover, the experimental group showed a significant correlation between improved performance in executive function from pretest to posttest and reported expected final grades compared to controls.

Bartolotti, Marian, Schoeder and Shook (2011) tested a group of 24 young adults on their ability to learn the words of an artificial language, based on the structure of the Morse code, from exposure to a stream of auditory input. In this study the words were identified in the exposure in implicit learning conditions and without the help of an explicit association of the word form with a meaning. Because of this, the study, unlike other work focusing on word learning, did not measure executive control effects associated to the processing or production of different word forms with the same meaning, but instead manipulated the form of the language input in one of the two conditions in order to induce inhibitory effects. After verifying the absence of a correlation between bilingual skills and inhibitory control, participant were grouped according to the level of their bilingual abilities (low/high) as well as to the level of inhibitory control measured by a Simon task (low/high). All participants were then sequentially exposed to two conditions that differed with respect to the length of the pauses between letters and words in the input. In the first condition (low interference) the pauses between letters and words were of equal length so that, in the absence of additional cues, the only strategy for word identification consisted in the evaluation of the statistical transition probability between letters in the input. In the second condition (high interference) the pauses between words were shorter than the pauses between letters, and learners experienced interference from the exposure to previous version of the language, so that word learning was possible only through inhibition of the statistical transition cue. The results revealed a significant correlation between inhibitory control and learning in the second condition. However, although a high level of bilingual competence was found to have a positive effect on learning in the first condition, no significant correlation between the two was found.

Kapa and Colombo (2014) is another study that aimed to shed light on the relationship between executive function and L2 learning using an artificial language paradigm. Kapa and Colombo compared the proficiency of a group of 5 year-old children and a group of adults after teaching them a simplified version of SillySpeak, an artificial language used in previous studies with children in a comparable age range (Hudson Kam & Newton, 2005, 2009). Compared to previous artificial language research in this area, this study deployed a language with a richer syntax, including verbs and a two-argument structure.

After vocabulary training the participants were exposed to 300 animated videos with voiceover descriptions, which provided evidence of the language word order and of the linking rules between argument structure and associated thematic roles. In this study the learning conditions under which the participants learned the artificial language were partly explicit and partly implicit. Whilst the nouns were taught explicitly through a picture book, which included translation into English to facilitate memorization, both the verbs and the sentence word order had to be learnt implicitly from exposure to the video clips. The methods used to measure individual differences in vocabulary size and different components of executive function included the Peabody vocabulary test, a digit span task (working memory), a visual Simon task (inhibitory control and attentional monitoring), a flanker task (inhibitory control and attentional monitoring), and a Wisconsin Card Sorting Task (WCST, a measure of cognitive flexibility). All measures were used for both age groups, with the exception of the more age-appropriate Dimensional Change Card Sort Task (Zelazo, Frye & Rapus, 1996) being used instead of the WCST, for the 5 year-olds. The outcome measures of learning included two measures of vocabulary retention (production and comprehension), a GJT, and two measures of sentence accuracy (production and comprehension). Both age groups showed an overall above chance learning of the artificial language as well as a significant relationship between aspects of executive function and language learning. In the adult group a multiple regression analysis showed that inhibitory control (measured by the flanker task) was a significant predictor of language performance, after L1 vocabulary size and working memory were controlled for.

In the child group the only aspect of executive function that predicted language performance was cognitive flexibility (measured by the DCCS). For both adults and children a principal component analysis revealed that a single factor accounted for most of the variance, a fact the authors ascribe to the possibility that the learners substantially relied on vocabulary learning in the performance of the language tasks (Kapa and Colombo, 2014, p. 243). In other words it is possible that due to the relative simplicity of the artificial language deployed, specific challenges in word order acquisition that would have emerged in a language displaying a level of complexity more closely mirroring the one observed in natural languages, were bypassed.

