Doctoral Dissertation

Modulatory factors of grammar learning in second and third languages

Factores moduladores del aprendizaje gramatical en el segundo y tercer idioma

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Introductory Note

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Contents

Preface

In the current technological era, connection among people spread throughout the globe is the norm more than the exception and knowing languages has become a necessary tool for professional, educational, and social endeavors. To strengthen foreign language knowledge and use, many educational systems have implemented English courses as a core subject. For instance, the Spanish educational system has had bilingual programs since 2004 in elementary and secondary schools (Palacios-Hidalgo, 2020). Nevertheless, while younger generations have the opportunity, tools, and motivation to acquire English to a high level of proficiency, successfully learning a language during adulthood is challenging and subject to strong variation among individuals.

Advocates of the critical period hypotheses have focused much of their research on evidencing the difficulties in successfully achieving native-like proficiency after a certain age (Johnson & Newport, 1994; Hartshorne et al., 2018). However, language learning research has focused on understanding the variability associated with successful learning (Van Patten & Williams, 2015). As a result of these recent developments, different factors have been found to modulate language learning during adulthood, both intrinsic and extrinsic to the learner. Individual differences in cognitive abilities, especially those associated with memory abilities, cognitive (executive) control, and general intelligence, have been investigated in terms of their roles as intrinsic modulatory factors in successful learning. The main goal of this dissertation is to explore the complex interaction between intrinsic (individual differences) and extrinsic (learning condition, difficulty/complexity of the material, and testing time) factors in successful grammar learning during adulthood.

PART 1:

Introduction

Chapter 1. Individual differences in grammar learning

For most adults, learning a new language is a challenge; however, for some others, it can be rather easy (Carroll, 1990; Fillmore, 1982; Luque & Morgan-Short, 2021; Wong et al., 2017). As opposed to childhood, learning a language during adulthood is subject to great variability, and it is easy to observe large differences in the proficiency achieved by different learners. In the last few decades, several researchers in the field of second/third language learning have studied different factors intrinsic to the learner that could predict this variability (see Dörnyei, 2005 for a review). Individual differences in personality traits (see Derakhshan et al., 2022¸ MacIntyre et al., 2016; Miller & Godfroid, 2019), learning styles (Griffiths, 2012), or motivation toward learning (Pawlak, 2021; Pawlak et al., 2022) are often understood as the main predictors of successful language learning in a classroom setting (Ellis, 2004).

Similarly, individual differences in cognitive abilities have also been explored as modulatory factors in language learning. For instance, individual differences in language aptitude (Carroll & Sapon, 1959; Wen et al., 2017, for a review), general intelligence (Kempe et al., 2010), working memory (Faretta-Stutenberg & Morgan-Short, 2018; Linck et al., 2014; Tagarelli et al., 2015; Villegas & Morgan-Short, 2019), or declarative/procedural memory (Morgan-Short et al. 2010) consistently explain the variability found among adults when learning a new language. Importantly, differences in declarative/procedural memory abilities have been the focus of much work within this perspective (DeKeyser, 2020; Paradis, 2009; Ullman, 2020).

From a theoretical point of view, the Declarative/Procedural model (DP model; Ullman, 2001; 2004; 2016) suggests that both the declarative and procedural memory systems are involved during language learning. The declarative memory system is involved in the learning and knowledge about facts and events (semantic and episodic knowledge), and the procedural memory system is involved in the learning and maintenance of different sensori-motor and cognitive procedures, such as habits and skills (Eichenbaum, 2010). These two memory systems have been deeply studied in the memory field (Eichenbaum, 2010; Eichenbaum & Cohen, 2004), as they involve different encoding and retrieval processes, and different neural systems. Thus, the declarative system is highly dependent on the work of the temporal lobes, and it is assumed to underlie intentional encoding and retrieval processes; in contrast, the procedural system is non-dependent on the temporal lobe but involves other neural circuits that include the cerebellum or the basal ganglia. Importantly, the procedural system underlies unintentional (implicit) encoding and retrieval, and it is at the base of many implicit effects, such as perceptual priming, which is dependent on mere exposure (Cohen & Squire, 1980; Squire & Wixted, 2011).

In the language learning field, the DP model (Ullman, 2004) proposes that the declarative system, associated with learning awareness and intention (explicit learning), is usually involved in explicit vocabulary learning, and more generally, when learning arbitrary information such as language irregularities and complex linguistic grammatical structures (e.g., irregular past tenses in verbs or idiomatic phrases). On the other hand, the procedural system, which does not involve intentionality and explicit strategies for learning but depends on the degree of exposure and practice, has been associated with grammar learning (e.g., structure of sentences or regular past tense formation; Ullman, 2001, 2004) in conditions where rules are learned by frequent exposure and without explicit intention to learn (non-explicit learning).

According to the DP model (Ullman, 2001, 2004, 2016), children and adults differ in the use of these two systems in language learning. The declarative system develops during childhood; therefore, children are highly dependent on the procedural system, but with age the development of their cognitive and neural systems brings greater use of the declarative system and of explicit strategies for language learning over non-explicit learning strategies (Ullman & Lovelett, 2018). Thus, whereas the procedural system is most often used during childhood, learning during adulthood seems to depend on the declarative system to a larger extent (see Hamrick et al., 2018 for a meta-analysis on the topic). Overall, and according to the DP model, both systems may support grammar learning but in different and complementary ways, which may depend on the age and features of the language to be learned or on the learning conditions (Ullman et al., 2020). See Chapter 2 for further details on the extrinsic factors related to the DP memory systems.

To test the predictions proposed by this model, several studies have examined individual differences in DP memory when learning different aspects of a new language such as the lexicon (Brooks et al., 2017; Hamrick et al., 2020; Murphy et al., 2021; Ruiz et al., 2021), the (morpho)phonology (Antoniou et al., 2015; Buffington & Morgan-Short, 2018; Saito, 2017, 2019), and the morphosyntax (Granena, 2013; Suzuki & DeKeyser, 2017; Walker et al., 2020). In addition, some experiments have shown evidence of the relation between DP memory and syntax learning (Brill-Schuetz & Morgan-Short, 2014; Faretta-Stutenberg & Morgan-Short, 2018; Granena, 2019; Hamrick, 2015; Morgan-Short et al., 2014; Pili-Moss et al., 2020; Ruiz et al., 2018; Saito, 2017; Tagarelli et al., 2016; Walker et al., 2020). For example, when learning regularities in an artificial language, Morgan-Short et al. (2014) assessed the declarative and procedural abilities of their participants, in addition to a learning task involving learning the regularities of an artificial language. To assess the participants' declarative ability, they completed verbal (MLAT-V test; Carroll & Sapon, 1959) and nonverbal declarative memory tasks. In the verbal task, they learned a pair of pseudo-Turkish words and English translations and then performed a recognition test where they were presented the pseudo-Turkish words and they had to select their English equivalents. For the nonverbal task, they used the equivalent *Continuous Visual Memory Task* (CVMT; Trahan & Larrabee, 1988), where participants viewed a series of complex, abstract designs on a computer screen and then indicated whether each design had been previously presented.

To assess procedural memory ability, they used the standard computerized version of the Tower of London task (TOL; Kaller et al., 2011; Kaller et al., 2012), and the Weather Prediction Task (WPT; Foerde et al., 2006), where participants predicted the weather ("sunshine" or "rain") based on patterns of four different "tarot cards" presented on the computer. Each combination of cards represents a different probability for "sunshine" or "rain." The goal of the task was for participants to learn the probabilities represented by particular combinations of cards. For the rule-learning task, participants were given examples of grammatical sentences in the artificial language in the context of a game, and they were not given explicit information about the regularities of the language. After an initial and the final training session, linguistic assessment of the artificial grammar was conducted using a grammatical judgment test (GJT), where participants were asked to say whether a set of sentences were grammatically correct. The results showed that declarative memory tasks strongly correlated with performance in the GJT at early stages of the learning process, whereas procedural memory tasks correlated with performance at later stages of the learning process. These results are in line with what is proposed by the DP model and show how differences in declarative and procedural memory skills predict L2 grammar learning (Morgan-Short et al., 2014).

Along this line, Brill-Schuetz and Morgan-Short (2014) found that procedural memory skills predicted grammar learning success when participants were not aware of the learning process. Additional evidence shows that declarative memory predicts grammar learning both when participants receive and do not receive explicit information about the learning process in the early stages (Carpenter, 2008; Hamrick, 2015; Ruiz et al., 2018). Hence, the implications of both declarative and procedural memory in different learning conditions are well established in the literature. However, there is less evidence of the possible implications of other cognitive processes underlying possible individual differences in language learning that may also mediate the relationship between DP memory and successful learning (Morgan-Short et al., 2022). In this context, executive functions (EFs) may make unique contributions to language learning.

EFs refer to a number of key goal-related mechanisms that are set to control cognition and action and that are associated with the efficient functioning of the prefrontal cortex (PFC) (Miyake & Friedman, 2012). These mechanisms have been related to several aspects of bilingualism and multilingualism (Antón, et al., 2019; Jylkkä et al., 2021). For instance, EFs are related to enhancement in L1/L2 processing (Cragg & Nation, 2010; Dörnyei, 2005), language use (Pérez et al., 2019), and language modulation (Beatty-Martínez et al., 2020; Morales et al., 2013) in bilinguals. Whereas many of these findings suggest that EFs are related to enhanced language processing, other empirical findings have also shown that lower engagement and even impairments in the PFC might benefit language learning in adults under certain conditions (Friederici et al., 2013; Smalle et al., 2017).

This mixed pattern of results regarding EFs and language learning has been related to the idea of the critical period. According to the critical period theories (Johnson & Newport, 1989), the variability associated with L2 language learning during adulthood is due to constraints in the learners' ability to acquire new languages beyond early childhood (Johnson & Newport, 1991). For instance, the ability to acquire syntax at a native-like proficiency level seems to decline by adolescence (i.e., 17.5 years old; Hartshorne et al., 2018) due to maturational changes, leading to a decrease in the ability to successfully acquire an L2 (Pakulak & Neville, 2011). Nevertheless, maturational changes are also related to an increase in cognitive capacity (Anderson, 2002; Cowan, 2016), which may benefit many cognitive domains, including language processing, memory, or attention (Cragg & Nation, 2010). Therefore, the critical period perspective hypothesized that while cognition is being reinforced by maturational processes (including PFC development), language learning might be impaired.

In an attempt to explain this paradox, the Less-is-More theory (Newport, 1990) suggests that strong cognitive control can be detrimental when acquiring different cognitive skills, not only for language learning. For instance, reduced control abilities may enable creative thinking or the possibility of acquiring novel information from the environment without explicit intention or awareness of the process (Tompshon-Schill et al., 2009). Thus, the fact that children are cognitive and neurally immature during childhood and the ease with which they learn new activities and skills (including language) provides evidence that more relaxed cognitive control might be beneficial during skill acquisition (Bjorklund, 2018). EFs are usually described as a cognitive filter for competitors toward the successful maintenance of the task goal (Miyake & Friedman, 2012). Hence, the absence of such an inhibitory capacity might be beneficial for detecting and learning regularities in the environment, including the regularities of a new language (Chrysikou et al., 2011). Thus, reduced cognitive control might allow access to a large amount of information that would benefit the implicit acquisition of recurrent patterns (Ramscar & Yarlett, 2007).

By contrast, the More-is-More theory (Brooks & Kempe, 2019) assumes that greater cognitive control leads to successful language learning. As such, EFs have recently been found to be an important predictor of language learning (words: Bartolotti et al., 2011; Bogulski et al., 2019; phonology: Darcy et al., 2016), and Kapa and Colombo (2014) found that inhibitory control, as measured by the Flanker task (Fan et al., 2002), correlated with better learning during adulthood while switching abilities, as measured by the Dimensional Change Card Sort task (Zelazo et al., 1996), predicted successful learning in pre-scholar children. However, other studies have not found this correlation (Linck & Weiss, 2015; Stone & Pili-Moss, 2016).

Recently, Luque and Morgan-Short (2021) took a different approach to EFs and explored the relationship between proactive/reactive control and L2 learning. According to the Dual Mechanisms of Cognitive Control framework (DMC, Braver, 2012), proactive control is an anticipatory process that controls the selection and maintenance of relevant information, biasing attention and action toward a given goal. Reactive control, on the other hand, is a late correction process that inhibits interference after it is detected competing with the task (Braver, 2012). Crucially, the two types of cognitive control have been shown to play a role in bilingualism as a tool to successfully resolve the coactivation of different languages in the brain (Beatty-Martinez et al., 2020; Morales et al., 2013), but very importantly, it is the specific combination of proactive/reactive control mode that may predict proficiency and not necessarily an overall enhancement of executive functioning. In their experiment, Luque and Morgan-Short (2021) explored the role of proactive/reactive control as a predictor of L2 proficiency in intermediate L2 learners of Spanish. The authors found reactive control to predict higher L2 proficiency in these learners. That is, participants who were better able to detect the conflict and adjust to it when detected (reactive control) had higher L2 proficiency, as measured by different tasks focused on written and spoken proficiency. These results suggest that exploring these types of cognitive control (proactive/reactive control), might account for a fine-grained understanding of the implication of cognitive control abilities in language learning. However, in their experiment, they only involved intermediate L2 proficiency levels, and no research to date has explored the role of proactive/reactive control in early stages of language learning. Hence, an important goal of this dissertation is to explore the interaction between proactive and reactive control and language learning at the very early stages of learning. Hence, the aim of the studies that we report in the empirical section of the thesis is to investigate the role of proactive and reactive control in thy initial stages of language learning. See Chapter 3 for further details on the goals and hypotheses of the empirical section.

Interestingly enough, previous research looking at proactive and reactive control has shown two additional factors that may play a role in language learning during adulthood. First, individual differences in linguistic experience (e.g., knowledge and use of more than one language) have been found to be related to a more efficient use of both proactive and reactive control strategies (Beatty-Martinez et al., 2020; Morales et al., 2013); second, research comparing younger and older adults has shown that whereas younger adults have a tendency to use proactive control when needed, older adults are more prone to use reactive control strategies even in situations where they might benefit from proactive control (Braver & Barch, 2002). Hence, in the following section, we review the literature on linguistic experience and aging as individual differences in language learning, and in our experiments, we will empirically explore the role of these two variables during language learning and their interaction with cognitive control.

