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Research paper

The relationship between cognitive control and second language proficiency

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ABSTRACT

In the past 20 years, the field of bilingualism has made a substantial effort to better understand the set of cognitive mechanisms that allow bilinguals to functionally manage and use their languages. Among the mechanisms that have been identified, cognitive control has been posited to be key for proficient bilingual language processing and use. However, the role of cognitive control in developing bilingualism, i.e., among adult learners learning a second language (L2), is still unclear with some studies indicating a relationship between cognitive control and adult L2 development/developing bilingualism and other studies finding the opposite pattern. This set of contradictory findings merits further investigation in order to deepen our understanding of the role that cognitive control plays during the process of becoming bilingual. In the present study, we aimed to address this open question by examining the role of cognitive control among adult L2 learners of Spanish at the intermediate level using multiple behavioral measures as a way to provide a multidimensional perspective on the role of cognitive control and developing bilingualism. Our results indicate a significant relationship between cognitive control abilities, specific to reactive control, and overall L2 proficiency. We also found a significant relationship between speed of processing and overall L2 proficiency. The results of this study contribute to the existing body of knowledge on cognitive factors related to developing bilingualism and provide critical new insight into the underlying cognitive mechanisms that may contribute to adult L2 learners becoming bilingual.

1. Introduction

In today's world, many adults find themselves in a situation in which it is beneficial or even necessary to learn a second language (L2). Yet, we can argue that L2 learning is possibly one of the most challenging and complex tasks for the adult mind. Indeed, adult L2 learners often struggle when learning an L2, resulting in a great deal of variability in their learning outcomes, with some learners reaching favorable milestones in their language learning experience while some other learners do not. Given the great deal of variability in learning success across adult L2 learners, researchers in the field of second language acquisition (SLA), for over five decades now, have been interested in investigating the different characteristics that lead to successful adult L2 learning (e.g., Carroll, 1981; Dörnyei & Skehan, 2003; Gardner & Lambert, 1965; Segalowitz, 1997). Despite the large number of SLA studies that have shed light on our understanding on how adult L2 learning takes place and the different conditions that may enhance it, explaining the varying

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success in adult L2 learning is still an open question.

One way in which SLA researchers have attempted to provide answers as to why some adults succeed when learning an L2 while others struggle has been to identify the role that internal factors, i.e., factors that are directly related to the learner, play in successful adult L2 development. A variety of individual factors, or individual differences, have been proposed and explored empirically (see Dörnyei, 2006, for review) with the goal of identifying the ways in which they contribute to adult L2 learning. Among the characteristics that have been identified, we find individual differences related to three different sets of factors, (a) biological, such as age or sex (e.g. DeKeyser, 2012; MacIntyre, Baker, Clément, & Donovan, 2002), (b) cognitive, such as language aptitude, intelligence, attention, or working memory (e.g., Harley & Hart, 1997, pp. 379–400; Kormos, 2000; Tagarelli, Borges-Mota, & Rebuschat, 2011) and (c) affective, such as personality, learning styles or motivation (e.g., Carson & Longhini, 2002; Grey, Williams, & Rebuschat, 2015; Ushioda, 2012). In particular, research that focuses on investigating the role that individual differences in cognitive abilities play in L2 learning has proven to be useful in accounting for some of the large variability found among adults learning an L2. Findings from this area of research have provided critical new insight into identifying the underlying cognitive and brain mechanisms that may contribute to adult L2 learning.

In addition to the abovementioned set of individual cognitive factors that have been found to play a role in adult L2 learning, one cognitive factor that has received special attention in bilingualism research but that has only started to be explored empirically in adult L2 learners is cognitive control, which is central to executive functioning. Indeed, executive functions are understood to consist of domain-general control mechanisms that have been posited to reflect one's ability to regulate the dynamics of human cognition and action, specifically in regard to self-control and self-regulation ability (Braver, 2012; Miyake & Friedman, 2012). The interest in cognitive control is motivated by the increasing number of studies with bilinguals that have found a relationship between cognitive control and bilingualism, suggesting that cognitive control may be one of the underlying mechanisms that allows the mind and brain of bilinguals to accommodate the presence of two languages (Green, 1998; Green & Abutalebi, 2013). These studies provide evidence that suggests that, even in monolingual contexts, bilinguals have their languages active at all times (e.g., Hatzidaki, Branigan, & Pickering, 2011; Hernandez, Li, & MacWhinney, 2005; Hoshino & Thierry, 2011; Jacobs, Fricke, & Kroll, 2016; Oppenheim, Wu, & Thierry, 2018; Sunderman & Kroll, 2006). The constant co-activation of bilinguals' languages has been shown to generate cross-linguistic competition (e.g., Marian, Bartolotti, Rochanavibhata, Bradley, & Hernandez, 2017; Marian & Spivey, 2003). Such competition seems to require bilinguals to recruit cognitive control mechanisms in order to correctly select the language they intend to use while having, at the same time, to control and regulate the resulting interference derived from having their other language active at all times (e.g., Abutalebi & Green, 2008; Bialystok, Craik, & Luk, 2008; Kroll, Dussias, Bogulski, Valdes-Kroff, & 2012).

Given the attested role of cognitive control in bilingual language selection and use, we might expect cognitive control to also play a role in adult L2 learning (i.e., developing bilingualism). Nonetheless, only a few studies to date have investigated the role that cognitive control abilities play in adult L2 outcomes with some indicating a positive relationship (Levy, McVeigh, Marful, & Anderson, 2007; Linck, Kroll, & Sunderman, 2009; Bartolotti, Marian, Schroeder, & Shook, 2011; Kapa & Colombo, 2014; Grant et al., 2015; Darcy, Mora, & Daidone, 2016) whereas some others do not (Linck & Weiss, 2015; Stone & Pili-Moss, 2016). Our study aims to extend the L2 literature by investigating the relationship between cognitive control abilities and L2 proficiency in developing bilingualism by assessing different dimensions of cognitive control in intermediate-level L2 learners of Spanish. Below, we provide a brief review of the role of cognitive control in bilingualism that is followed by a more in depth review the few studies of cognitive control in L2 in order to motivate our study.

1.1. *The role of cognitive control in bilingualism: A brief review*

Before we review the relevant literature, it is important to note that in the bilingual literature, the terms 'cognitive control' and 'inhibitory control' are frequently used interchangeably. For the present paper we adopt a broad understanding of cognitive control and a specific understanding of inhibitory control or inhibition. 'Cognitive control' will be used to refer to one's ability to "regulate thoughts and actions in accordance with internally represented behavioral goals" (e.g., Braver, 2012, p. 106). Whereas 'inhibitory control' or 'inhibition' will be used to refer more specifically to a particular subcomponent of general cognitive control ability that is used "for suppressing dominant of prepotent responses" (Miyake et al., 2000, p. 54). However, in cases where authors used the term 'inhibitory control' or 'inhibition' more generally, we will adopt their specific terminology.

A series of theoretical models have attempted to conceptualize how bilingual language selection and use takes place and have posited that bilinguals' ability to functionally manage their languages may be directly linked to cognitive control. Both the IC and BIA + models propose that the amount of control that needs to be exerted for bilingual language selection and use to occur is of a reactive nature. In other words, they posit that individuals utilize reactive cognitive control, defined as one's ability for detecting and solving interference in a conflicting context (Braver, 2012), in response to the degree of activation of the competing representations from the non-target language. In the same vein, Green and Abutalebi (2013) have proposed a revised version of the IC model, the Adaptive Control Hypothesis (ACH), which attempts to incorporate other factors within the reactive control account perspective of bilingual language selection in order to better capture the complexity of the bilingual experience. Specifically, the ACH argues that bilingual language control, selection, and use may not only be of reactive nature, instead it may also require proactive control, defined as one's ability to help select and maintain task goals by selecting the most relevant and/or appropriate candidate before competition occurs (Braver, 2012), in order to adapt to the ever-changing demands placed by the intrinsically diverse interactional contexts in which bilinguals often find themselves. Thus, the ACH poses that bilingual language control, selection, and use may require speakers to exercise as well as coordinate both reactive and proactive control mechanisms to achieve proficient bilingual performance.