This brief review of studies concerning the modulating effects of executive function on L2 learning highlights that advances in L2 proficiency have mainly been quantified in terms of vocabulary learning, either by design, or because the measures adopted turned out to rely heavily on lexical retention due to the lack of complexity of the linguistic input. Ideally, a measure of L2 gains following exposure to a novel language should be able to analyse separately how executive function relates to vocabulary learning, and to the acquisition of novel morpho-syntactic patterns. This would be a desirable methodological choice, especially in view of the growing body of research suggesting that these two aspects of language learning are supported by separate long-term memory systems, the declarative memory system for vocabulary and semantics-related learning and the procedural memory system for word order and syntactic rules (Ullman, 2001, 2005). The present study will investigate the relationship between executive function (inhibitory control and shifting) and language learning, with the aim of teasing apart learning of vocabulary and morpho-syntax, while shedding light on how executive function relates to these two different aspects of language knowledge. In doing so we will adopt Brocanto2 (Morgan-Short, 2007), a miniature artificial language displaying a full syntax including internally complex NPs, morphological gender agreement and verb modifiers. Given this paradigm, we define the research question as follows:

RQ: What is the relationship between executive function and the learning of morpho-syntax and vocabulary in a syntactically complex artificial language?

3. Methods

3.1 Participants

Ten native, and ten near-native English speakers with a range of L1s including Greek, French, German and Italian, took part in the study. Participants completed a language history form, and were excluded from the study if they were found to be proficient in Spanish, due to the fact that the artificial language Brocanto2 is based on grammatical features of this language.

3.2 Artificial Language

The participants were exposed to the artificial language Brocanto2 (Grey, 2014; Morgan-Short, 2007; Morgan-Short et al., 2010; Morgan-Short, Faretta-Stutenberg et al., 2014; Morgan-Short, Finger, Grey & Ullman, 2012; Morgan-Short, Steinhauer et al., 2012). Brocanto2 is based on an original language called Brocanto (Friederici, Steinhauer & Pfeifer, 2002) but is centred on the grammatical rules of Spanish, to avoid any transfer from L1 English participants. The language is taught in the context of a computer board game.

There are 13 lexical items in Brocanto2, including the tokens' names (*pleck, neep, blom, vode*), adjectives to describe the tokens' shapes (*troise/o, neime/o*), an article (*li/u*), four verbs to describe the type of move (*klin, nim, yab, praz*) and adverbs to indicate the move direction (*noyka*, *zayma*). Brocanto2's nouns have a formal grammatical gender, either feminine or masculine, and adjectives and articles, agree with the grammatical gender of the noun. Brocanto2 employs a fixed SOV order, with adverbs appearing at the end of a sentence (Figure 1).

Sentence Type	*Brocanto2 Stimuli*					
Correct sentence	*Blom*	*neimo*	*lu*	*neep*	*li*	*praz*
	Blom-piece	square	the	neep-piece	the	switch
	"The square blom-piece switches with the neep-piece."					
Word-order violation sentence	*Blom*	**nim*	*lu*	*neep*	*li*	*praz*
	Blom-piece	*capture	the	neep-piece	the	switch
	"The *capture blom-piece switches with the neep-piece."					

* denotes violation.

Figure 1. Correct and ungrammatical Brocanto2 sentences (Morgan-Short et al., 2010).

Participants were exposed to Brocanto2 during vocabulary training, auditory language exposure, comprehension and production training, and the grammaticality judgement task.

3.3 Vocabulary training, language training and language practice

During vocabulary training, participants were exposed to audio recordings of each Brocanto2 word along with its corresponding visual symbol or move configuration. A vocabulary test was then administered where participants were required to reach a score of 100% before continuing with the rest of the experiment. If a participant scored lower than full marks, they were required to view and listen to the lexical items again and repeat the testing stage until 100% accuracy was gained. Number of attempts until 100% accuracy was gained was used as a measure of vocabulary learning.