Previous linguistic experience

Recent research has shown that contact and experience with other languages, even if this experience is restricted to just contextual exposure, seem to facilitate L2 vocabulary learning in monolinguals (Bice & Kroll, 2019). For instance, Bice and Kroll (2019) found that English monolinguals living in an environment where a language other than English was spoken (e.g., Spanish in California) had better performance in new vocabulary learning (Finnish vocabulary) than English monolinguals living in an environment where just English was spoken (e.g., Central Pennsylvania). Additionally, research has also shown that bilinguals learning an L3 have better vocabulary acquisition than monolinguals learning an L2 (Cenoz, 2003; Bartolotti et al., 2011; Kaushanskaya & Marian, 2009a; 2009b). Kaushanskaya and Marian (2009a) examined the vocabulary learning of an artificial language in English monolinguals, and in English-Spanish/ English-Mandarin bilinguals and they found a bilingual advantage in performance, which they attributed to early experience of the bilinguals with two linguistic systems. Specifically, they associated this advantage with the inhibitory capacity of the bilingual participants inhibiting their L1 during L2 language use (Kaushanskaya & Marian, 2009b). Thus, previous linguistic experience seems to provide learners with tools that facilitate the L3 learning process, including (1) metalinguistic abilities, such as the ability to consciously reflect on the regularities composing a new language (Herdina & Jessner, 2000; Jessner, 2008), and (2) cognitive processes, such as the ability to inhibit competitors from the L1 when learning a new language (Bogulski et al., 2019; Hirosh & Degani, 2018). In this line, Cenoz (2013) proposed that the effectiveness of these tools was modulated by L2 proficiency and language use.

The benefits of previous language experience over new learning have been mainly found in tasks where people are learning new vocabulary (e.g., Bartolotti & Marian, 2012; Bogulski et al., 2019; Wang & Saffran, 2014) and phonology (Antoniou et al., 2015; Bartolotti et al., 2011; Trembley & Sabourin, 2012). However, only a few studies have tested the benefits associated to bilingualism/multilingualism in grammar learning (Cox, 2017; Grey et al., 2018; Lado, 2008; Nation & Mclaughlin, 1986; Nayak et al., 1990). For instance, Nation and Mclaughlin (1986) found that multilingual participants were better than bilinguals and monolinguals when learning artificial grammar, although they were not aware of the learning goal (implicit learning). By contrast, Nayak et al. (1990) found that multilinguals had better results than monolinguals when learning word order rules in conditions where they were made aware of the learning goal (explicit learning). In this line, Grey et al. (2018) found that during explicit learning, bilinguals showed brain patterns associated with native-like language processing in low proficiency stages of the artificial language. Hence, multilingual/bilingual learners seem to have an advantage when learning new grammar, but this advantage may depend on the learning conditions. However, it is not clear at the moment which conditions or strategies benefit bilinguals the most. Hence, more research is needed to clarify this issue.

One of the possible factors that may influence the relationship between previous language experience and new language learning is how language experience is conceptualized and assessed. Thus, studies suggesting that multilinguals/bilinguals use different learning strategies when learning new grammar have compared multilingual/bilinguals' performance to the learning performance of their monolingual counterparts (Grey et al., 2018). However, the comparison of monolingual and multi/bilingual learners might obscure the role of language experience, since participants are categorized into low/high proficiency groups, whereas language experience and proficiency is a continuous variable that may vary from passive exposure to another language to very active and frequent use of the languages. In fact, Bice and Kroll (2019) have shown that even passive experience with a language (i.e., being exposed to a language in the environment) predicted benefits in vocabulary learning. Hence, understanding proficiency as a continuum might predict grammar learning to a greater extent than the categorical differentiation between monolinguals and bilinguals (see the introduction of the paper in Chapter 5 for details). Thus, in one of our studies, language experience is considered a continuous variable and is introduced in the context of language learning and cognitive control.

Aging

As mentioned, a second variable of interest in the relationship between language learning and cognitive control is aging. Interestingly, the bilingual advantages in language learning mentioned in the previous section seem to be maintained at older ages (Cox, 2017). Specifically, a recent study (Cox, 2017) found that monolingual and bilingual older adults showed good performance in a GJT task after explicitly learning regularities in Latin (new language), even though GJT performance in bilinguals was better than the performance of their monolingual counterparts (Cox, 2017). Hence, these results suggest that learning at older ages is still possible and that the advantage of language experience on new language learning is still present at older ages. However, studies on new language learning at older ages are scarce, and the role of aging in L2 grammar learning is not well understood. In the following paragraphs, we review the literature on aging as it relates to language learning and cognitive control.

Learning a language at older ages is associated with benefits on social (Pot et a., 2019) and cognitive levels (Bialystok et al., 2016; Wong et al., 2019; see Nilsson et al., 2021 for a review). However, learning a new language at older ages is threatened by cognitive decline (Craik & Grady, 2002; Ingvalson et al., 2017; Park et al., 2002) and, more specifically, by the decline observed in EFs (Verssimo et al., 2021), working memory (WM) (Pliatsikas et al., 2019; Salthouse, 2009), and declarative memory (Hedden & Gabrieli, 2004; Ullman, 2016; Ward et al., 2020). As part of these impairments, it seems that older adults have difficulties maintaining relevant information while reducing contextual interference (Braver & West, 2011; Xiang et al., 2016). It has been suggested that older adults compensate for their impairment in maintaining relevant information and goals by reactively responding to a conflict once it is present (employing reactive control; Braver & Barch, 2002).

This differential use of reactive strategies by older participants as compared to younger adults (who are more prone to the use of proactive strategies; Braver, 2012) may also be related to the fact that learning with implicit strategies seems to be well preserved in aging (structural priming, Hardy et al., 2019; speech production, Muylle et al., 2021; motor learning, Ristin-Kaufmann & Gullberg, 2014), especially for those adults with greater cognitive abilities (Fu et al., 2020; Howard & Howard, 2013; Ward et al., 2020). Along this line, a few studies exploring differences in grammar learning associated with aging have concluded that older adults are less effective than younger adults when using explicit but not implicit strategies (Kürten et al., 2012; Midford & Kirsner, 2005; Wagnon et al., 2019). However, this relationship has been scarcely studied, and there are few experiments with older adults directly comparing the use of explicit learning strategies with conditions where explicit strategies are not encouraged and relating this manipulation with cognitive control. The use of explicit learning strategies seems to be induced by the presence/absence of metalinguistic instructions during the learning phase (Midford & Kirsner, 2005; see the introduction of the paper in Chapter 6 for details); therefore, in one of our studies, we manipulated the learning condition in older adults while also assessing proactive/reactive control.

However, importantly, and as a conclusion for this section, the existence of individual differences underlying the variability in successful language learning strongly suggests that the same learning conditions might not be useful for everyone. For instance, personalized learning (Wong et al., 2017) promotes the study of modulatory factors, extrinsic to the learner, that might influence successful learning and the interaction with intrinsic factors. Hence, in the next chapter, we review the role of different extrinsic factors as modulators of the interaction between individual differences in cognitive abilities (including cognitive control) and successful grammar learning.

Chapter 2. Extrinsic factors in grammar learning

As we have previously framed, learning a language during adulthood differs between learners to a greater extent than learning a language during childhood. This variability has been strongly related to individual cognitive differences (Morgan-Short et al., 2022; see Chapter 1 for details). Interestingly, the role of individual differences differs according to the characteristics of the learning process as important factors in the recruitment of cognitive abilities toward a goal. Hence, the characteristics of the learning environment can also affect successful language learning (Wong et al., 2017). This chapter reviews the literature exploring extrinsic factors as modulators of successful language learning.

Following the DP model (Ullman, 2001, 2004, 2016, 2020) introduced in the previous chapter, different extrinsic factors can lead to the recruitment of either the declarative or procedural system. For instance, the declarative system is recruited when learners are conscious of the need to learn something, focusing attention on the learning process and when learners receive explicit information about the to-be-learned material (metalinguistic information). On the contrary, the procedural system is recruited when there are non-explicit learning instructions, reduced attention focus on the to-be-learned material or high complexity of the to-be-learned material (Ullman, 2020). For example, learning complex rules decreases the possibilities to explicitly detect those rules, to maintain them in WM while learning, and, more importantly, it diminishes the possibility of engaging the explicit strategies that define declarative learning. Hence, when learning complex regularities, the procedural memory system might be recruited to facilitate learning (Ullman, 2001, 2004, 2016, 2020). Similarly, time is a critical variable for these two systems. The declarative and procedural systems also differ in the time needed to acquire knowledge and in the time to which they maintain it: while learning under the declarative system is assumed to be fast but short-lasting, learning under the procedural system is assumed to be slow but long lasting (Ullman, 2004). Hence, differences in the learning condition (Morgan-Short et al., 2010), complexity of the material to learn (Gao & Ma, 2021; Tagarelli et al., 2016), or testing time (Morgan-Short et al., 2014) are understood as extrinsic factors that can modulate successful language learning. In this chapter, we aim to frame how they are found to modulate successful language learning and their interactions with individual differences. Additionally, in the experimental section, we manipulate these extrinsic factors to test their effects in early stages of grammar learning.

Learning conditions

The experience of learning a new language differs according to the goal of the learner, which is strongly related oh the information available to the learner. From simple exposure to instructed procedures, different learning conditions have been studied in the literature (DeKeyser, 2005; Spada & Tomita, 2010; Williams, 2009). First, participants under **incidental/implicit learning** conditions are asked to answer comprehension questions about a set of sentences following the to-be-learned regularities, but they are not given any information relative to the regularities, nor are they aware of the need to learn those regularities. Hence, under incidental conditions, participants do not focus their attention on learning, resembling the conditions in which the language is learned during early childhood. By contrast, participants under **intentional learning** conditions are asked to learn the regularities in word order and structure of a set of presented sentences, but they are not explicitly given the rules underlying those regularities. Hence, under intentional conditions, participants' attention turns toward discovering and learning the regularities. Finally, participants under **explicit learning** conditions are both asked to learn the regularities followed by a set of sentences and they are given metalinguistic information about the to-be-learned rules. Thus, in explicit conditions, participants are aware of the learning process, and hence, their attention turns toward the rules that they are asked to maintain in memory while reading the sentences and learn. Both the intentional and explicit conditions resemble a classroom learning environment.

If we think about the acquisition process during childhood, language is acquired by simple exposure to the language without awareness or intention to learn (incidental/implicit learning). Hence, if the child is living in a bilingual context, they would acquire both first and second languages unconsciously, without effort. The process of language acquisition during childhood generates the capacity to detect grammatical errors, but not metalinguistic awareness of the rule, which allows the specific violation to be explained (Williams, 2009). During adulthood, acquiring a new language may have similarities with implicit learning during childhood; conscious awareness of the regularities is not necessary to learn them. However, during adulthood, the process of learning a language is usually characterized by awareness of the learning process and the intention to learn (explicit learning; DeKeyser, 1995). Hence, children and adults usually differ in the frequency with which they use different learning conditions, which in turn are associated with the presence/absence of learning awareness and intention to learn. These differences in learning experiences between children and adults might also account for the differences in successful learning between them (Brooks & Kempe, 2019).

It is important to note that the same learning conditions do not always follow the same terminology in the literature; being instructed to learn a new rule and receiving metalinguistic information of the to-be-learned rule (explicit learning) is often labeled as intentional learning. Likewise, being exposed to the regularities to comprehend the new language (incidental learning) is often labeled implicit learning. Across the different chapters of the thesis and specifically in the experimental section, we have tried to consistently label our learning conditions as follows: 1) *incidental* to conditions where participants are asked to answer comprehension questions about the sentences that they are reading, without awareness of the presence of a specific rule (Experiments 1, 2, and 4); 2) *intentional* to conditions where participants are instructed to learn a rule but are not given any metalinguistic information about the rule (Experiment 1); 3) *explicit* to conditions where participants are instructed to learn a rule and are given metalinguistic information about it (Experiments 2, 3, and 4), and we explore the role of those different learning conditions in successful new grammar learning in adults. Note that in experiment 4 (Chapter 6), the explicit condition is labeled as intentional following a reviewers' request.

The first studies on grammar learning mechanisms during adulthood categorized the learning conditions as explicit and implicit (Reber, 1967), where explicit learning was understood as a conscious and effortful process, and implicit learning was understood as an effortless process independent from awareness. Reber et al. (1980) explored the differences in learning between conditions when participants learned a set of letter strings following some regularities (artificial grammar). When learning under explicit conditions, participants were better able to generalize the regularities to new letter strings than participants learning under implicit conditions. Later, the differences between explicit and implicit learning have also been explored when learning vocabulary (Bisson et al., 2013, 2014, 2015, 2021) and syntax (Bell, 2017; Ellis, 1993; Ishikawa, 2019; Leow, 2019; Rebuschat, 2015; see Goo et al., 2015, for a meta-analysis). Overall, learning under explicit conditions has been found to have better results than under implicit conditions (DeKeyser, 2005; Robinson, 1996; Tagarelli et al., 2016; Robinson, 1997; see Goo et al., 2015; Norris & Ortega, 2000; Spada & Tomita, 2010, for meta-analysis; see DeKeyser, 2008; Hulstijn, 2005; Williams, 2009, for reviews). Yet, some learning has been associated with occurring under non-explicit conditions.

For instance, Robinson (1997) created four learning conditions that differed in the information provided to monolingual speakers of Japanese when learning English as an L2. In the explicit condition, participants received metalinguistic information about the rule that they needed to learn, together with instructions to learn it. In the intentional condition, participants were just instructed to learn a rule from a set of sentences following the same rule. In two incidental/implicit conditions, participants were asked to focus on comprehending the set of sentences or on the form (the position of the subject in the sentence), but they were not given any instructions or information regarding the grammatical rule. For all conditions, after training, the participants were asked to perform a GJT to assess their knowledge of the rules. The results indicated that performance in the GJT was better in the explicit condition than in any of the other conditions (Robinson, 1997). In addition, there were no differences in GJT performance between the intentional condition (they were told to detect the rule and learn it) and the semantic- incidental condition (instruction to comprehend the sentences). Interestingly, there were differences between the two incidental-implicit conditions, so that participants were better in the semantic condition than in the form condition, suggesting that when processing is happening (to understand the meaning of a sentence), learning occurs even without an explicit intention to learn (Grey et al., 2015; Guillemin & Tillmann, 2020; Morgan-Short et al., 2010; Williams & Kuribara, 2008).

While the advantage associated to explicit/intentional learning seem to be robust, the benefits associated with the implicit/incidental conditions of learning are often related to other differences in the context of learning. For instance, the DP model proposes that complexity of the material and testing time can modulate the learning of regularities as extrinsic factors (Ullman, 2001, 2004, 2016, 2020). Therefore, in the following sections, we review the literature on complexity and testing time as they are related to language learning, and in our experiments, we will explore the role of these extrinsic factors during grammar learning and in interaction with learning conditions.