Empirical evidence supporting cognitive control accounts of bilingualism comes from several methodological approaches. Initial evidence emerged from behavioral studies that employed language-switching tasks on the lexical level (see Abutalebi & Green, 2008, for review). One of the earliest studies to test this hypothesis was conducted by Meuter and Allport (1999). In their foundational study, Meuter and Allport (1999) examined bilingual performance on a language-switching task and found evidence of bilinguals controlling their first language (L1) while they were asked to name items in their L2. Interestingly, Meuter and Allport found that the amount of cognitive control exerted, which they interpreted as inhibition, was greater when bilinguals were asked to name items in their L2 then when they did so in their L1. Subsequent research has also provided evidence of bilinguals' control of their L1 via inhibition while using the L2 (see also Van Heuven, Dijkstra, & Grainger, 1998; Costa & Santesteban, 2004; Wodniecka, Bobb, Kroll, & Green, 2005). Additional behavioral evidence for the role of cognitive control in bilingual language processing has been found for semantics, grammar, and speech planning (e.g., Hoshino & Thierry, 2012; Morales, Paolieri, & Bajo, 2011; Misra, Guo, Bobb, & Kroll, 2012). Furthermore, evidence for the role of cognitive control in bilingualism comes from studies reporting that bilinguals often tend to outperform monolinguals in non-verbal tasks that require the use of cognitive control (e.g., Bialystok & Martin, 2004; Ryan, Bialystok, Craik, & Logan, 2004) although results have been mixed (e.g., Costa, Costa-Faidella, & Sebastián-Gallés, 2009; Paap & Greenberg, 2013; De Bruin, Treccani, & Della Sala, 2015; Duñabeitia & Carreiras, 2015). These findings also seem to converge well with a growing body of neurocognitive research with bilinguals that has provided evidence that brain regions associated with cognitive control and other executive function mechanisms, such as the left dorsolateral pre-frontal cortex, the left anterior cingulate cortex, and the caudate nucleus, have shown increased activation during bilingual language processing (e.g., Luk, Green, Abutalebi, & Brady, 2012; Abutalebi et al., 2013; Calabria, Costa, Green, & Abutalebi, 2018).

Overall, the available empirical evidence suggests that bilinguals seem to engage cognitive control to manage the competition between their languages. This evidence generally supports extant theoretical accounts that posit a role for cognitive control mechanisms in bilingualism. Considering the fact that L2 learners are emerging bilinguals, we should also consider the extent to which cognitive control abilities are related to successful adult L2 learning.

1.2. Relationship between cognitive control and adult L2 learning

Drawing from the relevance of the findings that suggests that cognitive control plays a functional role in bilingualism, studies in the field of L2 learning have recently started to investigate the relationship between cognitive control and adult L2 learning. Emerging evidence for a role of cognitive control in adult L2 learning has been found at the lexical, phonological, grammatical levels and also for cognitive control training, as evidenced by both behavioral and neurocognitive studies (for lexical: Linck et al., 2009; Bartolotti et al., 2011; Grant, Fang, & Li, 2015; for phonological: Levy et al., 2007; Darcy et al., 2016; for grammatical: Kapa & Colombo, 2014; for training: Chen, Ma, Wu, Zhang, Fu, Lu, & Guo, 2020). However, contradictory results have been found indicating no relationship between cognitive control abilities and adult L2 learning (for grammar: Linck & Weiss, 2015; Stone & Pili-Moss, 2016).

Among the studies that have found a relationship between cognitive control abilities and adult L2 learning, we find two main patterns of interesting findings. First, similar to proficient bilinguals, empirical evidence suggests that adults L2 learners (i.e., developing bilinguals) engage cognitive control in order to regulate the influence of their L1 when using their L2 (Levy et al., 2007; Linck et al., 2009). Specifically, effects of cognitive control have been found in the L1 when looking at adult L2 learners' L1 performance on behavioral tasks after L2 use. For example, using a picture-naming task adapted to a retrieval practice paradigm, Levy et al. (2009) asked beginning L2 learners of Spanish, who had all completed at least one year of college-level Spanish and whose L1 was English, to repeatedly name target items in each one of their languages. The amount of trials that participants had to spend naming target items in each language was critically manipulated in order to investigate whether naming an item in the participants' L2 would result in controlling, which they referred to as inhibition, of the corresponding representation in the participants' L1. Results showed that naming target items in the participants' L2 ten times in a row significantly decreased the number of L1 target items generated by the participants, suggesting that increased use of an L2 required participants to exercise cognitive control as a strategy to regulate the influence of the phonological representations in their L1 during L2 use, making them less accessible and thus, harder to retrieve.

Linck et al. (2009) examined performance on both L1 and L2 verbal fluency tasks for intermediate L2 learning of Spanish and compared performance for learners who had been immersed in the L2 during a semester abroad with learners who had L2 classroom experience only. Participants were told that they would be presented with a category (e.g., fruits) and had to produce as many examples of that category as they could within 30 s (e.g., "apple, pear, banana, etc."). Participants performed the verbal fluency task in both their L1 and their L2. Results indicated that immersed participants were able to produce significantly more examples in the L2 than the classroom learners. Interestingly, the immersed learners produced significantly fewer examples in their L1 than the classroom learners. These results provide further evidence of cognitive control, which they referred to as inhibition, of the L1 during L2 use. Additionally, their results show that access to the L1 may be differentially attenuated depending on the context of learning (immersion *vs* classroom learning), with the L1 being less accessible after immersion when the L2 is more available.

Additional evidence of a role for cognitive control during L2 processing comes from a longitudinal study using functional neuroimaging (fMRI). Grant et al. (2015) investigated whether L2 lexical processing as compared to L1 lexical processing would reveal increased activation of brain regions associated with cognitive control, such as those areas related to cognitive control, in early L2 learners. Participants completed a lexical decision task while their brain activity was being recorded. They were asked to identify both language-ambiguous words (e.g., Spanish–English homographs such as *pie*, which means foot in Spanish but cake in English) and language-unambiguous words (e.g., clearly English words such as *king* versus clearly Spanish words such as *mesa*). Results revealed significantly increased activation in cognitive control areas, such as the anterior cingulate cortex, when adult L2 learners were asked to resolve cross-linguistic interference from competing language ambiguous representations. In sum, these results suggest that adult L2 learning, like proficient bilingualism, engages domain-general cognitive control mechanisms to manage the consequences of having to juggle two languages in one mind.

Second, studies have found an association between cognitive control abilities and L2 learning outcomes, for words (Bartolotti et al., 2011), for phonology (Darcy et al., 2016), and grammar (Kapa & Colombo, 2014). For L2 word learning, Bartolotti et al. (2011) asked native speakers of English with different L2 learning experiences (i.e., from low to high bilingual experience) to learn words from two novel languages that were based on International Morse Code. Interference between the two languages was manipulated by introducing two highly conflicting cues that competed to define word boundaries differently across languages. Participants' general cognitive control abilities were assessed via a Simon task, a widely used behavioral task to assess general cognitive control ability. Results indicated that when interference was high during L2 word learning, participants with stronger cognitive control abilities performed significantly better than participants with weaker general cognitive control abilities. Researchers interpreted the effect by claiming that stronger general cognitive control abilities allowed participants to better selectively attend to the set of cues that were key for word segmentation in the high-interference condition, suggesting that stronger general cognitive control abilities may contribute to better L2 word learning in general, but, importantly, may also contribute to word segmentation ability, both key abilities in L2 learning.

For L2 grammar learning, Kapa and Colombo (2014) had participants, who reported having no prior L2 learning experience, learned an artificial language to examine whether executive function abilities would predict how easily an L2 can be acquired. Participants were exposed to a simplified version of the artificial language via an implicit training task, i.e., grammar rules were never explicitly taught. Participants' ability to learn the small artificial language system was measured with six tests of receptive and expressive knowledge, including a grammaticality judgment task to assess L2 grammatical learning. Cognitive control abilities were assessed using the Attentional Network Task (ANT; Fan et al., 2002). Results found a relationship between cognitive control abilities and learners' performance on the grammaticality judgment task. The researchers concluded that the relationship between cognitive control and L2 learning that was found in the study may have be related to the participants' ability to regulate the influence, which they referred to as inhibition, of their L1 during L2 grammar learning, suggesting that individuals who may be able to better control access to their L1 during L2 learning may be better equipped to ultimately become more successful L2 learners.

Finally, for L2 phonological learning, Darcy et al. (2016) asked L2 learners of Spanish at the intermediate level to complete a speeded ABX categorization task and a delayed sentence repetition task to assess L2 phonological processing in both perception and production. Additionally, they used a retrieval-induced inhibition task to measure learners' general cognitive control ability. Results indicated a relationship between L2 learners' ability for segmental perception and consonant production and cognitive control abilities. These results suggest that cognitive control abilities may play a role in L2 phonological acquisition, where cognitive control abilities may aid L2 learners with the processing of phonologically relevant acoustic information in the L2 input, which would ultimately lead to the development of more accurate phonological representations in their L2. These findings in the phonological domain complement previous findings for a role of cognitive control in L2 word and grammar learning.