During language training (auditory exposure), participants were exposed to 13.5 minutes of Brocanto2 training in which they listened to an explanation of the language including lexical items and categories, and information such as word order and gender. The audio information was aided by visuals. After this, the participants were exposed to some sample sentences along with their corresponding visual moves on the game board. The exposure of the sample sentences aimed to approximate learning a language in a natural setting. Although there were elements of explicit instruction in the training, the participants were not asked to explicitly search for rules at any point during the experiment.

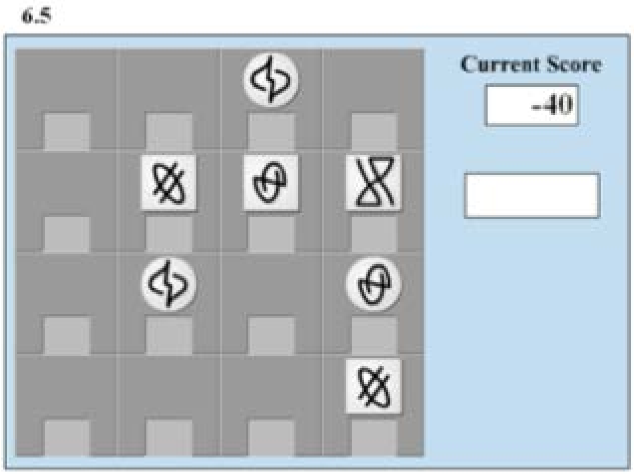

Figure 2. Computer-based Brocanto2 game board (Morgan-Short et al., 2013).

The computer-based board game was used as the basis for language practice and included six comprehension and six production modules (Fig 2). During the comprehension, participants listened to 20 Brocanto2 sentences per module and moved pieces on the game board to match. During the production modules, participants watched a series of 20 moves on the game board per module and then were asked to verbally describe them using Brocanto2. ‘Correct’ or ‘incorrect’ feedback was provided after every answer, enabling trial and error decisions to be made.

Within the testing element we looked at the percentage correct for all participants in the comprehension modules (1,2,5,6,9,10) and production modules

(3,4,7,8,11,12) separately. Figure 3 shows the mean accuracy of comprehension and production modules across all participants. There was a clear upward trend as the practice modules progressed. In general, considering the chance level was at 50%, comprehension module 1 was significantly below chance t(18) =-3.252, p < .004; the final module, 12, t(9)= 1.991, p<.078 was significantly above chance, with the modules in between expressing a gradual progression, reaching above chance in comprehension module 6 and production module 7.

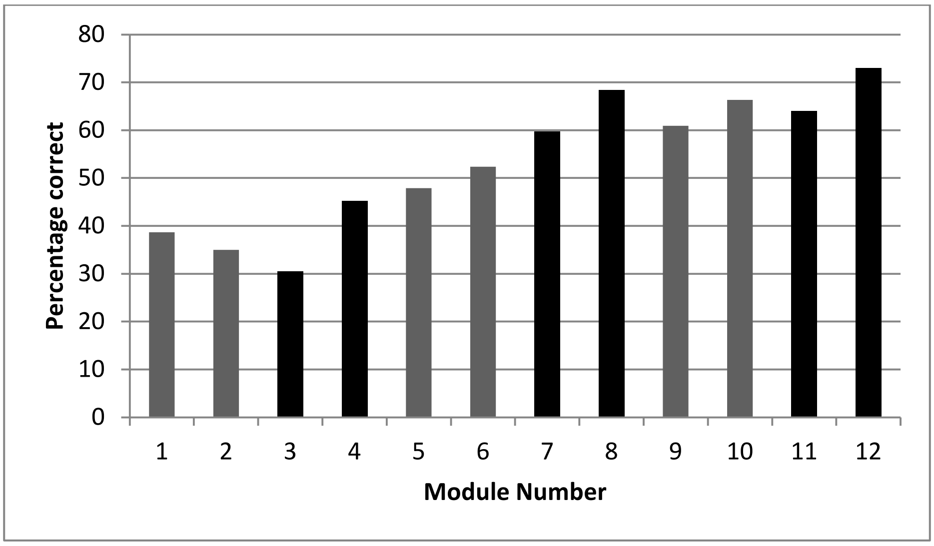

Figure 3. Mean percentage correct on comprehension (light grey) and production (black).