Difficulty/Complexity

When learning a language during adulthood, there are rules that seem easier to learn than others. However, the factors that contribute to making them easier to learn are unclear. When learning new syntax, difficulty/complexity refer to different properties associated with the to-be-learned linguistic feature. Although the terminology used in the language learning literature is ambiguous regarding the terms complexity and difficulty (Bulté & Housen, 2012, 2014), complexity is usually understood in terms of *cognitive complexity* as the representation of how costly or complex one feature is for a learner in a specific learning context. Likewise, *structural complexity* is understood as the linguistic properties inherent to the system in terms of the number of components associated with the to-be-learned feature (Housen & Simoens, 2016). Nevertheless, *cognitive complexity* is often labeled as *difficulty* in the literature to better conceptualize the differences with *structural complexity*, often labeled as *complexity* (Bulté & House, 2012; Pallotti, 2009). Following this terminology, we understand *cognitive complexity* as difficulty associated with the characteristics of the to-be-learned rules (Bulté & House, 2012; Pallotti, 2009). On the other hand, we understand *structural complexity* as complexity associated with the number of terms in a sentence (Housen & Simoens, 2016). In this sense, in two of our experiments (Experiments 1 and 2), we manipulated the difficulty of the regularities that the learners needed to learn by asking a group of judges with expertise in language learning to rate the difficulty of the rules employed (based on Robinson 1996, 1997). Additionally, in two other experiments (Experiments 3 and 4), we manipulated the complexity of the presented sentences by introducing sentences that varied in structure so that they had (complex) or not (simple) a subordinate clause (Following Maie & DeKeyser, 2020). Hence, it is possible to independently manipulate difficulty and complexity, but more importantly, both manipulations will influence the memory system that will be engaged during learning, and they both can interact with other extrinsic and intrinsic factors. Therefore, we focus our manipulation of difficulty/complexity associated with the to-be-learned material as a modulatory factor of grammar learning related to other extrinsic factors.

Following the DP model, the characteristics of the to-be-learned material are key in the recruitment of strategies for successful learning. For instance, learning complex rules decreases the possibility of explicitly detecting these rules and recruiting declarative memory. Hence, when learning complex regularities, the procedural memory system is recruited to facilitate learning (Ullman, 2001, 2004, 2016, 2020). Despite its importance, difficulty/complexity has not been largely studied as a relevant research variable in the literature (Housen & Simoens, 2016). The studies that have manipulated these variables have found that they are key factors in modulating learning success (e.g., Andringa et al., 2011; DeKeyser, 1995, 1998, 2016; Housen et al., 2005; Reber et al.,1980; Tagarelli et al., 2016; see Spada & Tomita, 2010 for a meta-analysis; see DeKeyser, 2005; Ellis, 2006 for reviews on the topic). For example, Robinson (1996) presented an easy and a difficult rule in English to a group of L2 English learners and manipulated the learning conditions (explicit, intentional, incidental, or implicit) to explore the differences in the role of difficulty/complexity as related to different learning conditions. In this experiment, the results showed an interaction between difficulty and learning condition. Thus, participants in the explicit condition outperformed participants in the other groups in the GJT but only when they were learning the easy rule. However, when they were learning the difficult rule, no differences were found between the groups. The author concluded that the task demands associated with the difficulty of the materials eliminated the advantage of the explicit instructions (Robinson, 1996). On the other hand, Reber (1993) claimed that implicit learning conditions would benefit learning difficult patterns because difficult rules cannot be easily explained and learned in an explicit way. However, empirical work testing these assumptions has not always provided evidence for them. Thus, Housen, Pierrard, and Van Daele (2005) tested how explicit and implicit instruction affected learning of easy or difficult rules by asking participants to perform a GJT before and after explicit or implicit training of easy/difficult rules, Results indicated that explicit instructions to learn produced better learning as measured by the GJT for both the easy and difficult rule. Similarly, Spada and Tomita (2010) reported a meta-analysis that also suggested that explicit learning conditions produced better learning for both easy and difficult rules.

Hence, the overall pattern of results suggests that the benefits associated with implicit learning when learning difficult rules are complex, and that contrasting results may be due to other factors also involved in successful learning. As we introduced earlier, the role of difficulty/complexity is understood in interaction with learning conditions, the characteristics of the to-be-learned material, and individual differences associated with the learner. Hence, the interaction between the three variables needs to be explored to better understand the role of difficulty/complexity (Tagarelli et al., 2016). We review the literature on this interaction later in this chapter and in our experiments.

Testing time

As mentioned, testing time is also a variable of interest in the study of new language learning. According to classical paradigms on memory and learning, the role of testing is associated with the delay after the learning session (Anderson, 2000), showing the process of consolidation of the learned material (Tse et al., 2011). However, the role of testing time in language learning literature is often explored as an extrinsic factor that can modulate the implication of different memory skills. The DP model (Ullman, 2001, 2004, 2016) framed the declarative information (associated with the learning process) to decay fast after the learning session. Hence, after explicit learning, the results in the immediate test might be significantly better than those in delayed tests. However, the information acquired through the procedural system, while in need of larger exposure to be acquired, is understood to be long lasting and perhaps less affected by testing time.

Testing these predictions, Morgan-Short et al. (2010) found that performance in the early stages of language learning (low proficiency) was modulated by individual differences in declarative memory skills, whereas performance in later stages of the learning process was modulated by individual differences in procedural memory skills. In addition, in accordance with the DP assumptions, Hamrick (2015) asked participants to learn a semi-artificial language under incidental learning conditions, that is, without explicit information of the rules, and found declarative memory to better predict language learning in an immediate GJT test compared to a test after a time of no-exposure (delayed test). On the contrary, procedural memory skills were not found to predict successful learning results in the immediate test but in the delayed test. These results have been consistently found in the literature (Brill-Schuetz & Morgan-Short, 2014; Carpenter, 2008; Morgan-Short et al., 2014), supporting the claims of the DP model (Ullman, 2001, 2004, 2016).

Interaction between extrinsic and intrinsic factors

As mentioned, the DP model proposes that the characteristics of the environment are key in the recruitment of declarative/procedural strategies during language learning in adults (Ullman, 2001, 2004, 2016, 2020). On the one hand, intentional/explicit learning conditions, easy material, early learning stages, and immediate testing account for the recruitment of declarative memory strategies. On the other hand, incidental/implicit learning conditions, difficult material, late learning stages, and delayed testing seem to recruit procedural memory; therefore, better procedural skills tend to benefit successful language learning in these conditions (Brill-Schuetz & Morgan-Short, 2014; Carpenter 2008; Gao & Ma, 2021; Morgan-Short et al., 2010).

Cognitive abilities and learning conditions. In the previous section, we discussed evidence that the declarative skills of the participants benefit from successful language learning in these conditions (Carpenter, 2008; Morgan-Short et al., 2014; see Spada & Tomita, 2010 for a meta-analysis). However, the interactions between learning conditions and other cognitive abilities are not well established. For instance, individual differences in WM have shown contradictory results. In some studies, WM seems to better predict grammar learning and new language processing under implicit conditions (Faretta-Stutenberg & Morgan-Short, 2018; LaBrozzi, 2012; McDonald, 2006; Sagarra & Herschensohn, 2010; Sunderman & Kroll, 2009). However, other studies relate WM to explicit learning conditions (Linck & Weiss, 2015). For example, Faretta-Stutenberg and Morgan-Short (2018) explored the role of declarative, procedural, and WM abilities during an "at-home" (classroom) or "study-abroad" (immersion) learning contexts. Participants completed a GJT in L2 Spanish at the beginning and end of a semester at home or abroad, and EEG was also recorded. Participants showed successful learning both behaviorally and in a neurocognitive L2 processing index (EEG) when learning at home, but performance was not predicted by individual differences in any of the cognitive abilities measured. However, in the study-abroad group, individual differences in WM predicted an increment in the neural response between the pre- and post-test. Additionally, procedural memory skills were found to predict GJT performance. Hence, procedural and WM skills were found to predict learning under implicit conditions. By contrast, Linck and Weiss (2015) asked their participants to complete a proficiency measure (standardized test of L2 grammar and vocabulary: DELE) at the beginning and end of a semester enrolled in Spanish courses (explicit condition). Additionally, participants completed an operation span task to measure WM (Turner & Engle, 1989) and the Simon task to measure inhibitory control (Simon & Rudell, 1967). In this experiment, the results indicated that WM, but not inhibitory control, positively predicted L2 proficiency, as measured by the differences in proficiency between the pre- and post-test, when learning an L2 in a classroom setting. The authors concluded that WM was a relevant component of successful L2 explicit learning, especially at early stages of the learning process (see Atwell, et al., 2003; Kalra, et al., 2019; Rönnlund, et al., 2005 for similar conclusions).

In a more recent study, Tagarelli et al. (2016) directly explored the interaction between rule difficulty, learning condition, and cognitive individual differences (WM and procedural skills). To test the learning of a semi-artificial language (English lexicon, German syntax), participants learned three different rules that varying in difficulty. The manipulation of the difficulty was associated with the presence/absence of one or two extra complements in the easy structure. Therefore, participants learned one easy and two difficult rules (difficult 1, and difficult 2) under different learning conditions. Some participants were asked to comprehend a set of sentences (incidental condition), while others received metalinguistic information about the regularities to learn (explicit condition). Individual differences in WM were measured using the reading span task (Daneman & Carpenter, 1980), and procedural learning skills were measured using the alternating serial reaction time task (Howard & Howard, 1997). The results showed better performance in the GJT when learning the easy rules under explicit than under incidental learning conditions. Moreover, although the correlations between cognitive abilities and learning outcomes accounted for little of the variance in global performance, some unexpected results were observed: Participants with better procedural skills performed worse in the GJT in the incidental group. Additionally, WM was found to predict better performance for the difficult rules in the incidental condition (see Gao & Ma, 2021 for similar results). This incongruent observation might be related to the shift of language processing toward more explicit processing due to their untimed GJT procedure, which may have left time to explicit reflections on the sentences and to explicitly notice the mistakes in them.

Hence, it seems that the role of individual cognitive differences in successful grammar learning might need to be explained by complex interactions between intrinsic and extrinsic factors to the learner. However, whereas most studies have been directed to show the role of WM capacity in explicit and implicit language learning, and WM has been found to strongly relate to cognitive control (Wiemers & Redick, 2018), very few studies have been directed to explore the role of individual differences in cognitive control as a modulatory factor of successful language learning.

Similar to the DP distinction in memory skills, cognitive control varies between proactive and reactive control (Braver, 2012), and this variation seems to be sensible to environmental demands (i.e., task demands or complexity; Braver et al., 2009). However, no studies to date have explored how the interaction between extrinsic factors interacts with individual differences in cognitive control. Hence, an important goal of this thesis is to explore the interaction of learning condition, difficulty/complexity, and testing time as related to individual differences in proactive/reactive control. As discussed in Chapter 1, the use of proactive/reactive control is also associated with differences in the resources available to the learner (Braver et al., 2009), and these resources, in turn, have been found to be modulated by individual differences in linguistic experience (Beatty-Martinez et al., 2020; Morales et al., 2013) and aging (Braver & Barch, 2002), among others.

Linguistic experience. As reviewed in the first chapter, linguistic experience with a second language has been found to be related to efficient uses of both proactive and reactive strategies (Beatty-Martinez et al., 2020; Morales et al., 2013) and to providing learners with tools that facilitate the new learning process (Bogulski et al., 2019; Jessner, 2008; Hirosh & Degani, 2018). However, only a few studies have explored the role of previous linguistic experience in grammar learning with different learning procedures (Cox, 2017; Grey et al., 2018; Lado, 2008; Nation & Mclaughlin, 1986; Nayak et al., 1990; see Chapter 1 for details), and the results are not conclusive in terms of understanding under which conditions the linguistic experience is critical to successful learning. Nation and McLaughlin (1986) asked their participants (monolinguals, bilinguals, and multilinguals) to learn the regularities of artificial grammar (letter string order). Participants were asked to discover the regularities of certain letter strings (intentional condition) or were not instructed to learn (implicit condition). In this experiment, multilinguals were found to have better performance in the implicit condition compared to bilinguals and monolinguals, and no differences were found in the explicit condition. On the contrary, Nayak et al. (1990) indicated that multilinguals to have better results after explicitly learning word order regularities in an artificial language. More recently, Grey and colleagues (2018) found that bilinguals were more sensible to regularities of a new language at early stages of an explicit learning process as compared to monolinguals. While at a behavioral level monolinguals and bilinguals had similar results, some differences were evident when looking at neural data. Thus, bilinguals showed brain patterns (P600) that were similar to those previously found in native speakers' language processing (P600, Friederici & Mecklinger,1996), and this pattern was not evident in monolinguals. Hence, the authors concluded that bilinguals, under explicit learning conditions, might achieve earlier the type of native-like processing of syntactic information. In line with this conclusion, Grey et al. (2018) reported that the bilingual participants' advantage was due to the better use of explicit learning strategies acquired during their L2 process of learning. One possible explanation for the contradictory results in the literature is the differences in the complexity of the to-be-learned material. Strong metalinguistic abilities acquired during L2 learning may be more useful when learning through word-rule mapping (artificial language) than when learning letter string orders (artificial grammar). However, more research is needed to explore the interaction between extrinsic factors and differences in linguistic experience related to proactive/reactive control.

Age. Similar to language experience, the age of the participants might also modulate adult language learning. Cognitive control has been shown to decline with age (Marcotte & Ansaldo, 2014), and declarative memory also impairs at older ages (Ward et al., 2020). On the contrary, the procedural memory system, associated to incidental/implicit learning seems to be preserved (Hardy et al., 2019; Howard & Howard, 2013; Muylle et al., 2021; Ristin-Kaufmann & Gullberg, 2014). In this line, older adults have shown impairments in explicit but not implicit learning of a new language when compared to young adults (Kürten et al., 2012; Verneau et al., 2014; Wagnon et al., 2019). Hence, extrinsic factors associated with the recruitment of resources might have different consequences for older and younger adults.

For instance, Midford & Kirsner (2014) showed better performance in a GJT when learning under explicit than implicit conditions for both older and younger adults. However, the effect of learning conditions and age interacted with difficulty. Thus, the differences between the explicit and implicit conditions were only evident when learning an easy rule, but not when learning a complex rule. In addition, younger adults were found to have better explicit learning than older adults when learning an easy rule; however, these differences were not found when learning a complex rule. Therefore, the authors concluded that while implicit learning is preserved in older adults, allowing them to have similar performance to young adults, explicit learning strategies are affected by aging, making the recruitment of explicit strategies more difficult during learning (Midford & Kirsner, 2014). These differences seem to be associated with the age-related decline in cognitive resources that reduce the use of intentional strategies, preserving the use of implicit learning processes (Ingvalson et al., 2017) when the environment allows it (difficult rule learning or incidental/implicit learning conditions).

In sum, the evidence reviewed in this chapter suggests that successful language learning is modulated by complex interactions between intrinsic (individual differences in cognitive abilities) and extrinsic factors (learning condition, difficulty/complexity, and testing time) to the learner. However, these complex interactions have been scarcely studied in the context of adult language learning and cognitive control. Hence, the goal of the experimental section is to shed light on these complex interactions, with a special focus on the role of proactive/reactive control on language learning. Focusing on the Dual Mechanisms Framework (Braver, 2012), different goals and hypotheses have surged to explore the role of cognitive control under different learning circumstances and in different populations.