The results from these studies suggest that the additional cognitive demands of incorporating a new language into an already established linguistic system might be less challenging to those individuals who have stronger cognitive control abilities. In that vein, based on the available evidence one would predict that one's ability to better regulate the influence of a strong L1 during L2 learning may yield significant benefits. However, despite the empirical evidence above that suggests such a role for cognitive control in adult L2 learning, other studies have found no relationship. For example, in a correlational study Linck and Weiss (2015) found the no effect of cognitive control. Twenty-five university students, who were enrolled first- or third-semester L2 Spanish classes, were asked to complete the Diploma of Spanish as a Foreign Language Test to assess L2 grammatical competence, and a Simon task, as a measure of general cognitive control ability. Results revealed no relationship between cognitive control abilities and L2 grammatical proficiency for adults learning an L2 in a classroom context.

Additionally, and contrary to Kapa and Colombo (2014)'s findings, Stone and Pili-Moss (2016) found no relationship between cognitive control abilities and participants' ability to learn an artificial language. In their study, participants, who were native or near-native English speakers, were trained in the artificial language Brocanto2 (developed by Morgan–Short, Sanz, Steinhauer, & Ullman, 2010; Morgan-Short, Steinhauer, Sanz, & Ullman, 2012), which is comprised of rules that are common to Romance languages, such as Spanish. Participants received explicit training, i.e., grammar rules were explicitly taught, of Brocanto2 grammar via a computer board game that contained six comprehension and six production modules of language practice. After the practice modules were completed, participants were asked to complete a grammaticality judgement task to assess L2 grammatical development. Cognitive control abilities were evaluated via a Flanker task (Eriksen & Eriksen, 1974), a task typically used to assess general cognitive control ability, specifically with regards to one's ability to suppress, which the authors referred to as inhibit, responses that are inappropriate in a particular context. Results showed no relationship between performance on the Flanker task and grammaticality judgment task scores, thus suggesting no relationship between cognitive control and the early stages of L2 grammatical development under explicit learning conditions.

Although results are mixed, the majority of evidence to date suggests that L2 learners may engage cognitive control when using their L2 and that their cognitive control abilities may be associated with L2 learning. Also, the findings in bilingualism research, which suggest a consistent role for cognitive control in proficient bilingualism, motivate the need to continue studying this relationship, as L2 learners are developing bilinguals. Thus, advancing this line of research in the field of SLA may positively shed light on the different underlying cognitive mechanisms that may be involved in adult L2 learning.

Note that studies to date that have explored the role of cognitive control in L2 have largely tested beginning-level L2 learners. This is especially true for studies that have examined the relationship between cognitive control and L2 learning (Stone & Pili-Moss, 2016; Bartolotti, 2011; Kapa & Colombo, 2014; Linck & Weiss, 2015). Indeed, the null effects found in Linck and Weiss (2015) and Stone and Pili-Moss (2016) could be partially explained by the fact that their participants were at very early stages of L2 learning, and thus, cognitive control effects may not have emerged because learners may have not had enough experience controlling their two languages and/or may be still rely heavily in their L1 knowledge while using their L2. Among these studies, three out of four employed artificial linguistic stimuli. The use of artificial linguistic systems can be effective for addressing specific questions about L2, but research should be extended to natural languages as well (Morgan-Short, 2020). Thus, it might be useful to extend the research to examine the relationship between cognitive control and L2 learning in intermediate-level L2 learners in a natural language.

Second, studies with proficient or relatively proficient bilinguals suggest that the engagement of cognitive control may go beyond the inhibitory or reactive account and also be proactive and, thus, adaptive (e.g., Gullifer et al., 2018; Morales, Gómez-Ariza, & Bajo, 2013; Zirnstein, van Hell, & Kroll, 2018) as hypothesized by the ACH model (Green & Abutalebi, 2013). Also, recently it has been argued that the Flanker and the Simon task, the tasks used by Linck and Weiss (2015) and Stone and Pili-Moss (2016) to assess cognitive control in their respective studies, may have low task reliability, and thus, using them as the only assessment of cognitive control may not provide the best measure of one's general cognitive control ability (Paap & Greenberg, 2013). In that regard, there is a growing consensus that suggests that due to the complexity of the *becoming* bilingual experience, multiple cognitive control tasks should be utilized to assess both the unique and diverse nature of cognitive control (i.e., reactive and proactive) in order to explore in what ways and at what stages cognitive control may play a role during adult L2 learning (e.g., Miyake & Friedman, 2012; Morales et al., 2013).

1.3. *Current study*

These open questions lead to the main goal of the current study aimed at investigating the relationship between cognitive control abilities and L2 proficiency in developing bilingualism. Given that (a) cognitive control has been linked to proficient bilingualism but (b) the relationship between adult L2 learners' cognitive control abilities and L2 proficiency outcomes merits further research, we pose the research question: *Is there a relationship between cognitive control abilities and L2 proficiency?* The current study aims to provide new insight into this question by using multiple measures of cognitive control abilities, such as general as well as reactive and proactive control ability, and L2 proficiency in order to capture the diverse nature of the experience of becoming bilingual as well as the dynamic and adaptive nature of the cognitive mechanisms underlying proficiency outcomes in developing bilingualism.

2. Methods

2.1. *Participants*

Twenty-eight adult L2 intermediate learners of Spanish ($N = 20$ females) participated in this study. All participants were speakers of American English, between the ages of 18 and 35, with normal or corrected-to-normal vision and/or hearing, and with no reported history of drug or alcohol dependence or psychiatric, neurological, or learning disorders. Participants' first average age exposure to Spanish was 14 years (the common age for starting high school in the United States) and had occurred in classroom environments. They

Table 1
Participants' background and language experience characteristics.

	M (*SD*)
Age (years)	20.94 (2.23)
Years of Education	15.96 (2.42)
Age first exposed to L1	0 (0)
L1 Self-Rated[a] Reading Proficiency	10 (0)
L1 Self- Rated[a] Writing Proficiency	9.65 (.56)
L1 Self- Rated[a] Speaking Proficiency	10 (0)
Age first exposed to L2	14.5 (.99)
L2 Self- Rated[a] Reading Proficiency	6.89 (1.33)
L2 Self- Rated[a] Writing Proficiency	6.75 (1.41)
L2 Self- Rated[a] Speaking Proficiency	6.50 (.95)
WM-Composite Score[b]	0.03 (0.61)
WM-OSpan[c]	18.46 (8.00)
WM-RSpan[c]	16.28 (8.40)
WM-SymSpan[d]	7.94 (5.58)
IQ[e]	9.61 (3.20)
L2 Self-Reported Daily Use	34% (2.95)

Note.
[a] Reported on a scale from 1 = no proficiency to 10 = native-like proficiency.
[b] Average of standardized scores from each of the WM three tasks.
[c] Maximum score on OSpan & RSpan = 75; SymSpan = 42 (following absolute scoring protocol).
[d] Maximum score on OSpan & RSpan = 75; SymSpan = 42 (following absolute scoring protocol).
[e] Maximum score Raven's Task = 18.

had completed (or placed out of) the basic Spanish language program at the large, urban, Midwestern university where they were tested, and they were enrolled in high-intermediate or low-advanced level university Spanish courses at the time of testing. They did not have any study abroad experience. Participants completed a language history background questionnaire (LEAP-Q, Marian, Blumenfeld, & Kaushanskaya, 2007) to gather comprehensive information about their overall language experience (see Table 1). All participants provided written informed consent to participate in the study and received monetary compensation for their time.

2.2. Materials and procedure

2.2.1. Cognitive control tasks

Cognitive control abilities were assessed via two widely used tasks that include the presence of competing or conflicting information that must be controlled in order to successfully perform the task. Two different tasks were used in order to facilitate a valid and diverse measurement of cognitive control ability (Miyake & Friedman, 2012). Specifically, we administered a Flanker Task (Flanker; Eriksen & Eriksen, 1974) and the Automated Continuous Performance Task (AX-CPT; following Morales et al., 2013).