3.4 Cognitive tests

The Flanker test, first developed by Eriksen & Eriksen (1974), was used to test inhibitory control. The task uses a computer screen and target stimuli in the form of chevrons (Fig 4). There were three types of non-target stimuli: congruent flankers, which were chevrons of the same type and same direction as the target; incongruent flankers, same type but opposite direction to the target; and neutral flankers, stimulus of a different type, e.g. squares. 'Congruent' trials involved one target red chevron surrounded by other black chevrons of the same type, pointing in the same direction; in 'incongruent' trials the surrounding chevrons point in opposite directions to the target chevron. Participants watched the screen and clicked left or right according to the direction of target stimulus, while simultaneously ignoring the non-target distractor stimuli. The Flanker task provides a measure of inhibitory control, calculated as the difference between reaction time (RT) on incongruent trials and congruent trials.

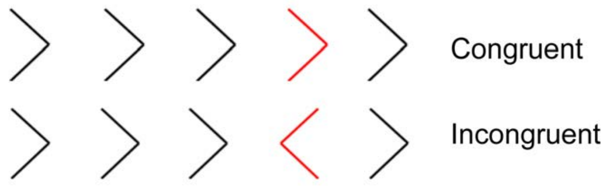

Figure 4. Examples of stimuli from the Flanker test (Luk et al., 2010).

The WCST, engineered by Berg (1948) and Grant and Berg (1948), is a computer-based card game and was used as a measure of cognitive flexibility (shifting). Participants were presented with a card sorting game and asked to match cards by a randomly changing rule; either, match by colour, match by shape, or match by number, using the 'incorrect' and 'correct' feedback to help them. The Psychology Experiment Building Language (PEBL) (Mueller & Piper, 2014) version of the WCST was used to conduct the experiment. Shifting ability was measured as the percentage of perseverative errors following the introduction of a new sorting rule.

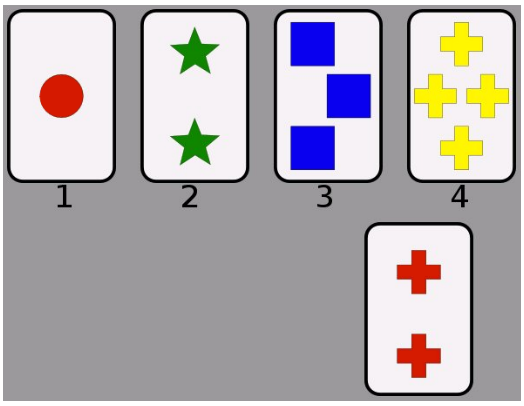

Figure 5. Screenshot from the PEBL computerized version of the Wisconsin Card sort.

3.5 Grammaticality Judgement Task

A grammaticality judgement task was deployed as a measure of language learning. Participants listened to 120 Brocanto2 sentences - 60 of which were ungrammatical - and had to judge whether they were 'good' or 'bad' sentences based on the information they had gained throughout the training and practice stages. They also had to state what their answer was based on, either '*guess*', meaning they might as well have flipped a coin; '*intuition*' where they believed their decision was correct but [they] didn't know why; '*memory*', meaning they relied on recollection or memory; or based on '*rule knowledge'*, meaning they thought they knew the rule and were able to verbally describe it. Above chance performance on *guess* and *intuition* answers indicated implicit knowledge. In this case people would be able to comprehend a language, without a real understanding of how they know or are able to use it (Reber, 1967). Conversely, a score of above chance on *memory* and *rule knowledge* categories would indicate explicit language knowledge.