Chapter 3. Aims and outline of the experiments

Research has demonstrated that learning a new language during adulthood is affected by complex interactions between learners' intrinsic and extrinsic factors. For instance, individual differences in DP memory modulate grammar learning to a different extent depending on the characteristics of the environment. The DP model (Ullman, 2001, 2004, 2016, 2020) suggest that the recruitment of the declarative or procedural system during learning depends on the instructions given to the learner (learning condition), the difficulty/complexity of the to-be-learned material, and the delay between the learning and the testing (testing time).

Likewise, following the DMC (Braver, 2012), cognitive control varies between two modes: proactive and reactive control. On the one hand, proactive control oversees early selection and continuous maintenance of relevant information toward the goal, while reactive control is responsible for the corrective mechanisms immediately after an event interferes with the goal (Braver, 2012). For example, during grammar learning, proactive control may be needed to maintain the instructions to learn a new rule, whereas reacting to a grammar error once committed might involve reactive control. Proactive control has been found to be implicated in the resolution of the interference between L1 and L2 (Morales et al., 2013). In particular, proactive control has been found to have a role in the regulation of the L1 activation while immersed in an L2 environment (Beatty-Martinez et al., 2020) or learning new vocabulary (Bogulski et al., 2019). On the other hand, reactive control has been found to have a role in the L2 proficiency of intermediate language learners (Luque & Morgan-Short, 2021). However, no study to date has explored the role of proactive/reactive strategies during new grammar learning. For most cognitive tasks, proactive and reactive control are engaged for successful performance, but the implication of the two types of processes is likely to depend on the task characteristics (how complex the task is) or the cognitive resources available to the learner (Braver, 2012; Braver et al., 2009).

The aim of our experimental series was to understand the role of proactive/reactive control in new grammar learning. For this, we designed four experiments in which we manipulated different external conditions (i.e., learning conditions, difficulty/complexity of the rule, and testing delay) and measured individual differences in cognitive control by using the AX-CPT task (AX-Continous Performance task; Braver & Barch, 2002; Ophir et al., 2009). In the **first and second experiments (Chapter 4) of the thesis**, we explored the role of proactive/reactive control in young adults while learning the regularities of a natural language (English). In particular, we were interested in examining the role of proactive/reactive strategies when the instructions supported incidental, intentional, or explicit learning, and the difficulty of the rules were manipulated.

Thus, in the first experiment, one group of participants was not instructed to learn the rule but asked to answer some comprehension questions about the presented sentences. Hence, participants in this group were not aware of the learning goal (incidental condition). In contrast, a second group of participants received instructions to learn a grammatical rule, which was instantiated by all the sentences they were presented (intentional condition). All sentences followed an easy rule in English (dative rule by Robinson, 1997), but no metalinguistic instructions were given regarding the rule to either of the two groups. Although participants in the intentional condition were told to learn the rule represented in the sentences, they did not explicitly talk about the specific learning rule they were to learn. In the second experiment, we manipulated the difficulty of the rule; that is, participants learned two rules: the dative rule (Experiment 1) or a more difficult pseudocleft rule taken from Robinson (1996). In addition, the rules were presented under different learning conditions. In the first condition, participants were not told about the presence of a rule but were instructed to answer some comprehension questions (incidental condition). In the second condition, participants received metalinguistic information on the to-be-learned rule before reading the sentences (the explicit condition), and they also needed to answer a metalinguistic question after each sentence. The presentation of the rules was blocked, and each was assigned to a learning condition (counterbalanced across participants). After the learning phase (presentation of the sentences in the two blocks), participants were asked to perform a GJT (immediate test) in which new grammatical and ungrammatical sentences were presented. To calculate the extent to which participants learned the rule(s), we calculated a d' index representing the capacity of the participants to discriminate between grammatical (hits) and ungrammatical (false alarms) new sentences (this index was calculated in every experiment). The GJT was also presented 24 h and 1 week after the learning phase.

Our predictions for these experiments (the first study) were that the learning conditions would mediate the role of proactive/reactive control. First, we predicted that, similar to other studies on L2 learning, rule learning would be better achieved in intentional conditions than in incidental conditions. In addition, since attention to salient characteristics of the sentences and goal maintenance is critical for intentional learning, and proactive control involves monitoring and maintenance of goal-relevant information, we hypothesized that proactive control would play a larger role in intentional conditions, and this, in turn, might also be modulated by the number and difficulty of the rules to be learned. We predicted that the role of proactive control might be more evident in Experiment 1, where participants were not told about the specific rule, and they had to monitor each sentence to find and hold the regularities across sentences. Thus, it was possible that proactive control would be necessary when the goal was to detect regularities, and less so when the regularities had already been given.

Thus, the purpose of **experiment 3 (Chapter 5)** was twofold: First, we aimed to understand the relation between cognitive control and language learning in Experiments 1 and 2, and second, we wanted to explore the possible role of individual differences in language experience in predicting language learning. Thus, we approach the first objective by testing the role of proactive control on grammar learning when the metalinguistic information about the rule was made explicit. That is, in Experiment 3, participants were told about the rule and asked to learn it since they would have to answer a metalinguistic question after each presented sentence. In addition, in this experiment, we used *Japañol,* a semi-artificial language using Spanish lexicon and Japanese syntax. The use of a semi-artificial language that involved the participants' L1 facilitated the learning process relative to Experiments 1 and 2. Nevertheless, we manipulated the complexity of the material so that the presented sentences could be simple (without subordinated clauses) and complex (with subordinated clauses). Participants in this experiment were learning the semi-artificial language for five consecutive days and were tested immediately (immediate) and 2 weeks (delayed) after the last day of learning.

Since in Experiment 3, participants were just learning one rule in a semi-artificial language using the lexicon of the participants' first language, we could think that cognitive resources would not be overloaded, at least for the simple sentences. Hence, if the role of proactive control in grammar learning is resource dependent, we expected to see a relation between proactive control and grammar learning that may be modulated by the difficulty of the sentences (the relation would be more evident for simple sentences). However, if the role of proactive control in learning is not dependent on the possible overload of the available resources but on the need to monitor and detect regularities to infer the rule, we would expect that the relation between proactive control and learning would not be evident since in Experiment 3, participants were explicitly told about the rule, and they did not have to infer it.

As a second objective, in Experiment 3, we were interested in exploring the role of language experience in language learning, and the possible interaction of this variable with cognitive control. According to the DMC framework proposes, differences associated with the individual might account for the implication of proactive/reactive control. Previous linguistic experience has been suggested to modulate the use of proactive/reactive strategies in young adults (Beatty-Martinez et al., 2020; Morales et al., 2013). Concretely, bilinguals have been found to better adjust proactive/reactive control to achieve more accurate responses than their monolingual counterparts (Morales et al., 2013). Previous linguistic experience has also been hypothesized to predict successful language learning (Cenoz, 2013; Jessner, 2008). Thus, in Experiment 3, we assessed the language experiences of our participants in L2 (English). We hypothesized that proficiency would predict successful grammar learning.

Finally, in **Experiment 4 (Chapter 6)**, we aimed to further explore the role of individual differences in language learning by varying the age of the participants (younger vs. older adults). The DMC framework proposes differences in proactive/reactive control associated with aging (Braver & Barch, 2002). Younger adults have been found to rely on proactive control to a greater extent than older adults, who tend to use more reactive strategies as compensation for their decline in cognitive resources (Braver et al., 2009). Since previous studies in this experimental section aimed to examine the role of proactive/reactive control in young adults, in Experiment 4, the goal was to explore the differences between younger and older adults as they could be explained due to differences in the use of cognitive strategies, and the possible interaction between proactive/reactive control and learning conditions in the two age groups.

For this purpose, older and younger participants were presented *Japañol* (the semi-artificial language used in Experiment 3) either with instructions to read each sentence and answer whether it was (or not) plausible in *Japañol* (incidental condition) or with explicit instruction to learn the rules and metalinguistic information about them (explicit condition, labeled as intentional in the Chapter). Afterwards, an immediate GJT test was run. First, we expected younger adults to achieve better learning, at least under explicit conditions. Individual differences in aging have been observed, depending on the learning conditions. Older adults show impaired performance under explicit but not incidental conditions compared to younger adults (Kürten et al., 2012; Midford & Kirsner, 2005). Hence, older adults' learning seems to rely more on incidental than intentional strategies (Wagnon et al., 2019), and we expected that age differences would be more evident in explicit learning conditions.

In addition, we expected that the role of proactive/reactive control in learning would be dependent on the learning conditions and the age group. For the younger group, we expected that proactive control would be related to explicit learning and less so to incidental learning, as indicated by the results of our previous experiments. For older adults, in line with previous results (Braver & Barch, 2002), we expected reduced proactive control compared to their younger counterparts. Hence, we hypothesized that it was possible that older people would more often rely on reactive control when learning, and this might be more evident under incidental conditions where goal maintenance and monitoring are not as engaged than in explicit learning conditions.

Overall, the overarching goal of the thesis was to unveil the role of individual differences (e.g., cognitive control, language experience, and aging) in grammar learning under several forms of unintentional/intentional learning conditions. It is worth noting that this is just a first attempt to explore the interactions among these factors. Therefore, this experimental section opens up a new line of research that needs to further be explored in the future.

PART 2:

Experimental

section

Chapter 4. Second language acquisition of grammatical rules: The effects of learning condition, rule difficulty, and executive function[1]

Abstract

Learning a new language is an important goal that many individuals find difficult to achieve, particularly during adulthood. Several factors have related this variability to different extrinsic (learning condition, difficulty of the materials) and intrinsic (cognitive abilities) factors, but the interaction between them is barely known. In two experiments, participants learned English grammar rules in intentional (Experiment 1) or explicit (Experiment 2), and incidental learning-contexts. Overall, results of this study indicated that intentional-explicit conditions benefitted rule-learning, as compared to incidental conditions. This benefit was mainly present when participants were learning an easy-

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rule; explicit and incidental learning did not differ in the case of participants learning a difficult rule (Experiment 2). Moreover, individual differences in executive functioning predicted successful learning in interaction with difficulty. When learning an easy-rule, proactive control facilitated intentional learning. In contrast, when participants were learning a complex-rule, incidental learning was enhanced by lower involvement of proactive control.

Keywords: Second Language Learning; Individual differences; Context of learning; Proactive Control.

Introduction

Learning a second language (L2) is a great challenge and an important accomplishment, particularly when the L2 is mastered during adulthood. There are large individual variations in learning pace. Some learners easily achieve high proficiency, while others struggle to achieve minimum proficiency. During the previous few decades, research has related this variability to several factors that are either extrinsically or intrinsically related to the learner. For example, the condition of learning (Bell, 2017; Hulstijn, 2005; Lichtman, 2020) or the relative difficulty of the material (DeKeyser, 2005; Ullman, 2016) are extrinsic variables affecting learning, whereas individual differences in cognitive abilities (Luque & Morgan-Short, 2021) such as working memory (Atkins & Baddeley, 1998; Faretta-Stutenberg & Morgan-Short, 2018; Miyake & Friedman, 1998), metalinguistic abilities (Brooks & Kempe, 2013), or variation in declarative or procedural learning/memory (Morgan-Short, et al., 2014), are factors intrinsically related to the learners that also contribute to learning success. However, the complex interaction between learning conditions and individual differences during L2 learning is still an open question. Accordingly, the main goal of this study is to investigate this interaction.

Second language learning context

During childhood – particularly for a child living within a bilingual context – the first and second languages are acquired by simple exposure without awareness of the learning process. When language is acquired by simple exposure, it becomes possible for individuals to detect grammatical errors; they may not, however, be able to explain which rule is being violated (Williams, 2009). In contrast, the process of L2 acquisition during adulthood is generally more complex; language can either be unconsciously *acquired* or consciously *learned* (Dekeyser, 1995). Language *acquisition* in adults may sometimes resemble the implicit childhood learning process where learners do not need conscious awareness of language regularities in order to acquire them.

Other times, it may involve explicit intention to learn and to be instructed through the language rules, consciously developing metalinguistic knowledge as a result. Both types of learning have been investigated in the context of vocabulary (Bisson, et al., 2013, 2014, 2015) and grammar learning (Bell, 2017; Ellis, 1993). Overall, it has been found that when participants have intention to learn, performance is far better than when they are not conscious of the learning process (DeKeyser, 2005; Robinson, 1996; Tagarelli, Ruiz, Vega, & Rebuschat, 2016; see Goo, Granena, et al., 2015; Norris & Ortega, 2000; Spada & Tomita, 2010, for meta-analyses; see Dekeyser, 2008; Hulstijn, 2005; Williams, 2009, for reviews), despite the fact that some learning does indeed occur under unintentional conditions. For example, in a study by

Robinson (1997), participants learned a grammatical rule under four different learning conditions. In the first condition, and before training, participants received instructions to learn together with metalinguistic information about the specific rule to be learned (explicit condition). In contrast, participants were not informed about the rule in the other three conditions. Thus, in the second condition, participants were told that all the training sentences followed a specific rule and that they should try to find and learn the rule while answering questions about the meaning of the sentences (intentional condition; no metalinguistic information). In the third condition, participants were told that their task was just to answer questions about the meaning of the sentences (incidental condition); whereas in the fourth condition, participants were asked to answer questions about the form of the sentences (implicit condition). In all conditions, participants completed a Grammatical Judgement Test (GJT) after training, and this included previously studied sentences, new grammatical sentences, and new ungrammatical sentences. The results showed that – in comparison with the rest of the groups – the explicit condition group was more accurate in judging the grammaticality of the sentences.

Additionally, the incidental group judged fewer ungrammatical sentences as grammatical (showed fewer false alarms (FA) to new ungrammatical sentences) than participants in the implicit condition, although they did not differ from the incidental condition. This suggested that when processing is directed to find the regularities and/or understand the meaning, rule-learning also occurs under incidental conditions. Rule-learning in intentional and incidental conditions has been found with different paradigms (Guillemin & Tillmann, 2020; Morgan-Short, et al., 2010; Williams & Kuribara, 2008).

It is important to note in this context that the terms intentional/explicit and incidental/implicit learning can be theoretically charged and that they may convey different meanings depending on the theoretical approach. For example, incidental-implicit and intentional-explicit types of learning have been related to the procedural and declarative memory systems respectively (declarative/procedural model; Ullman, 2001, 2004), indicating that the type of acquired knowledge differs in nature. However, in the present paper, we used the terms intentional, explicit, and incidental to label our different learning conditions by using Robinson's (1997) terminology. One goal of our experiments was to assess how differences in the learning conditions can shape learning success.

Thus, intentional in our experiments refers to the condition where participants are instructed to learn a rule, although they are not told about the rule (Experiment 1); explicit refers to the condition where participants received explicit information about the specific rule/rules that they should learn (Experiment 2); incidental refers to the condition where participants are asked to pay attention to the meaning, and they do not receive information about the presence or the type of rule (Experiment 1 and 2). Hence, across Experiments 1 and 2, we compare intentional (Experiment 1) or explicit (Experiment 2) to incidental learning conditions (Experiment 1 and 2). In addition, we aimed to investigate if the effectiveness of the learning conditions was modulated by individual differences in cognitive skills.