Flanker task. We first chose to obtain a general measure of cognitive control ability by administering a Flanker task. The Flanker task is a widely used task that requires that participants suppress conflicting information in order to make a correct response. For our Flanker task, participants were presented with a series of arrows pointing to the left or the right and were asked to indicate as quickly and as accurately as possible whether the central arrow (the target item) points to the left or right by pressing the left-side mouse button when the target arrow points to the left, or the right-slide mouse button when the target arrow points to the right. In this task, the target arrow was always presented in the center of 4 flanker arrows following one of the 3 following conditions: (a) the target arrow pointed in the same direction as the flanker arrows (i.e., congruent trials), (b) the target arrow pointed in the opposite direction of the flanker arrows (i.e., incongruent trials) or (c) the target arrow was surrounded by flanking lines without arrowheads (i.e., neutral trials). After 12 practice trials, a total of 72 trials distributed across 4 blocks were presented with all conditions appearing equally often. The task procedure was as follows: (a) a fixation cross appeared on the center of the screen and remained there during the whole trial, (b) a cue (an asterisk) was presented for 100 ms, (c) a fixation cross appeared for 400 ms after the cue, (d) the target arrow and the flankers were presented simultaneously for 1700 ms or until the participant's response, (e) the target and flankers disappeared after a response was made and the next trial began. Accuracy and reaction time (RT) were recorded. General cognitive control ability was assessed via the Flanker effect, operationalized as the RT difference between incongruent and congruent trials.

Automatic Continuous Performance Task (AX-CPT). As suggested by the ACH Model (Green & Abutalebi, 2013), the ability to use and coordinate different domain-general control mechanisms may be important for achieving efficient language selection, control, and, ultimately, bilingual-like language performance: Both reactive and proactive control are expected to contribute to bilingual selection and use, and their role should be examined in L2 as well. In order to obtain specific measures of both reactive and proactive control, we administered the AX-CPT task (following Morales et al., 2013).

In the version of the AX-CPT that we administered in the current study, participants were presented with strings of five letters that began with a cue of either the letter "A" or any other letter as a 'B' cue, ended with a probe of either the letter "X" or "Y", and had three other random letters in the middle. Participants were asked to respond to specific cue and probe combinations, namely press "Yes" when the letter "X" (the probe) was preceded by the letter "A" (the cue, comprising an AX trial) and press "No" for all other sequences (AY, BX and/or BY). To clarify, AY trials consist of an "A" cue that is followed by a "Y" cue rather than by an "X" cue. BX trials consists of a 'B' cue that could be any letter, but an "A" followed by an "X" letter probe. BY trials are control trials where neither the cue nor the probe overlap with the target AX trials. The task consisted of one practice block comprised of ten trials including all four possible experimental trial types (i.e., AX, AY, BX, and BY). Participants were provided with feedback on accuracy and RT after each practice trial. Completion of the practice block was followed by the experimental block, which was comprised of 100 trials. For both the practice and experimental blocks, target AX trials appeared 70% of the time whereas non-target AY, BX, or BY trials appeared only 10% of the time each.

Following Morales et al. (2013), proactive and reactive control were assessed by comparing performance on the different types of trials. Specifically, reactive control was based on the performance on AY trials, as participants would have to control their reactive response to "X" when it did not follow "A,". Additionally, proactive control was based on performance on BX trials, as participants would need to proactively control their response to "X" given that the first letter was not "A." Finally, of general interest were the BY control trials, which are hypothesized to index speed of processing ability. Performance measures for both these trials types included error rate and reaction time.

2.2.2. L2 proficiency

The current study included three measures of L2 proficiency. The measures of L2 proficiency used in this study included a modified version of the Diploma of Spanish as a Foreign Language test (DELE, Montrul, 2005), a verbal fluency task (VF, adapted from Sanoudaki & Thierry, 2015) in both English and Spanish, and an elicited imitation task in Spanish (EIT, Ortega, 2000). These measures are described below.

2.2.2.1. L2 proficiency. Diploma of Spanish as a Foreign Language. Participants in the study completed a modified version of the Diploma of Spanish as a Foreign Language (Diploma de Español como Lengua Extranjera, DELE), an objective, written proficiency measure focused on vocabulary and grammar (Montrul, 2005). The DELE is comprised of a cloze portion, in which participants filled in missing words in a text (20 items), and a multiple-choice version that required participants to select the most appropriate word to complete a sentence from a list of four options (30 items). Scores on this task reflected the number of correctly answered items out of 50.

Verbal Fluency task (VF). Participants in the study also completed a category fluency task (adapted from Sanoudaki & Thierry, 2015) as a relative proficiency measure (Sandoval, Gollan, Ferreira, & Salmon, 2010) where they were asked to produce as many words as they could in 30 s separately for four different categories (i.e., animals, professions, fruits, and home furniture). Participants completed this task in both English and Spanish. Language order and task versions were counterbalanced across participants. Following Sanoudaki and Thierry (2015), the recordings were transcribed by two independent raters and then rated either 0 or 1 (0-not acceptable to 1 acceptable) following a scoring protocol based on the acceptability on each of the items that were produced. Repetitions and variations of the same word and proper names of people/places were excluded. Interrater reliability was 100%. The total number of words produced was calculated for each category for each participant. Finally, participants' number of acceptable responses across each category were summed together.

Elicited Imitation task (EIT). Participants in the study completed an EIT (Ortega, 2000) as an additional measure of L2 spoken proficiency. Participants were asked to listen to 30 increasingly complex sentences in Spanish, which were presented one at a time, and to repeat each sentence out loud as closely as possible after hearing a beep that sounded after each sentence. Participants' responses were digitally recorded. Following Ortega (2000), the recordings were transcribed by two independent raters and then rated from 1 to 4 following a scoring protocol based on how accurately (1-not accurately to 4 very accurately) each response represented the content from the original sentence. Interrater reliability was 90% but raters came to an agreement for the 10% of the items they had initially rated differently. Scores on this task were the sum of their ratings out of 120.

Composite L2 proficiency score. As the aim of this study is to examine the relationship between cognitive control and L2 proficiency, we decided to generate a general proficiency score that was not specific to a particular L2 proficiency task (cloze task, production) or to a modality (e.g., written, oral). Thus, we created a general composite L2 proficiency score by converting participants' scores on each of the three L2 proficiency tasks into z-scores (i.e., [Participant Score – Group Average Score)/Group Standard Deviation]) and then averaging the three z-scores together as the final composite score of L2 proficiency for each participant.

2.2.3. *Control measures*

Individual difference measures of working memory (OSpan, RSpan, SymSpan, Oswald, McAbee, Redick, & Hambrick, 2015) and general intelligence (IQ) (Raven's; Arthur & Day, 1994) were collected in the study in order to control for any intervening effects these variables may have on the relationship between the cognitive control abilities and L2 proficiency. These measures are described below.

2.2.3.1. *Working memory.* Working memory (WM) and cognitive control are hypothesized to co-occur and support one another and rarely is one needed but not the other (Diamond, 2013). Thus, in order to independently examine the role of cognitive control, we controlled for WM using scores from three shortened versions of established WM capacity tasks (following Oswald et al., 2015) namely the operation span task (OSpan), the reading span task (RSpan), and the symmetry span task (SymSpan). Each one of these tasks was designed to tap into both the processing and storage components of WM (Baddeley, 2012) by specifically asking participants to (a) make judgments about a given series of items and (b) to recall a specific list of given series of elements.

O-Span Task. In this task, trials consisted of simple math problems (e.g., "Is $(1 + 5)/2 = 3$?"). Participants were asked to verify whether the solution provided was correct or incorrect. Approximately half of the equations presented were correct. After each math problem, participants were presented with a letter from the alphabet (e.g., "L") and were asked to store it in memory for recall at the end of a set of trials. Set sizes ranged from 3 to 7 trials, including both math problems and letters, with three administrations for each set size for a total of 75 total operation-storage pairs.

R-Span Task. In this task, trials consisted of sentences of approximately 10–15 words in length. Participants were asked to determine whether the sentences presented made sense, i.e., they describe situations that are likely to occur on a daily basis (e.g., John was asked to sit on a chair) or not (e.g., John was asked to sit on a cloud). Approximately half of the sentences presented were sensical/nonsensical. After each letter, participants were presented with a letter from the alphabet (e.g., "L") and were asked to store it in memory for recall at the end of each set of trials. Set sizes ranged from 3 to 7 trials, including both sentences and letters, with three administrations for each set size for a total of 75 total sentence-storage pairs.

Sym-Span Task. In this task, trials consisted of 8×8 matrices of black and white squares. Participants were asked to judge if the matrices were symmetrical with respect to the vertical axis or not. Approximately, half of the matrices presented were symmetrical. After each matrix, participants were presented with a 4×4 matrix with one red square and were asked to store it in memory for recall at the end of each set of trials. Set sizes ranged from 2 to 5, including 8×8 and 4×4 matrices, with three administrations for each set size for a total of 42 total symmetry-storage pairs.