4. Results

4.1 Vocabulary training

The average number of trials taken for all participants during vocabulary training was 2.05 (*SD* = 0.887). No participant took more than 4 attempts and 6 subjects took only 1. The number of trials necessary to reach the full score was taken as a measure of vocabulary learning proficiency and the value of the positive correlation between this and the score of the Wisconsin Card sorting test was found to closely approach significance ($r = .300$; $p = .058$).

4.2 Grammaticality Judgement Task

Performance on the GJT was deployed as a measure of language learning. In terms of overall accuracy, participants classified on average 70.68% (*SD* = 17.57%)

of the test items correctly. Performance was above chance, t (19) = 5.265, $p < .001$, where chance was taken as 50%, which indicates that exposure resulted in a clear learning effect. Looking at the mean correct percentages of grammatical and ungrammatical items separately, both were above chance, with grammatical items at 73% (*SD* = 20%) and ungrammatical items at 67% (*SD* = 19%).

4.3 Source attributions

The use of source attributions allowed us to see how participants viewed their own knowledge, and meant that we could distinguish between implicit and explicit knowledge gained. Implicit knowledge is categorised here as *guess* and *intuition* (Reber, 1967). Looking within the separate categories of *guess*, *intuition*, *memory* and *rule knowledge*, we can see a clear trend of increasing accuracy with the lowest being *guess* and the highest being *rule knowledge*, as would be predicted (see Figure 6). The mean accuracy value for the *guess* attributed phrases was 56.65% (*SD* = 15.16%). For the *intuition* category, mean accuracy was above chance at 64.78% (*SD* = 17.54%). When subjects responded with *memory*, they were 69.7% (*SD* = 18.27%) accurate. Finally, when the answer was based on *rule knowledge*, mean accuracy was 76.93% (*SD* = 21.98%).

A one-sample t-test indicated that subjects performed significantly above chance on responses based on *intuition*, t (19) = 3.674, $p < .001$, *memory*, t (16) = 4.314, $p < .001$, and *rule knowledge*, t (18) = 5.198, $p < .001$. However grammaticality judgments based on *guess* responses were at chance.

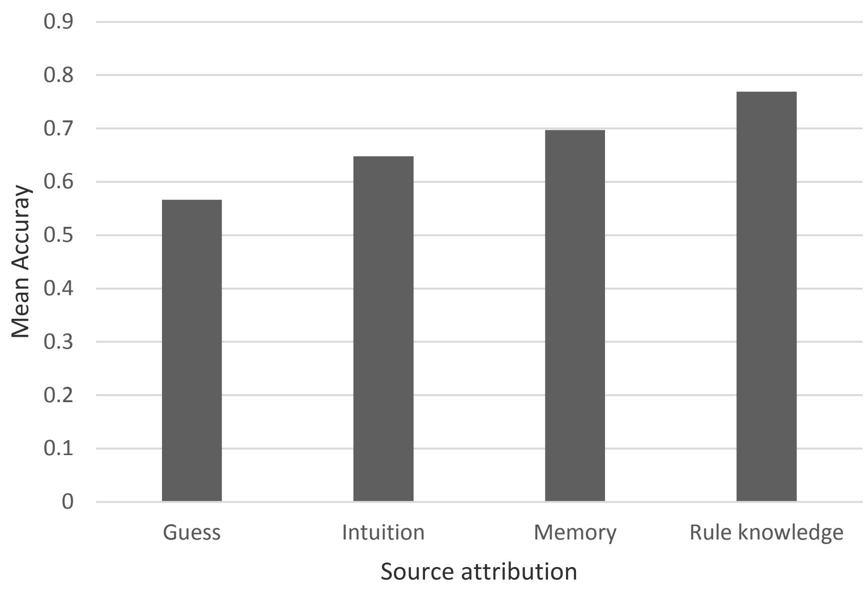

Figure 6. Mean accuracy for source attribution.