Interestingly, a number of studies point to the relevance of individual differences in cognitive abilities, although most of these studies have focused on procedural and declarative memory skills during L2 learning (Fu & Li, 2021; Morgan-Short et al., 2014; see Kidd, Donnelly, & Christiansen, 2018, for a review). For instance, Morgan-Short and colleagues (2014) found that better declarative memory skills were related to better learning as assessed by immediate tests, whereas better procedural memory skills were related to better learning as assessed by delayed tests (see Hamrick, 2015 for similar pattern under incidental conditions). Thus, it is apparent that different cognitive profiles can be related to learning, and that different learning conditions may potentially be useful depending on the learner's cognitive abilities (see Rebuschat, 2015; Goo et al., 2015, for metanalysis on the field; Dörnyei, 2005; Norris & Ortega 2001, for a review).

Role of individual differences

A wide range of individual differences has been related to language learning success, and these differences include aptitude (Carroll, 1990; Doughty, 2019), emotion (Miller & Godfroid, 2019), motivation (Dörnyei, 2005), thinking styles (Xie, et al., 2013), general intelligence (Kempe, et al., 2010), working memory (Faretta-Stutenberg & Morgan-Short, 2018; Tagarelli, Borges-Mota, & Rebuschat, 2015; Villegas & Morgan-Short, 2019) and declarative/procedural learning/memory ability (Fu & Li, 2021; Morgan-Short et al., 2014; see Kidd et al., 2018, for a review).

Although executive functioning (EF) has been in the spotlight of bilingualism/multilingualism research (Antón, Carreiras, & Duñabeitia, 2019; Jylkkä, Laine, & Lehtonen, 2021), they have only just begun to be empirically explored as factors modulating L2 learning during adulthood (Kapa & Colombo, 2014). EFs refer to a domain-general set of cognitive and brain mechanisms related to the prefrontal cortex (PFC); these mechanisms are triggered to control cognition and action with the purpose of attaining a specific goal (Miyake & Friedman, 2012). While cognitive control has traditionally been related to better performance in many cognitive domains at the adult age – including memory, attention, and L1/L2 processing (Cragg & Nation, 2010; Dönyei, 2005)), the relationship between language learning and EFs is more controversial.

Very few studies indicate a positive relationship between language learning and cognitive control (Darcy, et al., 2016; Kapa & Colombo, 2014). In fact, other studies have not found such a relationship (Linck & Weiss, 2015). Furthermore, it has also been suggested that high levels of executive control may bring about some of the difficulties in L2 acquisition during adulthood (Chrysikou, et al., 2011; Smalle,et al., 2017). Thus, it is possible that under some conditions, reduced cognitive control may facilitate language learning by giving the learner the possibility of spontaneously and implicitly acquiring recurring patterns from the environment (Thompson-Schill, Ramscar, & Chrysikou, 2009). This idea is based on the observation of the ease of language learning in children (Newport, 1990), but it is also based on specific empirical findings from transcranial magnetic stimulation (TMS; Smalle et al., 2017) and transcranial direct current stimulation (tDCS; Friederici, et al., 2013) in adults. The modulating role of EFs in language learning has been explored in the context of artificial language learning. For example, Kapa and Colombo (2014) asked participants to intentionally learn a grammatical rule through animated videos and sentences. Participants were then asked to produce similar sentences in different videos. The EFs profile of the participants was assessed by using a set of classical inhibitory (Fan, McCandliss, Sommer, Raz, & Posner, 2002), updating (Heaton & Par, 2003), and switching tasks (Monsell, 2003). Results indicated that better inhibitory control was associated with better learning in adults.

In a second experiment, using the same procedure with pre-scholar children, switching abilities predicted L2 learning. Children who were able to switch their attention between different stimuli were better at language learning than children with lower switching abilities. The authors concluded that inhibition and the capacity of switching played a role in L2 learning, depending on the developmental characteristics of the group (Kapa & Colombo, 2014). However, the majority of the studies on the role of individual differences in EFs have focused on intentional or explicit learning (Faretta-Stutenberg & Morgan-Short, 2018; Villegas & Morgan-Short, 2019; Wang, Schweizer, & Ren, 2019), and there are fewer studies on the role of executive control on incidental learning (Ruiz et al., 2018). Hence, we aim to explore the relationship between executive control and L2 learning in incidental and intentional-explicit learning conditions. Importantly enough, the relative difficulty of the materials to be learned has also been found to be a modulatory factor in the relation between learning context and individual differences in cognitive abilities.

The role of rule difficulty

The difficulty is understood as both the property of the linguistic feature intended to be learned (easy/difficult grammatical rule) and as the potential requirement to use cognitive resources to learn and process this feature (Housen & Simoens, 2016). In this sense, Tagarelli et al. (2016) measured the interaction between rule difficulty and individual differences in EFs within different learning contexts. They manipulated the difficulty of the learning materials by introducing three different rules varying in difficulty. A semi-artificial language (English lexicon on a German syntax) was used to create easy sentences and make them vary in difficulty by adding complements to the easy structure (easy, difficult 1, and difficult 2 structure). Participants in the incidental context were asked to read the sentences and try to understand their meaning, whereas participants in the explicit context (instructed by the authors) were explicitly informed about the rule system (metalinguistic information). After training, all participants completed a GJT where they had to judge the grammaticality of the presented sentences according to the rule system. In addition to this, they measured individual differences in Working Memory (WM; reading span task; Daneman & Carpenter, 1980) and procedural learning abilities (alternating serial reaction time task; Howard & Howard, 1997). Results indicated that performance in the GJT task was predicted by the type of learning exposure (incidental/ explicit) for the easier sentences. Thus, for easy sentences, participants in the explicit context showed better performance in the GJT task than participants in the incidental context. However, for the more difficult sentences, the type of exposure was not predictive of GJT performance, and procedural learning skills predicted performance independently of the type of exposure (see Gao & Ma, 2021 for similar results). Therefore, because difficulty may have a role in modulating individual differences in learning success, we also varied the difficulty of the materials across experiments.

In sum, the aim of the present study was to examine the influence of individual differences in EF in different contexts of learning. Thus, the goal of Experiment 1 was to examine the process of learning a grammar rule under intentional and incidental conditions, as well as to explore the role of individual differences in successful learning. In Experiment 2, the goal was to test the role of difficulty in the interaction between condition of learning and individual differences. Finally, to rule out possible explanations based on previous knowledge of English, we conducted Experiment 3 with an untrained control group to provide an untrained baseline condition to which compare actual learning from training.

Experiment 1

The aim of the present experiment was to examine the influence of individual differences in EFs. To do so, Experiment 1 entailed presenting participants with the dative rule used by Robinson (1997). To test the learning success, participants were asked to perform an untimed GJT with sentences previously shown during the learning phase as well as with new sentences (grammatical and ungrammatical). This task has been found to be a valid tool to measure learning outcomes (Ellis, 2005; Godfroid et al., 2015; Gutierrez, 2013).

The test was performed immediately after the learning phase, as well as both 24-hours and 1-week after the learning phase. A rule-learning *d' index* was calculated, representing the ability to discriminate between new-grammatical and new-ungrammatical sentences (Tagarelli et al., 2016). This index reflects the extent to which participants generalized the rule, so that – when presented with a new grammatical sentence – they were able to detect the rule and discriminate between grammatical and ungrammatical sentences that were never presented. Hence, this was the critical parameter in our experiments, as it indicated rule generalization beyond the specific examples presented during the study. Overall, in line with previous research (e.g., Spada & Tomita, 2010), it was expected that individuals in the intentional condition would have better learning performance as indexed by the rule-learning *d'* than people in the incidental condition. Two additional testing periods were included, since some theoretical accounts (Ullman, 2004, 2006) assume that rule-learning under incidental conditions may potentially last longer in comparison to learning under intentional conditions, where part of the declarative information may decline with time (Morgan-Short et al., 2014). Thus, it was expected that this rule-learning index would remain stable over the three testing intervals (immediate, 24-hours, and one week) for the incidental condition, but that some decline would occur with time under intentional conditions.

To explore the role of individual differences, participants were asked to perform the AX-CPT task (Braver & Barch, 2002) to display individual differences in proactive/reactive control (BSI index; Braver, 2012; see Cooper, Gonthier, Barch & Braver, 2017 for a psychometric study on the task). Proactive control can be understood as anticipatory selection and maintenance of goal-relevant information; this operates in a top-down manner, which minimizes interference before a potentially distracting event occurs (Braver, 2012). On the contrary, reactive control can be understood as a late correction mechanism operating in a bottom-up manner; this transiently recalls goal information whenever a task-relevant or interferential stimulus occurs. Proactive control has the advantage of an ahead-of-time adaptable behavior that is in line with the context to achieve the goal; its disadvantage, however, is that it is very demanding of Working Memory et al., 2009). Proactive control seems to be especially relevant in intentional learning contexts where attention to the relevant task features is critical. However, its role in incidental learning contexts is not evident. Hence, it was expected that proactive control would be linked with successful learning in the intentional context, whereas its role in the incidental context may be reduced.

Method

Participants

A total of 78 Spanish native-speakers from Granada (Spain) participated in the present study (range of 18-30 years of age; *M* = 22.84; *SD* = 3.39). All participants had formal education (*M* = 18.3; *SD* = 4.79) including learning English (information extracted from the LEAP-Q questionnaire (Marian, et al., 2007), but their English proficiency was very basic (participation requirement: level lower than or equal to B1 level in the European Language Framework; self-rated language skill: *M* = 4.3; *SD* = 1.37, on a scale from 1 to 7). Participants were randomly distributed into two groups regarding the condition of learning: an *intentional condition* (n = 39) and an *incidental condition* (n = 39); there were no differences in age, years of formal education, and self-rated language skills between groups. T-test comparisons showed no differences between context groups on WM measured (Dot Counting task, Wechsler, 1997) nor on intelligence, measured with the Raven's matrices task (Raven, 1989) (all *ts* (77) < 1; *ps* > .05). Participants were rewarded with 15€ for their participation.

Materials

Experimental tasks: learning and grammaticality judgment test

Grammatical rules and learning materials. A total of 55 sentences following a simplification of the Dative rule were presented during this phase (a rule usually unknown by English learners; see Robinson, 1997). In accordance with this rule, monosyllabic verbs (with one syllable in the stem, e.g., give) could take the 'to-object' construction or the dative alternation (*Marta gives her keys to Antonio/Marta gives Antonio her keys*), however disyllabic verbs (with two syllables, e.g., provide) can only occur with 'to-object' constructions (*Marta provides* *food to Antonio*). Following Robinson (1997) for this experiment, 3 sentences were included containing monosyllabic verbs in 'to-object' construction (*Marta gives her keys to Antonio*); 3 sentences containing disyllabic verbs in 'to-object' construction (*Marta donated her house to Antonio*); and 4 sentences containing monosyllabic verbs in dative alternation (*Marta gives Antonio her keys*). Each sentence was presented from 1 to 10 times (see supplementary materials for the experimental materials)[2]. Different from Robinson (1997), during the training phase, the sentences had a red box highlighting the verb (formed for one or two syllables in the stem) and the 'to' of the 'to-object' formation. For both the intentional and incidental contexts, participants were told to read each sentence and then answer a comprehension question about it. In the intentional context, participants were additionally told that all sentences followed the same grammatical rule and that they needed to learn it by paying attention during sentence presentation.

Grammaticality judgment test (GJT). Following training, all participants were told that all the studied sentences were grammatically correct and that they all followed the same rule (although they were not informed of the rule). Then, participants were asked to perform a GJT. Thirty sentences were randomly presented one at a time, and participants were asked to respond with *yes* or *no* as to whether the sentences were grammatically correct. The sentences remained on the screen until the participant responded. For the GJT, 10 sentences had been previously studied during the training phase (grammatical sentences), 10 were new sentences that followed the learned rule (new-

[2] The number of presentations for the sentences exactly replicated the procedure by Robinson (1997), and just like in his experiment, we found no learning differences depending on number of learning trials per studied sentence.

grammatical sentences), and 10 were new sentences that did not follow the rule (new-ungrammatical sentences).

AX-CPT task. This task was used to measure proactive/reactive control strategies (Locke & Braver, 2008). In this version of the task (Ophir, Nass, & Wagner, 2009) a set of five letters were shown in the middle of the screen following a specific presentation order, the first and last letters were printed in red, and the three middle letters were printed in white. There were four different conditions: a) AX-pattern, where the first red letter presented was an 'A' and the last red letter presented was an 'X'; b) AY-pattern, where the first red letter presented was an 'A' but the last red letter presented was not an 'X'; c) BX-pattern, where the first red letter presented was not an 'A' but the last red letter presented was an 'X'; d) BY-pattern, when the first letter was not an 'A', and the last letter was not an 'X'. The proportion of the patterns was as follows: 70% for the AX and 10% for each of the other patterns (AY, BX, or BY) from a total of 100 trials. Participants were instructed to press the 'yes' button when the first red letter presented was an 'A' (cue) and the last red letter presented was an 'X' (probe; AX-pattern). They were to press the 'no' button in any other situation (AY, BX, or BY patterns). They also were to press the 'no' button during the middle letters (printed in white). Participants had to answer as accurately as they could and as soon as possible. Participants did one practice block (10 trials) which included trials representing the four experimental conditions; during this practice block, participants were given feedback. Once they completed the practice trials, they began the experimental block (100 trials) with trials randomized for each participant. The letters were presented for 300 ms in the center of the screen. Between the presentation of the cue and the probe (printed in red), there was

4900 ms where the three distractor-letters (printed in white) were presented for 300 ms with 1000 ms of interval time between them. There was a delay of 1000 ms between trials.

Procedure

The experiment was divided into 3 sessions. The first session started with the syntactic learning task. Participants in the incidental context group were asked to read some sentences in English and answer simple yes/no comprehension questions about each of them. Participants in the intentional context group were explicitly asked to pay attention to the rule while reading the same set of sentences and to answer the same yes/no comprehension questions about it. For both incidental and intentional contexts, the sentence appeared and remained on the screen for 5 seconds after a fixation point (300 ms). Then, the comprehension question appeared and remained on the screen until the participant responded. Sentences were presented randomly. After the learning task, participants were told that all sentences were grammatically correct, and asked to perform an immediate GJT, including grammatically correct and incorrect sentences. Each sentence appeared on the screen until the participant made a response. The second session was 24 hours after participants performed the task, and they were told to complete a second GJT. The third session was one week after the second, and participants were again asked to perform the GJT. During the three GJTs, the same sentences were presented. Unfortunately, a number of participants (n = 8) did not return to the laboratory for the third session, and it was not possible to replace them due to the COVID pandemic. In order to maintain a bigger sample to maximize the effect size, and because a preliminary analysis including the three GJT times indicated that the one-week test did not change our conclusions, data from the last

GJT were not included in the analyses. During the sessions, participants did also the AX-CPT and the global-local task. Results from the global-local task are not reported in this paper since they were collected with a different aim, and they are the subject of another investigation.