For each span task, we calculated participants' 'absolute' WM score (Oswald, 2015), which is a count of the number of trials per set in which the participant responded to the processing questions correctly and recalled all elements in the correct order. This type of score provides a general assessment of WM ability as it takes into account both processing and recall responses in the analyses. Given the disparity between maximum score between the OSpan/RSpan (75), and SymSpan (42), following Faretta-Stutenbeg (2014) the OSpan, RSpan, and SymSpan scores were converted into standardized scores and then averaged together in order to calculate a composite WM ability score for each participant.

2.2.3.2. *General intelligence (IQ).* In order to control for any effects of general intelligence (IQ) on cognitive control, IQ was measured with a shortened Raven's Advanced Progressive Matrices Test (Raven's; Arthur & Day, 1994). The Raven is a measure of abstract reasoning. The version of the Raven's that we used in this study was computer administered and consists of 36 individual items presented in three segments of 12 items each. Within each segment, the items were presented in ascending order of difficulty. Each item consisted of a matrix of geometric patterns with the bottom-right pattern missing. Participants were asked to select, among either six or eight alternatives, the one that correctly completes the overall series of patterns that have been presented. Each matrix item was presented separately on the screen along with the response alternatives. Participants were asked to use the mouse to select the response from the ones presented that they thought would complete the pattern. Participants were allotted 5 min to complete each segment. Participants received two practice problems before starting with the experimental trials. Overall, the task took approximately 15 min to complete. IQ was computed as each participant's total number of correctly solved problems.

3. Results

Before reporting analyses specific to our research question, we provide a description of participants' performance on the proficiency and cognitive control tasks. In regard to proficiency, participants completed three behavioral measures: a verbal fluency task, an EIT, and the DELE, as described in detail in Section 2.2.2. Performance on these tasks provide insight into participants' (a) L2 lexical knowledge, (b) L2 oral proficiency skills, and (c) L2 written vocabulary and grammar skills. Before examining performance on these measures, scores were examined for outliers by checking whether any of the scores from the L2 proficiency tasks were more than 2.5 *SD*s from the group mean, and no outliers were identified. As described above, a composite L2 score representing overall proficiency was calculated based on the z-scores of the three specific L2 proficiency measures. Descriptively, individual level scores for the verbal fluency task, the EIT, and the DELE scores fell within the range of performance expected for intermediate learners (e.g., Bowden, 2016; Montrul, 2005; Sanoudaki & Thierry, 2015). Descriptive results for the L2 proficiency measures for the L2 group are provided in Table 2 and in Fig. 1.

Regarding cognitive control, participants completed two behavioral measures to assess cognitive control abilities, the Flanker and the AX-CPT task as described in detail in Section 2.2.1. Performance on these tasks provide insight into participants' (1) general cognitive control, (2) reactive control, (3) proactive control, and (4) speed of processing abilities. In regard to the Flanker, prior to analyzing participants' performance, trials with response times below 100 ms and over 1000 ms were removed comprising 6.5% of the data. In addition, trials that were over 2.5 standard deviations above the mean were also removed, comprising 2.9% of the data. The measure of interest is the Flanker effect (reaction time to incongruent trials minus reaction time to congruent trials), although we also report overall accuracy via error rate and reaction time by trial type. Participant data for the Flanker effect were examined for outliers by checking whether participant means were more than 2.5 *SD*s from the group mean, and no outliers were identified. Overall, participants performed near ceiling (98%) and showed a Flanker effect of 63 ms. Descriptive results for accuracy and the Flanker effect are provided in Table 3 and in Fig. 2, with results by trial type also indicated in Table 3.

In regard to the AX-CPT, data cleaning procedures were conducted prior to analyzing participants' performance, following Morales et al. (2013). Trials with response times below 100 ms and over 1000 ms were removed, comprising 7% of the data. In addition, trials that were over 2.5 standard deviations above the mean were also removed, comprising 5% of the data. Error rate and reaction time were then examined for the trial types of interest, that is AY (i.e., reactive control), BX (i.e., proactive control), and BY trials (i.e., baseline control condition hypothesized to index speed of processing abilities). Participant data for these measures were examined for outliers by checking whether any of the participant averages were more than 2.5 *SD*s from the group mean, and no outliers were identified. Descriptively, participants produced the fewest percentage of errors in the AX and BY conditions, whereas the BX and AY conditions produced the highest amount of errors, which seemed to be consistent with previous studies that reported performance on the AX-CPT task among language learners (e.g., Morales et al., 2013; Zirnstein et al., 2018). Reaction time was faster for trials starting with a 'B' and slower for trials starting with an "A". Descriptive results for error rate and reaction time are provided in Table 4 and in Fig. 3.

In order to address the study's research question, *is there a relationship between cognitive control abilities and L2 proficiency?* correlational and regression analyses were conducted. First, we examined correlations for an initial view of the relationship between the composite L2 proficiency score and the cognitive control measures (i.e., the Flanker effect as well as reaction times for the AY, BX, and BY trials from the AX-CPT task; see Table 5 and Fig. 4). There was no evidence that L2 proficiency was related to the Flanker effect (i.e., general cognitive control ability) or to the BX trials (proactive cognitive control) from the AX-CPT task. However, analyses revealed medium-sized[1] statistically significant negative correlations between L2 proficiency and the AY and BY trials (reactive control and speed of processing, respectively) from the AX-CPT task. Quicker responses to reactive control trials and faster speed of processing more generally was related to higher L2 proficiency.

In order to further probe the relationship between cognitive control and L2 proficiency, we conducted regression analyses to examine how each of the measures of cognitive control could account for L2 proficiency after controlling for IQ and WM. For these regression analyses, we used stepwise variable selection. In doing so, our goal was to include all meaningful predictors and only meaningful predictors, since the variance of the prediction of the model increases as the number of predictors increases (Montgomery, Peck, & Vining, 2013). We also considered the adjusted R^2, AIC, and BIC measures for evaluating the models (Montgomery et al., 2013), focusing on adjusted R^2. Adjusted R^2 tends to be characterized as the most intuitive measure to use, whereas AIC and BIC are both commonly used for statistical model comparisons, which we did not conduct. In addition, BIC might not be appropriate for small

[1] Effects sizes were interpreted according to Plonsky & Ostwald's (2014) field-specific recommendations for correlation analyses, with 0.25 indicating a small effect, 0.40 indicating a medium effect, and 0.60 indicating a large effect.

Table 2
Descriptive results of performance on L2 proficiency measures.

	L2 Verbal Fluency[a]	EIT[b]	DELE[c]	L2 Composite Score[d]
Mean (*SD*)	27.61 (8.62)	69.21 (24.82)	24.78 (6.66)	−0.01 (0.89)
[95% CI]	[24.26, 30.95]	[59.59, 78.84]	[22.20, 27.37]	[-.359, .337]

Note.
[a] Mean number of tokens produced across categories.
[b] Maximum score on EIT = 120.
[c] Maximum score on DELE = 50.
[d] Average of standardized scores from each of the L2 proficiency tasks.

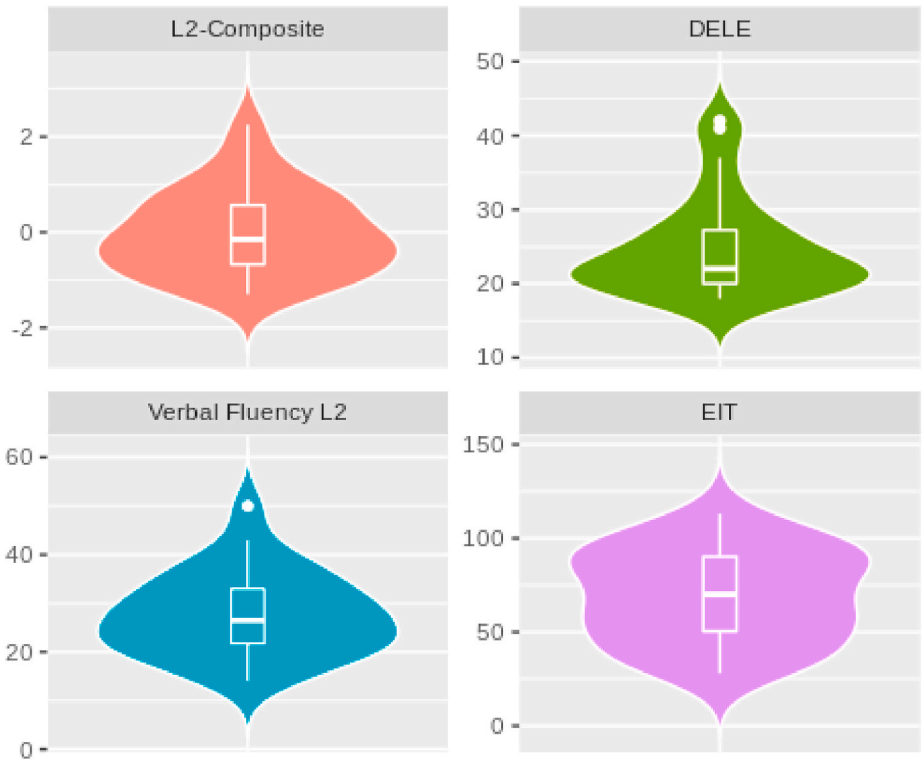

Fig. 1. Violin plots illustrating the distribution of the L2 proficiency data across the different measures.
Note. Violin plots visualize the distribution of the data by showing the kernel density estimate for each variable. Embedded within the violin plots are box plots that depict the quartiles of the data. Values on the y-axes represent (a) the average standardized score for the L2 composite proficiency score, (b) number of correct items out of 50 for the DELE, (c) total number of words produced across the different categories for the L2 verbal fluency task, and (c) the total sum of the ratings out of for the EIT.