4.4 Cognitive tests

For the Wisconsin card-sorting task, in addition to considering the number of correct and incorrect responses, we also looked at the number of perseverative responses; that is to say, the incorrect responses that would have been correct for the preceding rule.

Overall, the mean percentage accuracy was 82.2% (*SD* = 5%), ranging between 72.66% and 88.68% for individual scores (Figure 7). In terms of perseverative responses, there was an average of 40.45 items per participant, an average percentage of 32.75% (*SD* = 4.84%). Here no significant correlation between the WCST and the GJT scores was found, possibly showing that cognitive flexibility is unlikely to be related to how well you are able to learn an unfamiliar language. However, as mentioned before, the correlation between vocabulary learning proficiency and the Wisconsin Card sorting test was found to be closely approaching significance.

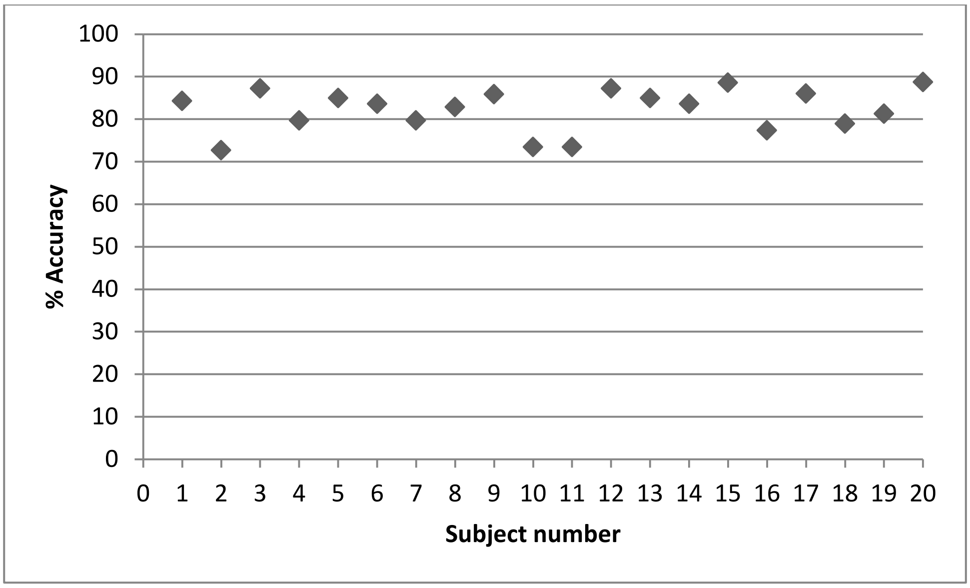

Figure 7. Mean percentage accuracy for the WCST for each subject.