Data analysis

Grammaticality Judgement Task. Performance was calculated through discrimination d' scores (Macmillan & Creelman, 2004). Participants with a FA rate above 89% (2DT above the mean) – a sign of poor performance - at the immediate test were removed from the analysis (6.4%). The extent to which participants generalized the rule to new sentences was assessed by calculating *d'* for hits on new-grammatical sentences (judging grammatical sentences as grammatical) – FA on new-ungrammatical sentences (judging ungrammatical sentences as grammatical) (Rule-*learning d'),* indicating more abstract representation of the rule. Differences from chance were calculated using one-sample t-test between hits and FA (Table 2).

AX-CPT task. For EFs tasks, the data below 100ms and 2'5 SD over each participant mean were filtered (Zirnstein et al., 2018), cleaning 3.6% of the data. In addition, 5.1% of the participants did not complete the task. Missing scores in the AX-CPT were substituted by the mean of the group in order to maximize the number of observations per condition. Note, however, that we also performed these analyses without missing-value substitution, and they revealed the same pattern (we report them as supplementary material).

The *Behavioral Shift Index* (BSI) was calculated as a combination of AY and BX trials (between errors and Response Time, RT; Braver, Paxton, Locke, & Barch, 2009). The BSI index goes from -1+1, where scores near 0 show a balance between proactive and reactive control (1 more proactive/-1 less proactive).

Results

For the rule-learning *d'* scores, results indicate that participants discriminated between grammatical (new/studied) and ungrammatical sentences beyond chance (see means and t-tests in Table 1).

Table 1.

Mean rates (SD) for d' scores. T-test reports for rule-learning d' and episodic-recognition d' on immediate and 24-hour GJT tests.

d' score	Incidental (n=37)	Intentional (n=36)
Rule Learning		
Immediate	.79 (.11)	1.59 (.11)
t-test	t (36) = 12.04, p < .001, 95% CI [.33, .46]	t (35) = 7.62, p < .001, 95% CI [.21, .37]
24-hours	.69 (.11)	1.09 (.11)
t-test	t (36) = 7.75, p < .001, 95% CI [.25, .42]	t (35) = 6.56, p < .001, 95% CI [.16, .32]

As mentioned, the aim was to assess the effects of learning condition and time of testing on rule-learning. Results of the ANOVA indicated that the main effect of condition was significant, F (1, 73) = 8.08, p < .001, μ = .10 Participants on the intentional condition were significantly better (M = 1.13; SD = .09) than those on the incidental condition (M = 0.75; SD =

.09). However, neither the main effect of time, F (1, 73) = 1.29, p =.25, μ=.02, nor the interaction between condition and time, F (1, 73) =.04, p =.84, μ =.0005, were significant (see Figure 1).

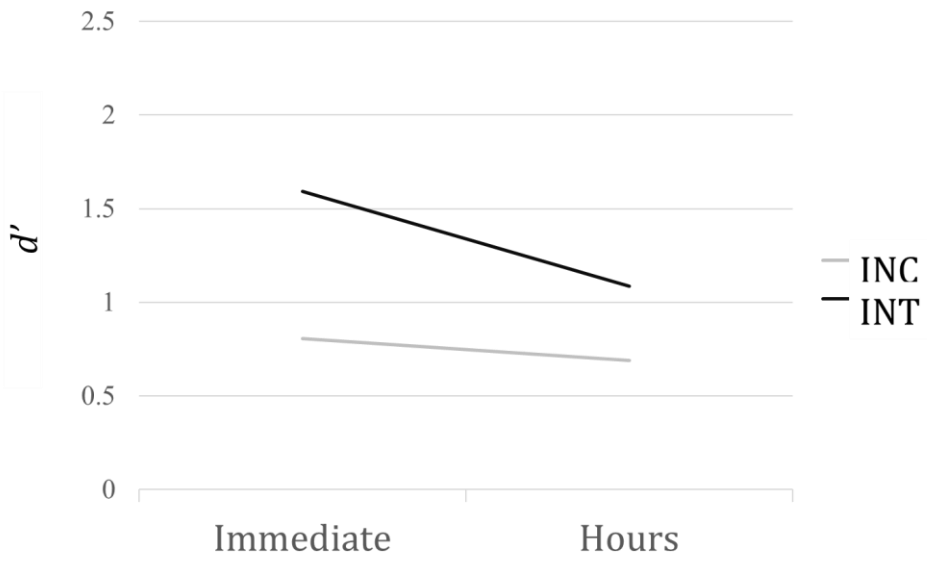

Figure 1. Rule learning d’ as a function of time (immediate and hours) x condition (INC-incidental and INT-intentional).

The role of EFs during learning was also explored in a Multiple Linear Regression analysis for the Rule-learning *d’* Index for incidental and intentional conditions, respectively. BSI was added as fixed factor (continuous variable). These analyses indicated no significant main effects of BSI, for the incidental condition, F (1, 72) = .0001, p = .99, *adjusted R2* = -.01 (see Figure 2). However, for the intentional condition, BSI was a significant predictor of language learning, F (1, 70) = 4.366, p = .04, *adjusted R2* = .04; β = 1.58, t = 2.09, p = .04. More precisely, participants had better discrimination (d’ = 1.46) if they showed higher BSI scores (more proactive).

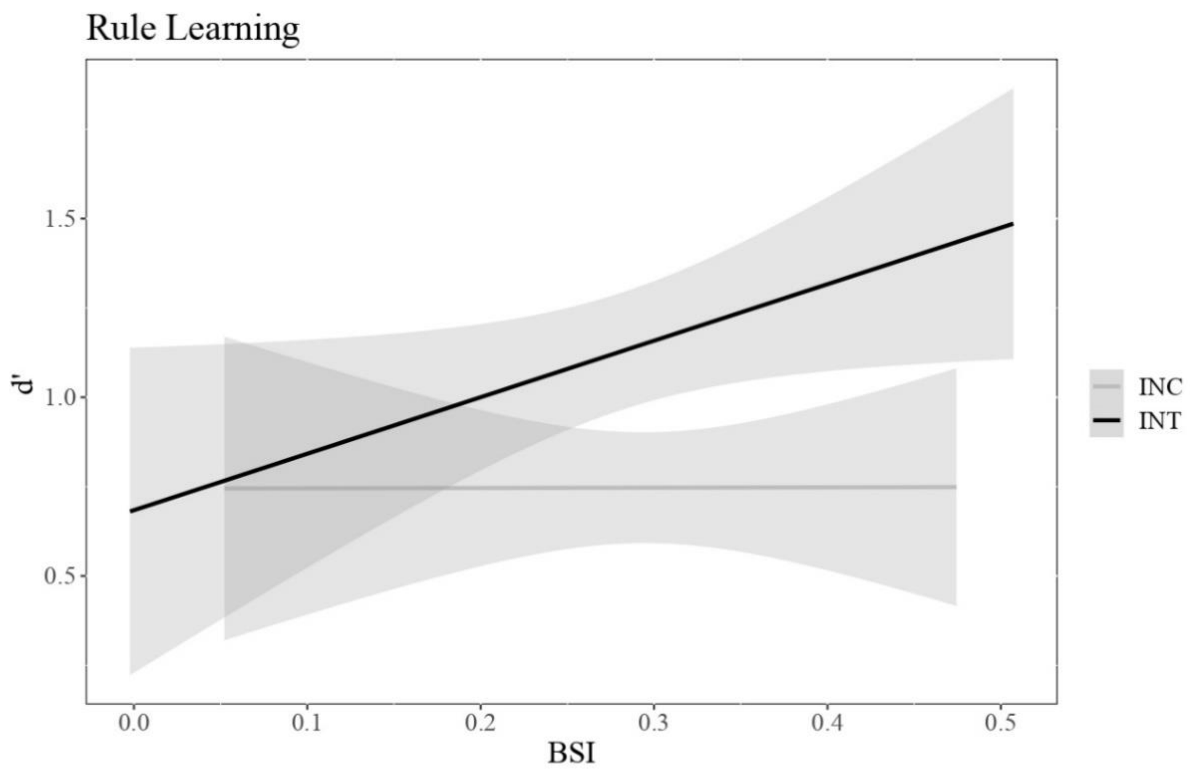

Figure 2. Rule-learning d-prime scores associated with BSI for incidental (INC) and intentional (INT) conditions. Highlighted areas represent Standard Error.

Discussion

Rule-learning was significantly better for participants in the intentional condition, both immediately and after 24-hours. These results are in line with previous results indicating better performance in intentional learning contexts rather than in incidental contexts (Hulstijn, 2005). Additionally, no differences were found between time of tests, nor was an interaction found between condition and time. This suggested that the initial intentional advantage remains for at least 24 hours. Hence, in contrast to prior predictions of lower GJT performance after a delay, the information extracted from intentionally studying the exemplar was still available after 24 hours.

More importantly, individual differences predicted participants' performance only in the intentional group: positive BSI (towards proactivity) was related to higher *Rule-learning d'* scores. This pattern is consistent with results reported by Kapa and Colombo (2014), where strong cognitive control predicted better performance during intentional learning. According to prior predictions, individual differences may also modulate success for the incidental learning process, although it might do so in different ways (it is possible that lower control might be preferred for incidental learning; Kaufman, DeYoung, Gray, Jiménez, Brown, & Mackintosh, 2010; Morgan-Short et al., 2014). However, no type of relation between the EFs and incidental learning was found.

Since incidental learning has been found to be useful for acquiring difficult structures and patterns (Ullman, 2001), one possible variable that may have influenced the results is the relative difficulty of the learning materials. It is possible that individual differences in EF may play a larger role when learning more difficult rules as it was found by Tagarelli et al. (2016). Hence, difficulty was manipulated in Experiment 2 to test the role of this variable in the interaction between condition of learning and individual differences.

Experiment 2

The goal of this experiment was to capture the possible interaction between learning condition, difficulty of the materials, and individual differences. The difficulty of the rule learning task was increased in Experiment 2 relative to Experiment 1 by including an additional rule. Thus, in Experiment 2, participants were presented with two rules (two blocks of trials). We decided on this type of presentation and number of rules based on the results of a previous pilot study where we added three different rules that were randomly presented during the learning phase in an intentional or incidental learning condition. Results from the pilot study indicated that intermixing the three rules was very difficult for the participants who showed a low level of performance and no significant effects, in any condition[3]. For this reason, we reduced the number of rules to two and we blocked their presentations (see Robinson, 1996; 1997). Additionally, in Experiment 2, we added metalinguistic explanations of the rules, instead of the simple intentional condition in Experiment 1 (providing information about the presence of the rule, but not about the rule itself). Hence, in this experiment participants were exposed to what Robinson (1997) termed "explicit condition". Finally, we again included three testing sessions (immediate, 24-hours, 1-week) with the hope that online participation would make it easier for participants to engage in the experiment for the third time, and we were able to assess learning under longer-delayed conditions.

Method

Participants

Due to restrictions as a result of the COVID-19 pandemic, all tasks were programmed, and the experiment was run using Gorilla.sc, an online platform for behavioral experiments (Anwyl-Irvine, Massonnié, Flitton,

[3] We first conducted an experiment where three different rules were randomly presented during the learning phase. Results indicated that intermixing the three rules was very difficult for the participants who showed low level of performance and no significant effects. For this reason, we reduced the number of rules to two and we blocked their presentations.

Kirkham, & Evershed, 2020). To ensure that the experiment was not underpowered – as some of the effects were close to significance in Experiment 1 – the expected power of fixed-effects a priori was calculated in Experiment 2 by using the simr package in R (Brysbaert & Stevens, 2018). The effect-size was planned on a pilot study with 12 participants, and the minimum requirement was estimated through powerCurve function (alpha=0.4). With 1,000 simulations, the simulation showed a sample size of 80 to achieve 80% statistical power. A total of 146 native Spanish speakers participated in the experiment however, 11% of them (n=17) did not perform the AX-CPT task due to a programming error. These participants were subsequently removed from the experiment. A total of 129 participants (age range 18-30 years; *M* = 24.32; *SD* = 8.55) completed the experiment. They all had formal education (*years: M* = 18.05; *SD* = 3.8), and English learning during school, but their English level was lower than B1 (*self-rated Language skill*: *M*=3.9; *SD*=1.31); information extracted from the LEAP-Q). Participants were rewarded with 0.3 credits as students at the University of Granada, or with a raffle ticket for a 50€ card from an online shopping website.

Materials

Experimental tasks: learning and grammaticality judgment test

Grammatical rules, learning materials, and procedures. Participants were exposed to two different rules: the dative rule (as in Experiment 1) and the pseudoclefts *of location* rule. The correct structure of a pseudocleft rule is as follows: *where – subject –to be [correct conjugation] – subject – adverbials of location*; the verb must agree with the subject (i.e., *Where Alba and Tania live is in Granada*). Additionally, a second location can be contrasted within the same sentence by joining the two locations with a *not* particle (i.e., *Where Alba and Tania live is in Granada not in Krakow*). A total of 60 sentences that followed four versions of the rule were created: (1) 12 sentences with two adverbials of location clauses (i.e., *Alba swims in the pool and Tania swims in the sea*); (2) 12 sentences with a singular subject that need to agree with two forms of the verb *to be* (i.e., *Where Alba is is in the swimming pool not in the beach*); (3) 12 sentences with plural subjects, which need an agreement with the main verb *to be* (i.e., *Where Alba and Tania are is in the pool*); and (4) 12 sentences with singular subjects which need an agreement with the two main verbs (i.e., *Where Tania lives is in Granada not in Madrid*). Each type was represented by two sentences, and each sentence was presented 3 times (see supplementary material for the experimental materials). Before the experiment, data were collected from 4 judges regarding the difficulty of the rules; 75% selected the dative rule as the easiest and judged the difficulty with 4 on a scale from 1– 7, whereas the pseudocleft rule was rated with a mean level of difficulty of 4.62. The sentences corresponding to each rule were blocked for presentation and followed by the GJT for the rule. The order of the rules was counterbalanced across participants. While most details of the sentence presentation were very similar to those of Experiment 1, boxes highlighting the critical points in the sentences were not used since they differed for the two rules. All other details regarding order and timing were identical to Experiment 1.

Grammaticality judgment test (GJT). For the dative rule, the same GJT was used as was used in Experiment 1. Additionally, an additional GJT was created for the pseudoclefts rule, following the same structure as was used in Experiment 1 (10 studied, 10 new-grammatical, and 10 new-ungrammatical sentences).

AX-CPT task

The same task was used as described in Experiment 1.