Table 3
Descriptive results of overall performance by trial type on flanker task.

	Congruent Trials		Incongruent Trials		Neutral Trials		Overall Accuracy	Flanker Effect[a]
	Error Rate	RT	Error Rate	RT	Error Rate	RT	Error Rate	RT
Mean (*SD*)	0.08 (0.01)	511.80 (59.32)	0.03 (0.03)	575.02 (51.42)	0.01 (0.01)	477.41 (33.25)	0.02 (0.01)	63.21 (31.05)
[95% CI]	[0.03, 0.14]	[488.86, 534.81]	[0.02, 0.04]	[555.07, 594.96]	[0.01, 0.02]	[447.24, 512.30]	[0.01, 0.03]	[51.17, 72.25]

Note.
[a] General cognitive control ability (Flanker effect: Incongruent-Congruent Trials).

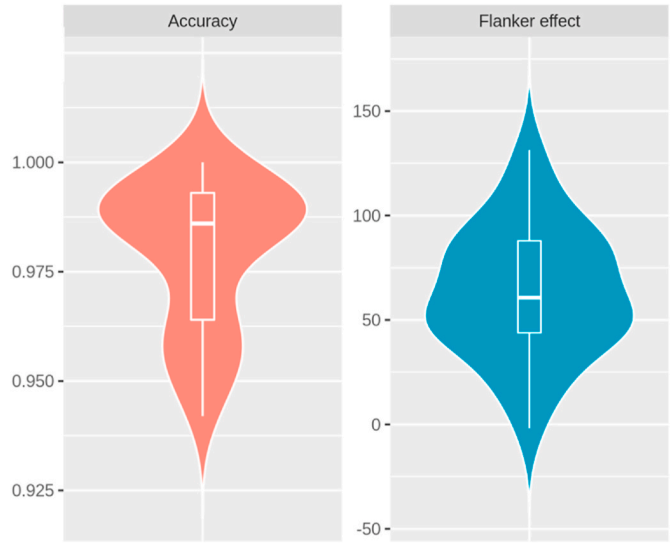

Fig. 2. Violin plots illustrating the data distribution on overall performance for the Flanker task.
Note. Violin plots visualize the distribution of the data by showing the kernel density estimate for each variable. Embedded within the violin plots are box plots that depict the quartiles of the data. Values on the y-axes represent rate of overall accuracy on the Flanker task and milliseconds for the Flanker effect.

Table 4
Descriptive results of performance on AX-CPT task.

	AX Trials		AY trials[a]		BX trials[b]		BY trials[c]	
	Error Rate	RT	Error Rate	RT	Error Rate	RT	Error Rate	RT
Mean (*SD*) [95% CI]	0.09 (0.05) [0.11, 0.05]	320.67 (33.51) [308.29, 335.12]	0.22 (0.20) [0.21, 0.14]	350.54 (62.62) [332.12, 382.51]	0.16 (0.19) [0.25, 0.06]	256.52 (47.47) [241.22, 281.70]	0.02 (0.07) [0.23, 0.01]	254.60 (51.08) [240.56, 278.66]

[a] Reactive cognitive control.
[b] Proactive cognitive control.
[c] Speed of processing (baseline control condition).

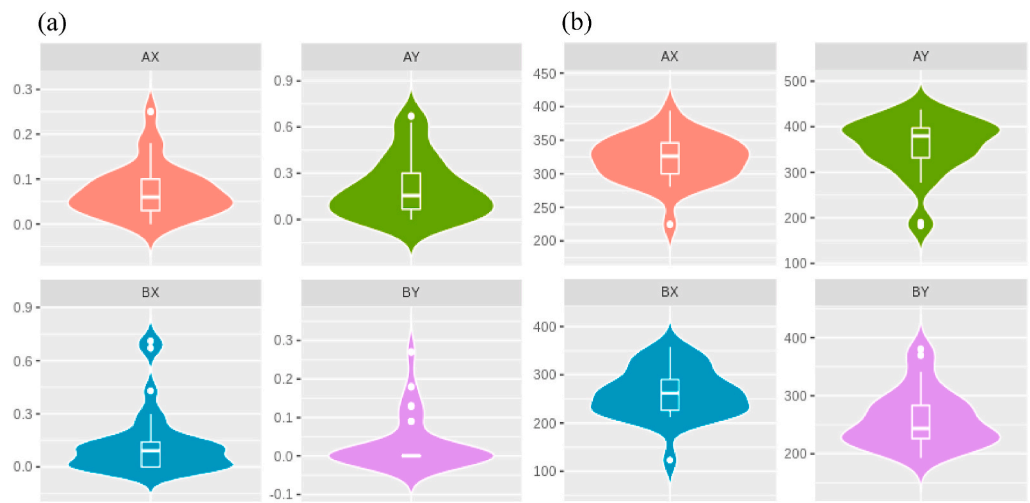

Fig. 3. Violin plots illustrating the data distribution on overall performance across the different trials of the AX-CPT task.
Note. Violin plots visualize the distribution of the data by showing the kernel density estimate for each variable. Embedded within the violin plots are box plots that depict the quartiles of the data. Values on the y-axes for each trial type represent (a) error rates and (b) reaction time.

Table 5
Correlation coefficients of individual difference measures between cognitive control and L2 proficiency.

	L2 Proficiency	DELE *r* (*p*)	VF *r* (*p*)	EIT *r* (*p*)	Flanker Effect *r* (*p*)	AY *r* (*p*)	BX *r* (*p*)	714 *r* (*p*)
L2 Proficiency (Composite)	–	.901** (.000)	.890** (.000)	.909** (.000)	0.009 (.962)	-.447* (.017)	0.152 (.439)	-.390* (.040)
DELE	–	–	.692** (.000)	.740** (.000)	0.080 (.686)	-.395* (.037)	0.206 (.293)	−0.313 (.105)
VF	–	.–	–	714** (.000)	0.002 (.992)	-.482** (.009)	0.186 (.344)	−0.267 (.170)
EIT	–	–	–	–	−0.057 (.774)	−0.329 (.087)	0.019 (.922)	-.472* (.011)
Flanker Effect	–	–	–	–	–	0.048 (.808)	0.249 (.202)	0.158 (.421)
AY	–	–	–	–	–	–	−0.039 (.846)	0.289 (.135)
BX	–	–	–	–	–	–	–	.415* (.028)
BY	–	–	–	–	–	–	–	–

Note. $^{*}p < 0.05$. $^{**}p < 0.01$.