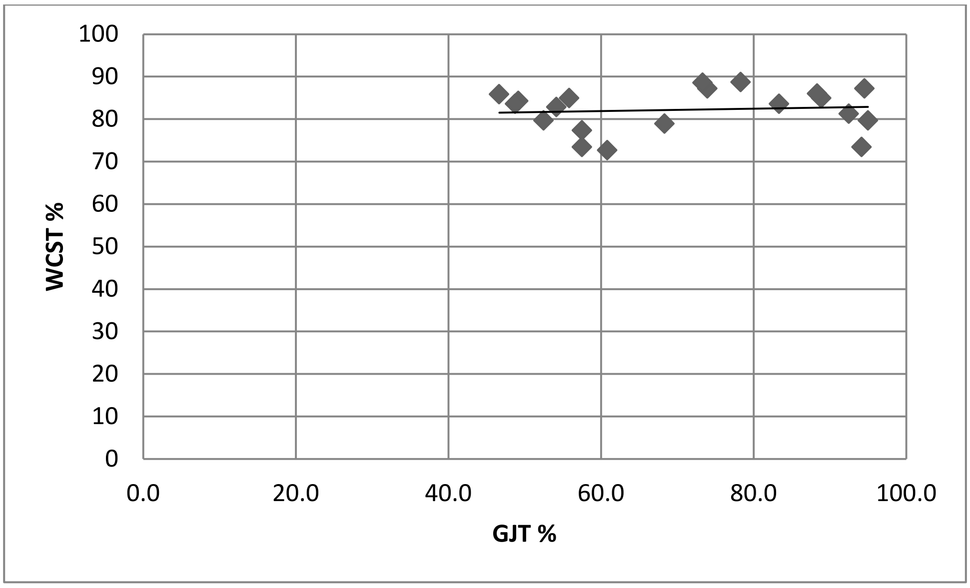

Figure 8. Correlation between mean correct WCST scores and mean correct GJT scores.

The Flanker effect is the average incongruent RT minus the average congruent RT within the CI (congruent/incongruent) block. Flanker effect scores were calculated in milliseconds as a measure of inhibitory control (*M*=32.90*; SD*=53.39), indicating the additional processing time needed for over-coming mental conflict, after accounting for the switch between congruent and incongruent trials. The mean reaction time across all stimulus types for correct answers was 433.92m/s. A one-sample *t*-test indicated that the flanker task scores were not significantly correlated with the GJT scores, t (20) = 27.96, p > .206 (Figure 9).

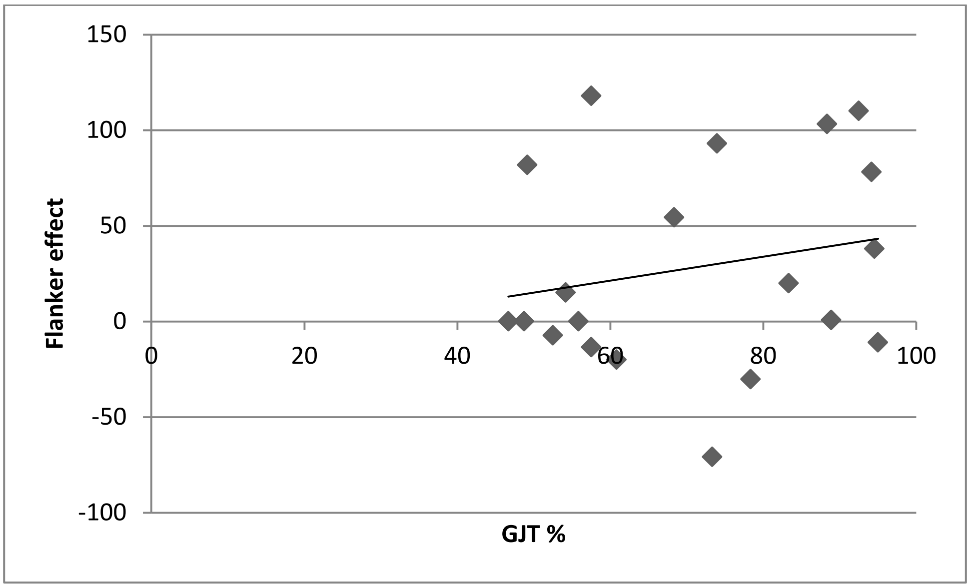

Figure 9. Correlation between flanker effect (milliseconds) scores and GJT scores.

5. Discussion

This study aimed to address whether individual differences of cognitive flexibility and inhibitory control as measures of executive function could account for the wide variation in L2 acquisition ability in adults. Using the Brocanto2 paradigm, a significant learning effect was found on the grammaticality judgement task, consistent with results from previous studies (Grey, 2014; Morgan-Short et al., 2014). The GJT learning effect also suggests that participants were able to learn, not only syntax, but also gender agreement and vocabulary. Extending Morgan-Short el al.'s (2014) research, the source attribution of the participants' knowledge was also measured and showed both conscious and unconscious knowledge. The *intuition* category was above chance at 64.8%, presenting that the learners had gained at least some implicit knowledge (Rebuschat & Williams, 2012). The *memory* and *rule knowledge* categories were also both above chance at 69.7% and 76.9% respectively, illustrating the explicit knowledge gained by participants (Tagarelli, 2015). However the explicit source attribution categories of *memory* and *rule knowledge* had a much higher accuracy rate overall, compared to that of *guess* and *intuition*, showing that explicit knowledge was the most reliable. This is not surprising considered that, although participant were not asked to actively search for rules, the language training included some elements of metalinguistic knowledge.