Procedure

The condition of learning (incidental/explicit) was manipulated within-subjects. Thus, during the first session, participants learned both rules through different contexts of learning. To ensure the incidental nature of the first learning task, participants were told that the aim of the first task was to measure their basic English level. They were also told that they were going to be presented with English sentences followed by comprehension questions. Immediately after this, they were asked to perform the incidental learning context task (i.e., read the sentence and answer a comprehension question). After incidental learning, an immediate GJT was taken, followed by the LEAP-questionnaire (e.g., as a distractor task separating the two learning blocks; this took approximately 15 minutes). Secondly, they explicitly learned the other rule on the explicit learning context task, which was the metalinguistic explanation of the rule (see Figure 3). This was presented on the screen until they felt ready to answer metalinguistic questions about sentences following the rule (M = 61302 ms (1'21''); SD = 1021 ms (3''). Finally, participants performed the immediate GJT test, corresponding to the rule they were supposed to learn. For both incidental and explicit contexts of learning, the sentence appeared and remained on the screen for 5 seconds after a fixation point (300 ms). Then, the comprehension/metalinguistic question appeared and remained on the screen until the participants responded. Sentences were randomly presented. The second session was 20 to 24 hours after the first one, and the third session was 5 to 7 days after the second one. These sessions included the AX-CPT and the global-local task. Since the experiment was run online, the Fullscreen mode was a requisite during the experiment. As in Experiment 1, results from the global-local task are not reported in this paper since they are the subject of another investigation.

Participants

Due to restrictions as a result of the COVID-19 pandemic, all tasks were programmed, and the experiment was run using Gorilla.sc, an online platform for behavioral experiments (Anwyl-Irvine, Massonnié, Flitton, Kirkham, & Evershed, 2020). To ensure that the experiment was not underpowered – as some of the effects were close to significance in Experiment 1 – the expected power of fixed-effects a priori was calculated in Experiment 2 by using the simr package in R (Brysbaert & Stevens, 2018). The effect-size was planned on a pilot study with 12 participants, and the minimum requirement was estimated through powerCurve function (alpha=0.4). With 1,000 simulations, the simulation showed a sample size of 80 to achieve 80% statistical power. A total of 146 native Spanish speakers participated in the experiment however, 11% of them (n=17) did not perform the AX-CPT task due to a programming error. These participants were subsequently removed from the experiment. A total of 129 participants (age range 18-30 years; *M* = 24.32; *SD* = 8.55) completed the experiment. They all had formal education (*years: M* = 18.05; *SD* = 3.8), and English learning during school, but their English level was lower than B1 (*self-rated Language skill*: *M*=3.9; *SD*=1.31); information extracted from the LEAP-Q). Participants were rewarded with 0.3 credits as students at the University of Granada, or with a raffle ticket for a 50€ card from an online shopping website.

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Grammaticality judgment test (GJT). For the dative rule, the same GJT was used as was used in Experiment 1. Additionally, an additional GJT was created for the pseudoclef*ts* rule, following the same structure as was used in Experiment 1 (10 studied, 10 new-grammatical, and 10 new-ungrammatical sentences).

AX-CPT task

The same task was used as described in Experiment 1.

Procedure

The condition of learning (incidental/explicit) was manipulated within-subjects. Thus, during the first session, participants learned both rules through different contexts of learning. To ensure the incidental nature of the first learning task, participants were told that the aim of the first task was to measure their basic English level. They were also told that they were going to be presented with English sentences followed by comprehension questions. Immediately after this, they were asked to perform the incidental learning context task (i.e., read the sentence and answer a comprehension question). After incidental learning, an immediate GJT was taken, followed by the LEAP-questionnaire (e.g., as a distractor task separating the two learning blocks; this took approximately 15 minutes). Secondly, they explicitly learned the other rule on the explicit learning context task, which was the metalinguistic explanation of the rule (see Figure 3). This was presented on the screen until they felt ready to answer metalinguistic questions about sentences following the rule (M = 61302 ms (1'21''); SD = 1021 ms (3''). Finally, participants performed the immediate GJT test, corresponding to the rule they were supposed to learn. For both incidental and explicit contexts of learning, the sentence appeared and remained on the screen for 5 seconds after a fixation point (300 ms). Then, the comprehension/metalinguistic question appeared and remained on the screen until the participants responded. Sentences were randomly presented. The second session was 20 to 24 hours after the first one, and the third session was 5 to 7 days after the second one. These sessions included the AX-CPT and the global-local task. Since the experiment was run online, the Fullscreen mode was a requisite during the experiment. As in Experiment 1, results from the global-local task are not reported in this paper since they are the subject of another investigation.

Dative alternation rule

Verbs with one syllable in the stem like ***gi****ve could take the 'to-object' construction or the dative alternation, therefore these sentences are both correct:*

1. *Dative alternation: Marta gives Antonio her key*
2. *'To-object' construction: Marta gives her keys* ***to*** *Antonio.*

However verbs ***with two syllables in the stem*** *like* ***provi****de can only occur with 'to-object' constructions, therefore Marta provides food* ***to*** *Antonio is the only correct sentence.*

Pseudoclefts rule

Some sentences talk about two things and locations. For example: ***Alice*** *stands on the right and* ***Judy*** *stands on the left.*

These sentences can be changed to emphasize one of the subjects and it location.

To do so, we select the subject we want to emphasize and add ***where*** *in front, followed by the subject and the verb. Hence, our sentence will start like this:*

Where Alice stands

It is important to know that the verb can not be in front of the subject.

Then we add the verb ***to be*** *with the right person conjugation and, finally, we add the location clause. Then the sentence will be:*

Where Alice stands ***is*** *on the right.*

Finally, we can add another location to ensure it (contrasting location) using ***not.*** *In our previous example:*

Where Alice stands is on the right ***not*** *on he left*

Figure 3. Metalinguistic explanations used in the explicit context for the dative *alternation* and pseudocleft*s* rules.

Data analyses

As in Experiment 1, performance in the GJT was calculated through discrimination d' scores. Participants with a FA rate above 89% (2DT above the mean) at the immediate test were removed from the analysis (26%; n = 34). For the AX-CPT task, data below 100ms and 2’5 SD over each participant mean; 5% of the data was removed. An additional 10% (n= 14) of the participants was removed from the analysis because they had BY errors = 1, showing that they did not understand how to answer to this task.

As in Experiment 1, overall statistics are reported for the d’ index corresponding to rule-learning (new-grammatical versus new-ungrammatical sentences).

Results

Grammatical judgment test

For the critical rule-learning *d’* scores, results indicate that participants discriminated between grammatical (new/studied) and ungrammatical sentences beyond chance both on the dative and pseudoclefts rules (see means and *t*-tests in Table 2).

Table 2.

Mean rates (SD) for d' scores for dative and pseudoclefts rules. T-test reports for Rule-learning d' and Episodic-recognition d' on immediate, 24-hour and 1-week GJT tests.

d' score	Incidental condition		Explicit condition	
Rule Learning	*Dative*	*Pseudoclefts*	*Dative*	*Pseudoclefts*
Immediate	1.07 (.72)	.74 (.71)	2.13 (1.13)	.45 (.98)
t-test	t (38) = 5.89, p < .001, 95% CI [.19, .39]	t (63) = 8.42, p < .001, 95% CI [.20, .32]	t (63) = 14.5, p < .001, 95% CI [.56, .74]	t (38) = 3.19, p < .001, 95% CI [.06, .26]
24-hours	2.21 (1.05)	1 (.88)	.89 (.7)	.94 (.73)
t-test	t (38) = 6.94, p < .001, 95% CI [.19, .35]	t (63) = 7.19, p < .001, 95% CI [.27, .40]	t (63) = 15.05, p < .001, 95% CI [.58, .75]	t (38) = 9.53, p < .001, 95% CI [.26, .40]
One week	.95 (.72)	.89(.87)	2.16 (1.11)	.7 (1.01)
t-test	t (38) = 9.23, p < .001, 95% CI [.24, .38]	t (63) = 8.43, p < .001, 95% CI [.20, .39]	t (63) = 14.5, p < .001, 95% CI [.52, .73]	t (38) = 3.19, p < .001, 95% CI [.06, .26]

ANOVA analyses of the effects of learning condition, type of rule, and time indicated a significant effect of condition, F (1, 166) = 48.8, p < .001, μ =.22 (explicit better than incidental), and rule, F (1, 85) = 75.52,

$p < .001$, $\mu = .47$ (the dative rule showing better performance than the pseudocleft rule). The interaction of condition and rule was also significant, $F\ (1, 146) = 17.4$, $p < .001$, $\mu = .11$, although this interaction was qualified by a higher order interaction of condition, rule and time, $F\ (4, 336) = 2.45$, $p = .04$, $\mu = .03$. This interaction indicated that for the easier dative rule, there was a main effect of condition, $F\ (1, 85) = 9.86$; $p < 0.001$; $\mu = .34$ at all testing times with better rule-learning for the explicit ($M = 2.16$; $SD = .11$) than incidental condition ($M = .97$; $SD = .13$). In contrast, the more difficult pseudocleft rule produced no differences in the GJT performance between the incidental and explicit conditions, with some variations produced by the times of testing, $F\ (1, 168) = 7.43$, $p <.001$, $\mu = .08$. Participants had better rule-learning after 24 hours ($M = .98$; $SD = .09$) as opposed to immediately afterwards ($M = .62$; $SD = .09$), $t\ (167) = 3.68$; $p <.001$, 95% CI [.17, .55]. In other words, differences in the type of learning were only evident for the easier dative rule which showed an explicit advantage immediately, as well as both 24 hours later and a week later (see Figure 4).

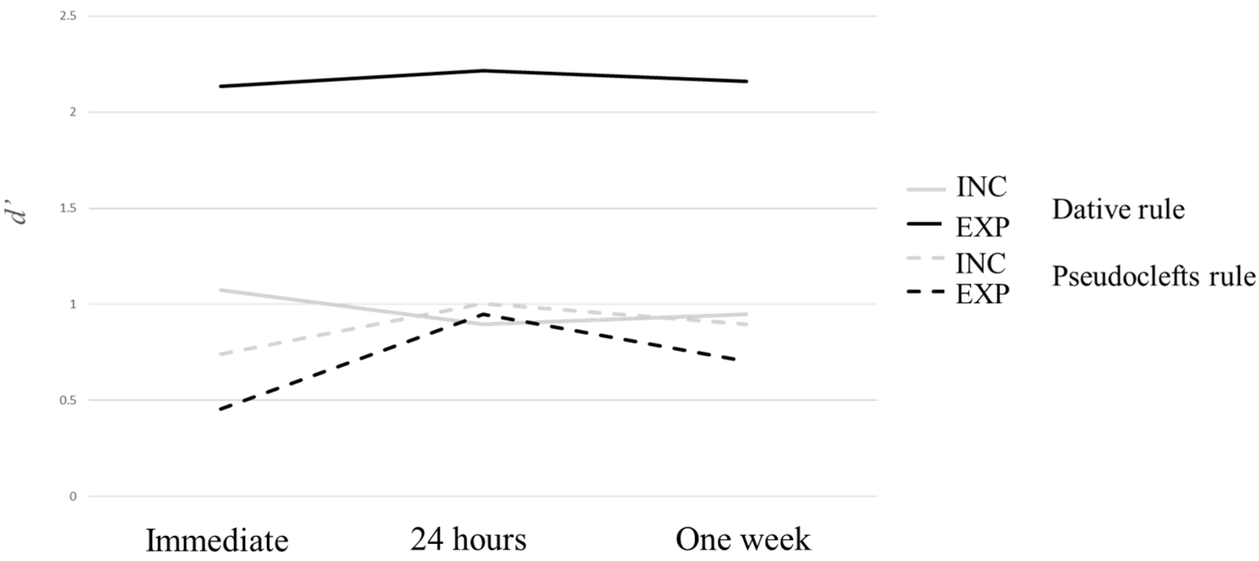

Figure 4. Rule *learning d' index* as a function of time (immediate and hours), condition (INC-incidental and EXP-explicit), and rule (dative and pseudoclefts).

As in Experiment 1, the role of BSI was explored in four Multiple Linear Regression analyses for each (Dative and pseudocleft) Rule-learning *d'* Index for incidental and explicit conditions, respectively. Results indicated that there was a significant effect in the incidental condition for BSI, β = -1.12, t = -3.59, p <.001 at the pseudocleft rule, F (1, 142) = 12.9, p =.001, *adjusted R2* = .08; Participants had 1.12 worse discrimination if they had greater scores in BSI (more proactive), suggesting that learning was enhanced if people were less proactive in the pseudocleft rule learning. That was not significant for the dative rule F (1, 106) = 1.025, p = .31, *adjusted R2* = .0002; β = -.37, t = -1.01, p =.314 (see Figure 5).This effect was not significant for the explicit condition for the dative, F (1, 143) = 1.728, p = .19, *adjusted R2* = .005; β = .55, t = 1.31, p = .2 or the pseudocleft rule, F (1, 106) = .24, p =.6, *adjusted R2* = -.007; β = -.23, t = -.49, p =.624.

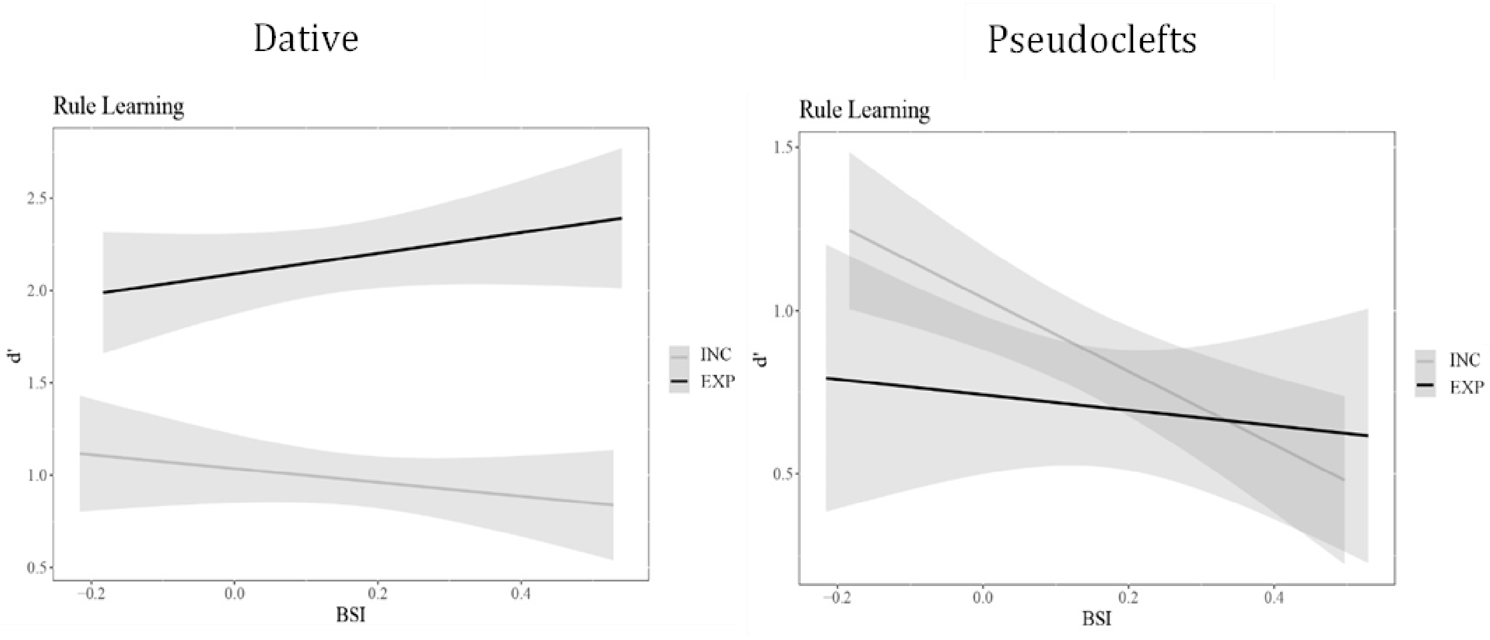

Figure 5. Rule-learning d-prime associated with BSI for incidental (INC) and explicit (EXP) conditions, for the dative (right) and pseudoclefts (left) rules. Highlighted areas represent Standard Error.