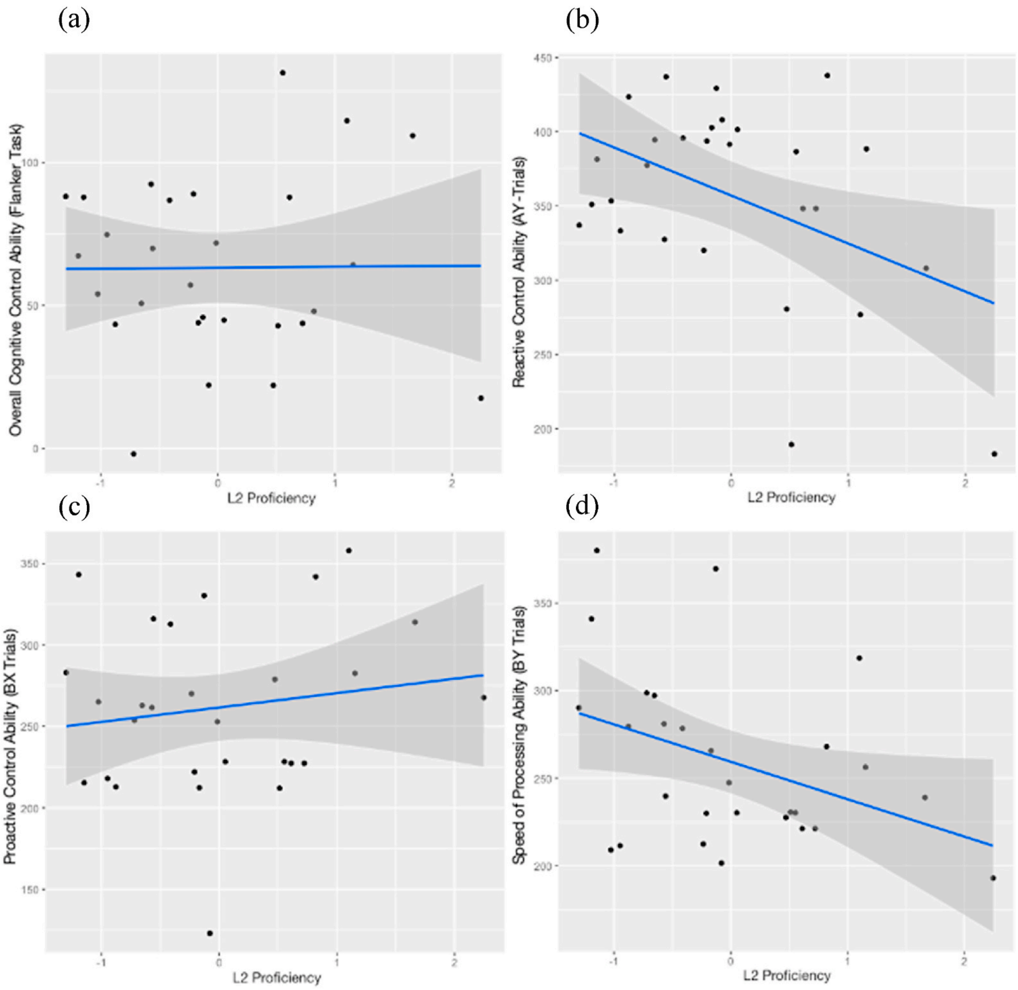

Fig. 4. Correlation scatterplots illustrating the relationship between L2 Proficiency and Cognitive Control abilities.

datasets like ours (Burnham & Anderson, 2004). In creating our regression models, we centered all predictor variables in order for the intercept to be interpretable as the predicted L2 proficiency score by having all predictors be at their mean value. Centering was revealed to not affect the estimate of the slopes of the predictor variables. For each measure of cognitive control, a sequential linear regression was conducted with the L2 proficiency composite score as the outcome variable.

Our first model consisted of our control variables (i.e., the WM composite score and IQ). This control model revealed an R^2 of 0.123 and an adjusted R^2 of 0.053, with $F(2, 25) = 1.757$, $p = 0.193$ and no significant predictors of L2 proficiency (see Table 6).

Secondly, we entered the Flanker effect (i.e., general cognitive control ability), as the predictor variable of interest. This model revealed an R^2 of 0.138 and an adjusted R^2 of 0.03, with $F(3, 24) = 1.283.$, $p = 0.304$. The Flanker effect was not a significant predictor of L2 proficiency (see Table 7). Also, the inclusion of the Flanker effect into the model slightly decreased the adjusted R^2 value from the control model (see Table 8). Thus, we chose not to maintain the Flanker effect as a predictor variable in our model.

Next, we included the AY (i.e., reactive control) measure from the AX-CPT task into the third step of the regression model. This model revealed an R^2 of 0.299 and an adjusted R^2 of 0.211, with $F(3, 24) = 3.409$, $p = 0.034$ (see Table 9). The model indicated that reactive control was a significant predictor of L2 proficiency. More specifically for every millisecond that the RT decreased in the AY condition, a participant's L2 composite score would increase by 0.006 points (95% CI: [-0.011; −0.001]). To put this on a more interpretable scale, this would mean a decrease of 100 ms would result in a 0.6 standard deviation increase of the L2 Proficiency Composite Score. In evaluating the model, we note that the adjusted R^2 was higher for this model. Thus, we chose to retain the AY measure in our regression model.

As a next step, we included the BX (i.e., proactive control) measure from the AX-CPT, as a predictor in the model including reactive control ability (AY). This model revealed an R^2 of 0.341 and an adjusted R^2 of 0.226, with $F(4, 23) = 2.974$, $p = 0.041$ (see Table 10). Performance on the BX trials were not a statistically significant predictor of L2 proficiency. Also, we note that the adjusted R^2 only slightly improved for this model. Thus, we chose not to retain the BX measure in our model.

Finally, we included the BY (i.e., speed of processing) measure from the AX-CPT in the regression model. The inclusion of BY in this new model revealed a R^2 of 0.326 and an adjusted R^2 of 0.175, with $F(5,22) = 2.127$, $p = 0.112.$, BY was not a statistically significant predictor of L2 proficiency (see Table 11). Note that the inclusion of this variable worsened the adjusted R^2 value as compared to the AY model, thus we did not retain BY in the model.

In conclusion, the model that yielded a statistically significant meaningful predictor and that had the highest adjusted R^2, as well as the lowest (better) values for AIC and BIC (see Table 8), is the regression model that includes the AY measure along with the control measures. As this is the model that we will interpret, we checked the assumptions for linearity of data, normality of residuals, and homogeneity of variance and did not find any violation of these assumptions. Additionally, and in order to check for multicollinearity among different factors, we calculated the variance inflation factors for all models, and they never displayed values above 1.5 indicating that we did not have multicollinearity in our final model.

4. Discussion

In the current study, we attempted to investigate the relationship between cognitive control abilities and L2 proficiency among intermediate adult L2 learners of Spanish. Results revealed a statistically significant relationship between cognitive control and L2 proficiency. Nonetheless, this relationship only emerged when participants were asked to complete a more complex and fine-grained cognitive control task, the AX-CPT, that required participants to not only exercise cognitive control to successfully complete the task, but, crucially, it also required participants to engage multiple control processes, i.e., reactive and proactive control. More specifically, the AX-CPT task required participants to regulate reactive and proactive control for different trials in order to successfully complete the task. This key methodological difference seemed to have allowed individual differences to emerge on the AX-CPT task unlike the Flanker task of general cognitive control ability, where our results indicated near-ceiling performance. The relationship that was evidenced between cognitive control and L2 proficiency on the AX-CPT task was specific to reactive control (AY trials). This finding indicated that participants who were better at detecting and resolving conflicts during information processing, in other words by adjusting their response when the wrong target appeared following an "A" on the AX-CPT task were those participants with higher L2 proficiency.

This set of outcomes is in line with the emerging body of research that has found that young adult L2 learners engage cognitive control when using their L2 (Darcy et al., 2016; Grant et al., 2015; Levy et al., 2009; Linck et al., 2015), that cognitive control abilities may be associated with L2 learning (Bartolotti et al., 2011), but that their posited role may vary along the different stages of L2 learning with reactive or conflict-focused control processes playing a more prominent role at the early and intermediate stages of L2 learning, as is the case for L2 learners who participated in our study, while proactive or meaning-focused control processes might play a more distinctive role once higher L2 proficiency and experience are attained (see Grant et al., 2015 and Gullifer et al., 2018 for a similar pattern of findings).

Note, however, that in the research addressing L2 learning specifically, relationships between cognitive control abilities and adult L2 learning are not always found, at least not in those studies that assess cognitive control using simpler or less cognitively demanding tasks such as the Flanker task (Stone & Pili-Moss, 2016) or the Simon task (Linck & Weiss, 2015), although Bartolotti et al. (2011) did find a relationship between performance on the Simon task and L2 vocabulary learning. Instead, the relationship may more reliably emerge when more complex tasks are used (Kapa & Colombo, 2014; Paap & Greenberg, 2013). Thus, the results from our study suggest that in order to capture individual differences in cognitive control abilities among young adults, especially considering the fact that young adults are at the peak of their cognitive performance during early adulthood, more complex measures of cognitive control ability may be needed. Incorporating such measures in L2 studies may have the potential to contribute to a better understanding of the distinctive role that cognitive control abilities play at different stages of L2 learning, for learners with different types of L2 experience as well as for different age groups.