Unlike previous research we did not find a correlation between inhibitory control or flexibility and artificial language learning. For flexibility, it is possible that the lack of variation in WCST played a role in the lack of correlation, as all the participants scored similarly in terms of accuracy, between 72.7% and 88.7%. Adapting the WCST to give a more in-depth test of cognitive flexibility could possibly solve this by giving a finer-grain and more accurate measure, highlighting the variation within the study (Waxer & Morton, 2011). Alternatively, additional measures of cognitive flexibility could be used to give a more reliable score for each participant, as it is known that ID tests do not always give reliable results when deployed in isolation (cf., Morgan-Short et al., 2014).

Also in the case of inhibitory control no significant correlation was found with L2 grammatical development in adults (Figure 9). Unlike what has recently emerged for bilingualism (Tagarelli, 2015; Bialystok et al., 2004), the present results do not support the idea that inhibitory control is related to L2 acquisition.

Considering specifically the type of instruction, Tagarelli (2015) suggested that inhibitory control abilities play a substantial role in the language learning of instructed learners primed to learn explicitly. Contrary to Tagarelli (2015), we found that no correlation between language learning and executive function emerged, although the type of language exposure provided to the participants in the present study included some elements of metalinguistic instruction. In the relationship between executive function and the learning of complex structures, future research will need to look at the possible different outcomes of instruction that simply provides metalinguistic information vs. instruction that invites more explicit learning strategies (e.g., active rule search).

Our results are also not in line with Kapa & Colombo (2014), who found that shifting ability predicted artificial language learning. However, the discrepancy between the results presented in Kapa & Colombo (2014) and the present study could be traced down to a number of factors, including the complexity of the artificial language and the treatment of vocabulary test scores. Kapa & Colombo (2014) used a much simpler language (Verb-Noun-Noun) compared to Brocanto2, possibly facilitating the learning of syntactic structure in the form of chunks. In terms of coding, the present study looked separately at the grammar and vocabulary results, whereas Kapa & Colombo (2014) included the vocabulary results in their correlations, which may have significantly affected them in ways that are supported by our own findings. Although no significant correlations were found between language learning and executive control, this study found that the correlation between vocabulary learning and cognitive flexibility closely approached significance, supporting a possible substantial role of lexis in the positive relationship with executive function measures (see also Festman, Rodriguez-Fornells and Munte, 2010; Hernandez and Meschyan, 2006).

6. Conclusions and further research

The relationship between enhanced executive function and L2 learning is debated and more research is needed in this area to disentangle the factors at play. An element that has emerged clearly from the literature and is confirmed by the results of the present study is the close relationship between vocabulary learning and higher scores in executive function measures. On the other hand, the findings of the present study did not support the association between executive function and language learning in terms of the acquisition of novel constructions, pointing at a difference between vocabulary and syntax learning which deserves further investigation in future research. It has to be noted that in this study the participant's L1 differed and although no participants were proficient in languages that shared the morpho-syntactic characteristics of the target, this constitute a variable that should be controlled in the future. Another issue is the relatively small number of participants, which by itself may have affected the statistical significance of the correlations. Further limitations of the study include the absence of more fine-grained cognitive measures, measures of working memory, and a more in-depth investigation of the relationship between executive function and type of instruction. In particular, future research will need not only to differentiate between implicit and explicit instruction, but also analyse which factors in explicit instruction are most likely to positively interact with executive function and support second language learning.

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