The results of the current study also extend findings of a relationship between cognitive control and L2 learning to intermediate learners of a natural L2. Previous studies that examined this relationship specifically tested beginner-level learners. Stone and Pili-Moss (2016), Kapa and Colombo (2014), and Bartolotti (2011) examined the contribution of cognitive control to L2 learning of artificial linguistic stimuli (for grammar and vocabulary), which means that learners did not have previous exposure or proficiency in the language. In Linck and Weiss (2015), participants could also be considered beginner or low-intermediate learners, as they were

Table 6
Regression model with control variables.

Variable	*B*	*SEB*	*t*	*Sig*
(Intercept)	−0.012	0.165	−0.070	0.945
IQ	0.085	0.054	1.572	0.129
Working Memory	−0.311	0.281	−1.109	0.278

Table 7
Regression model examining general cognitive control abilities (Flanker Effect) and L2 proficiency.

Variable	*B*	*SE B*	*t*	*Sig*
(Intercept)	−0.012	0.167	−0.069	0.945
IQ	0.090	0.055	1.630	0.116
Working Memory	−0.376	0.302	−1.247	0.224
Flanker Effect	0.004	0.006	0.638	0.529

Table 8
Summary table of model comparison measures.

Model	Adjusted R^2	AIC	BIC
Control	0.053	76.751	82.080
Flanker	0.030	78.279	84.940
AY	0.211	72.495	79.156
AY-BX	0.226	72.763	80.757
AY-BY	0.175	75.391	84.716

Table 9
Regression model examining reactive control abilities (AY) and L2 proficiency.

Variable	*B*	*SEB*	*t*	*Sig*
(Intercept)	−0.012	0.151	−0.077	0.939
IQ	0.091	0.050	1.834	0.079
Working Memory	−0.071	0.274	−0.259	0.798
Reactive Control (AY)	−0.006	0.003	−2.451	0.022[a]

[a] $p < 0.05$.

Table 10
Regression model examining the interplay between reactive (AY), proactive (BX) control abilities, and L2 proficiency.

Variable	*B*	*SEB*	*t*	*Sig*
(Intercept)	−0.012	0.149	−0.078	0.939
IQ	0.076	0.051	1.492	0.149
Working Memory	−0.100	0.273	−0.367	0.717
Reactive Control (AY)	−0.005	0.003	−1.954	0.063
Proactive Control (BY)	−0.004	0.003	−1.211	0.238

Table 11
Regression model examining the interplay between reactive control abilities (AY), speed of processing (BY), and L2 proficiency.

Variable	*B*	*SE B*	*t*	*Sig*
(Intercept)	−0.012	0.154	−0.075	0.941
IQ	0.096	0.051	1.869	0.075
Working Memory	−0.103	0.300	−0.344	0.734
Reactive Control (AY)	−0.006	0.003	−2.337	0.029[a]
Speed of Processing (BY)	0.002	0.003	0.787	0.440

Note.
[a] $p < 0.05$.

enrolled in first- or third-semester Spanish classes. In contrast, our learners had completed (or placed out of) at least two years of university-level Spanish and were enrolled in intermediate or advanced Spanish courses (e.g., literature, cultural studies, or linguistics). Thus, our results extend previous findings to a new population of L2 learners for a natural language.

More generally, the positive relationship between cognitive control abilities and adult L2 proficiency is consistent with previous research with relatively proficient to proficient bilinguals that has suggested that cognitive control may be among the factors that allow bilinguals to functionally manage and use their languages (e.g., Chen et al., 2020; Hoshino & Thierry, 2012; Kang, Ma, Kroll, & Guo, 2020; Misra et al., 2012; Morales et al., 2011; Wu & Thierry, 2017), although this is not without controversy (e.g., Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Duñabeitia & Carreiras, 2015; Leivada, Duñabeitia, Westegaard, & Rothman, 2020; Paap & Greenberg, 2013, Wu & Thierry, 2013).

Overall, the results of this study also support the hypothesis posited by the IC (Green, 1998) and BIA+ (Dijkstra & Van Heuven, 2002) models that propose that the amount of control that needs to be exerted for bilingual language control to occur is of a reactive nature. In addition, our results also support the hypothesis posited by Green and Abutalebi (2013) in their Adaptive Control Hypothesis (ACH) model, at least indirectly. The ACH situates reactive cognitive control as one of the underlying mechanisms that may allow the human mind and brain to accommodate the presence of two languages. In addition, the ACH argues that bilingual, language control may also involve the ability to coordinate different cognitive control processes to achieve proficient bilingual performance. Indeed, the results from our study suggest a role for reactive control in emerging bilinguals when reactive control is assessed with a complex cognitive control task. However, we did not find additional evidence for the ACH model as our results did not show a specific role for proactive cognitive control. In line with previous research, we interpret these findings as evidence that L2 proficiency and experience may modulate the type of cognitive control abilities that need to be utilized for efficient L2 selection and use to take place (e.g., Grant et al., 2015; Gullifer et al., 2018). Nonetheless, these null results should be interpreted carefully as this is the first study, to our knowledge, to specifically look at these dimensions of cognitive control with adult L2 learners at the intermediate level, and the null hypothesis can only be interpreted as a lack of evidence for a significant relationship. Finally, we note that our results also suggested a tentative role for speed of processing, given that there was a significant correlation between BY trials and L2 proficiency, although this predictor was not statistically significant in the regression.

5. Limitations and future directions

The current study is not without limitations. We tested 28 intermediate Spanish adult learners. An increased sample size would allow us to look at more complex relationships and interactions between different aspects of cognitive control and L2 proficiency. It would also be interesting to look at these questions at different proficiency levels, for different language pairs, and across the bilingual continuum more generally or even in interaction with different learning contexts, instructional practices, and processing conditions.

Another limitation of the current study is that we examined proficiency at one point in time. However, language learning is a dynamic process that generally occurs over the years, and as such, what L2 proficiency measures might be able to reveal about the becoming bilingual experience might be somewhat limiting. Future work using L2 proficiency measures as a proxy for gaining insight into L2 outcomes should strive to carefully consider that it might be possible that proficiency measures might be more reflective of the level of accuracy and mastery of the specific skill(s) that each measure is supposed to tap on, rather than being able to provide an objective and holistic account into one's overall L2 ability (see DeLuca, Rothman, & Pliatsikas, 2019 for discussion). Therefore, it would be interesting to expand this line of research to understand whether cognitive control abilities contribute to L2 development over time through a longitudinal research design. Such a design could also allow us to gain more insight into the directionality of the relationship between cognitive control and L2 development as well as to better understand the ways in which increased L2 exposure and different learning trajectories might modulate this relationship, which would also inform the ongoing debate regarding the cognitive consequences of bilingualism (see Blanco-Elorieta & Pylkkänen, 2018; Leivada, Westergaard, Duñabeitia, & Rothman, 2020; Lehtonen et al., 2018; Von Bastian, Souza, & Gade, 2016).

Third, the current study is limited by the fact that we only examined behavioral measures of overall L2 proficiency and cognitive control abilities. Future research could include measures of specific linguistic structures as well as online processing measures. Furthermore, the inclusion of neurocognitive methods, such as event-related potentials (ERPs), in future research could shed light more directly on cognitive control mechanisms and their relationship to developing bilingualism (see Luque, Mizyed, & Morgan-Short, 2018; Sanoudaki & Thierry, 2015).

Finally, an interesting direction for future research is related to the tentative finding of a relationship between speed of processing and L2 proficiency, as indexed by the control condition (BY trials) on the AX-CPT task. Although we only examined simple correlations, future research may want to examine whether individuals with higher processing speed abilities are be better equipped to engage cognitive control mechanisms in order to, for example, suppress a previously formed expectation (see Zirnstein et al., 2018 for a similar pattern of results with proficient bilingual speakers). This finding should be considered to be secondary, although it is suggestive that abilities related to the use and coordination of different cognitive control mechanisms may also be important.

6. Conclusions

In the present study, we aimed to examine the role of cognitive control among adult L2 learners with different L2 learning experiences using multiple behavioral measures as a way to provide a multidimensional perspective on the role of cognitive control and developing bilingualism, specifically at the intermediate stages of learning. We found a significant relationship between cognitive control abilities, specifically those related to reactive control, and L2 proficiency. Our analyses also revealed a possible relationship between speed of processing and L2 knowledge that should be probed further. The results of this study contribute to the existing body of knowledge on cognitive factors related to developing bilingualism and provide critical new insight into the underlying cognitive mechanisms that may contribute to adult learners becoming bilingual.

CRediT authorship contribution statement

Alicia Luque: Conceptualization, Methodology, Data collection, Data processing, Formal analysis, Visualization, Writing - original draft, Writing - review & editing. **Kara Morgan-Short:** Supervision, Conceptualization, Formal analysis, Writing - review &.

Declaration of competing interest

None

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