Discussion

Results of Experiment 2 showed an explicit learning advantage when learning the easier dative rule. However, this advantage was not evident when participants learned the more complex pseudocleft rule. These results suggest that intentionality and metalinguistic information benefits rule-learning when the information to be learned is relatively not difficult (e.g., the dative rule in both experiments). However, when the rule to be learned is more difficult, both the explicit and incidental conditions seem to produce similar learning levels. These results are similar to those reported by Tagarelli et al. (2016) and Gao and Ma (2021). We can conclude that the probability of explicitly detecting patterns would decrease for highly difficult rules, and learning would therefore depend on procedural memory; this factor, in turn, is not dependent on the nature of the learning task, hence the explicit advantages disappear (see Ullman, 2016, for similar conclusions).

More importantly, Experiment 2 also showed that, when learning a difficult rule, individual differences in EFs are related to incidental learning. Thus, BSI significantly predicted discrimination between new-grammatical and new-ungrammatical sentences in the *rule-learning d' index*. In simple terms, a less proactive profile predicted better rule-learning. Hence, as suggested by Chrysikou et al. (2011, see also Smalle et al., 2017), reduced EFs might produce better learning under specific conditions. As mentioned, proactive control involves a costly goal maintenance mechanism oriented to goal-relevant information in order to avoid interference from irrelevant information (Braver, 2012). This mechanism may potentially be advantageous in situations where the information needed to achieve the goal is easy to keep and maintain active while checking for possible regularities. However, when the information is difficult or there is not a clear goal, lower proactivity may better facilitate learning. This is in line with the results by Kapa and Colombo (2014), whose study with children reflected incidental learning processes facilitating the acquisition of a new language during childhood.

Contrary to findings from Experiment 1, proactivity did not significantly enhance explicit learning; this may be due to differences in procedure between the two experiments. In Experiment 2, the learning context within participants was manipulated, and the explicit condition was always presented after the incidental block. Thus, explicit learning was always performed after exposure to a different rule. It is possible that participants still maintained information from that previous rule in WM - since it needed to be retrieved and coded during the GJT - together with the metalinguistic information to learn the second rule, and this may have overloaded WM and reduced the possibility of using proactive strategies. In favor of this interpretation, manipulation of WM load reduces proactivity in the AX-CPT task (Mäki-Marttunen, Hagen, & Espeseth, 2019) and healthy aging (Paxton, Barch, Racine, & Braver, 2008). In this way, previous studies have related low capacity with worse goal-maintenance performance (Redick & Engle, 2011; Wiemers & Redick, 2018). Nevertheless, these results can also be explained by the fact that participants in the first study were encouraged to find the regularities in the sentences while in the second study we explicitly told them the regularities and asked to pay attention to them. Hence it is possible that proactive control is recruited in learning conditions where hypotheses need to be tested. Thus, in the intentional condition, participants might have tested the hypothesis for a specific rule every time that a sentence was presented. Morgan-Short et al., (2012) found WM to be highly related to successful learning in a condition where metalinguistic explanations were not provided, and they concluded that this pattern might be due to the increments in WM demands in conditions where analysis of the information is required (Morgan-Short et al., 2012). However, further investigation is needed to assess these possible explanations.

Finally, an alternative explanation for the pattern of results in both experiments might relate to the possibility that participants were using their previous knowledge of English, (instead of the learned rule) to make their grammaticality judgments. Although for all conditions in Experiments 1 and 2, we tested those participants who were performing above chance, suggesting that learning had occurred, it was possible that this above-chance performance was due to inferences from previous English knowledge. In order to rule out this interpretation, we decided to run an additional untrained control group from which we could compare trained versus untrained performance and reduce uncertain interpretation (Hamrick & Sachs, 2017).

Therefore, Experiment 3 was conducted to provide an untrained group where we could assess the influence of our learning conditions in Experiments 1 and 2 on the GJT beyond the possible influence of inferences from language knowledge.

Experiment 3

In Experiment 3, we run the GJT and executive control tasks as in Experiments 1 and 2, but without a previous learning phase. In this condition, we would expect that untrained participants would have significantly lower *d'* scores than participants in Experiments 1 and 2, indicating that both the incidental and intentional-explicit results were due to learning and no previous knowledge of English. In addition, we expected no significant effects of BSI in this untrained group, indicating that the obtained BSI effects in Experiments 1 and 2 were due to learning experiences and no to the use of previous language knowledge in the absence of learning.

Method

Participants

A total of 70 Spanish native-speakers from Granada (Spain) participated in the present study (range of 18-30 years of age; M = 23.05; SD = 3.7). All participants had formal education and learning of English, but their English proficiency was basic (participation requirement: level lower than or equal to B1 level in the European Language Framework). All participants were economically rewarded.

Materials

Grammatical Judgment tasks

For the dative rule, the same GJT was used as in Experiments 1 and 2 and for the pseudocleft rule, the same GJT was used as in Experiment 2.

AX-CPT task

The same task was used as in Experiments 1 and 2.

Procedure

In this control experiment, participants did two GJTs, one for the dative rule and one for the pseudocleft rule. Additionally, they were asked to do the AX-CPT task to measure the implication of proactive control on the test responses. All tasks were programmed, and the experiment was run using Gorilla.sc, the same online platform for behavioral experiments (Anwyl-Irvine, et al., 2020) that we used in Experiment 2. The experiment started with the dative GJT where they were asked to answer whether the sentences were grammatically correct or not in English, followed by the AX-CPT task and finally, the pseudocleft GJT. Since the experiment was run online, the Fullscreen mode was required during the experiment and participants had maximum of 50 minutes to complete it (the experiment lasted around 35 minutes).

Results

Data analyses

As in Experiments 1 and 2, performance was calculated through discrimination *d'* scores. For the AX-CPT task, data below 100ms and 2'5 SD over each participant mean; .3% of the data was removed. In addition, 17% of the participants (n= 12) were removed from the final analysis following the same procedure as the previous experiment.

Grammatical judgment test

For the rule-learning *d'* scores, results indicate that participants discriminated between grammatical (new/studied) and ungrammatical sentences beyond chance both on the dative, t (69) = 5.52, $p < .001$ and the pseudocleft rule, t (69) = 3.73, $p = .002$; as they had more hits than FAs in their responses. However, when comparing their responses with those from the incidental groups in Experiments 1 and 2, they performed significantly worse. For the dative rule, we found that participants in the untrained control group had significantly smaller d' discrimination indexes (M =.57; SD = .67) than participants in the incidental condition in Experiment 1 (M =1.05; SD = .55), t (105) = -3.73; $p < .001$, 95% CI [-.74, -.22]. They also had smaller *d'* than participants in the incidental condition in Experiment 2 (*M* =.88; *SD* = .55), *t* (104) = -3.13; *p* < .001, 95% CI [-.65, -.14]. For the pseudocleft rule, we also found that participants in the untrained control group had significantly smaller d' discrimination indexes (*M* =.39; *SD* = .73) than participants in the incidental condition in Experiment 2 (*M* =.88; *SD* = .70), *t* (116) = -3.64; *p* < .001, 95% CI [.38, .88]. Moreover, they also performed significantly worse compared to the intentional and explicit groups. For the dative rule, we found that participants in the untrained control group had significantly smaller d' discrimination indexes (*M* =.57; *SD* = .67) than participants in the intentional condition in Experiment 1 (*M* =1.18; *SD* = .57), *t* (105) = -5.55; *p* < .001, 95% CI [-.99, -.47]. They also had smaller *d'* than participants in the explicit condition in Experiment 2 (*M* =2.17; *SD* = 1.1), *t* (117) = -10.39; *p* < .001, 95% CI [-1.18, -1.28]. For the pseudocleft rule, we also found that participants in the untrained control group had significantly smaller d' discrimination indexes (*M* =.39; *SD* = .73) than participants in the explicit condition in Experiment 2 (*M* =.7; *SD* = .95), *t* (105) = -2.14; p = .03, 95% CI [-.61, -.02].

As in Experiments 1 and 2, the role of BSI was explored using Multiple Linear Regression analyses for each (Dative and Pseudocleft) Rule-learning *d'* Index respectively. We did not find significant interaction between BSI and *d'* in our untrained group when answering to the dative rule, *F* (1,56) = 2.617, *p* = .1, *adjusted-R2* = .02; nor when answering to the pseudocleft rule; *F* (1,56) = 2.25, *p* = .14, *adjusted-R2* = .02.

Discussion

The goal of Experiment 3 was to test whether the pattern of results obtained in Experiments 1 and 2 was in fact due to learning. Hence, we created an untrained control group (see Hamrick & Sachs, 2017 for nuances on this topic) where participants were just asked to give an answer to the GJT for both the dative and pseudocleft rules and we compared their performance with participants in Experiments 1 and 2 participants in the untrained group answered beyond chance, however, their *d'* scores were significantly lower than those found in our groups in Experiments 1 and 2. Hence, we can conclude that the results found in Experiments 1 and 2 were due to the learning phase, not to previous exposures to English.

Additionally, no significant interactions between BSI and *d'* were found in this group. Since we also demonstrated that participants in the experimental conditions were significantly better than those in the untrained control group, we can then conclude that the interaction between individual differences in proactive/reactive control and learning, or the lack of it, was due to the learning exposure manipulation nor previous exposure to the language.

Finally, the interactions between *d'* scores and BSI could be due to the interference associated with participants' L1, hence to the Spanish dative rules (Cuervo, 2007; Pulido & Dussias, 2020). However, if that were the case, we would find individual differences guiding the scores in the dative GJT, where participants would try to solve the interference from the L1 in the L2.

General discussion

Learning an L2 during adulthood is a challenge that is associated with large individual variations in learning success. This study aimed to investigate the complex interaction between intrinsic and extrinsic factors as possible sources of this variability in learning L2 rules. In the following subsections, evidence will be discussed regarding the role of extrinsic (learning condition and context's difficulty) and intrinsic factors (individual differences in EF) during L2 rule learning.

Role of Learning Conditions

Altogether – and across the two experiments – the results indicated that both intentional and explicit conditions benefit rule-learning relative to incidental conditions. This overall benefit coincides with the results reported by Robinson (1997) and many others (see Goo et al., 2015, for a review) where instructed groups showed better grammatical learning performance than groups exposed to the grammatical rules under incidental conditions. Thus, during adulthood –where the declarative system is fully developed and declarative learning processes are enhanced through many years of schooling – explicit learning processes seem to facilitate rule-learning (Ullman, 2004, 2001). However, the more interesting advantage of explicit learning strategies seems to be difficulty dependent. This was observed when participants were learning the less difficult dative rule (Experiments 1 and 2), but it was not evident when participants learned the more difficult pseudocleft rule (Experiment 2) where explicit and incidental strategies produced similar levels of learning. This interaction between learning condition and rule difficulty has also been reported by Tagarelli et al. (2016) and Gao & Ma (2021). In their experiment, they introduced three different rules varying in difficulty and manipulated the learning context (intentional/incidental). Similar to this study's results, they reported an advantage for explicitly learning easier sentences. However, for the more complex sentences, the type of exposure was not predictive of GJT performance. In this line, it has been argued that even though difficult rules can be taught, they are naturally too difficult for successful explicit learning Tagarelli et al., (2016).

For this reason, the probability of explicitly detecting patterns decreases as difficulty increases. This is most probably due to an overload in cognitive resources. Learning in this case would depend on procedural memory to a larger extent (Ullman, 2016), where regularities are detected and stored without intention (*Declarative/Procedural Model;* Ullman, 2001, 2004, 2016). Furthermore, we can conclude that the pattern of results in the explicit condition for learning the pseudocleft rule (no differences between explicit/incidental conditions of learning) was not due to an absence of learning, since scores in the experimental groups were significantly higher than in the untrained control group. Importantly, these results are found when testing the learned regularities in an untimed GJT (Ellis, 2005; Godfroid et al., 2015; Gutierrez, 2013). Further research should extend these findings to timed procedures.

In addition, individual differences have been recently found as factors modulating successful learning (Ullman & Lovelett, 2018). In particular, it has been found that better procedural memory benefits grammar learning (Hamrick, 2015; Morgan-Short et al., 2014). Hence, gaining benefits from intentional-explicit or incidental strategies seems to vary between individuals' cognitive characteristics (Wong, Vuong, & Liu, 2017).

Role of Individual Differences

The role of proactive control in rule learning was explored by including the AX-CPT task to assess proactive control (BSI index). Our results indicated that adults engage cognitive control in different ways during rule-learning, and this depends on the condition and type of rule.

Proactive control – which refers to anticipatory selection and maintenance of goal-relevant information (Braver, 2012) – was positively related to rule-learning in the intentional condition, when learning involved the easier dative rule in Experiment 1. The relation between cognitive control and intentional learning was previously found by Kapa and Colombo (2014). In their study, they found that better inhibitory control – measured through a Flanker task – was associated with better learning in adults. In this study, these results were extended by showing that proactive control is a good strategy for rule-learning under intentional conditions.

In addition, these results indicated that the relation between proactive control and rule-learning did not hold for the explicit condition of Experiment 2. As mentioned, participants learned two different rules in Experiment 2 (which changed in difficulty), the explicit condition was always presented in a second block after participants learned the first rule under incidental condition. In this context, the relation between proactive control and learning was not significant. This suggested that the potential benefits of proactivity can be masked by the overload in WM due to the learning context. Participants during the second block (explicit learning block) had to learn and maintain in WM the explicit rule, after having inferred the rule in the incidental condition of the first block. Although this explanation might seem inconsistent with the fact that participants in Experiment 2 had better performance (higher d' scores) than participants in Experiment 1 when learning the dative rule, we can assume that even if WM was overloaded by having in memory the incidentally learned rule and the metalinguistic information of a different rule, the presence of these metalinguistic explanations gave them a learning advantage that manifested in better performance in the GJT. In addition, it is also possible that proactive control is only recruited in learning conditions where hypotheses need to be tested, as in Experiment 1, where participants needed to test the hypothesis for a specific rule for every sentence (see Morgan-Short et al., 2012 for similar results), and therefore, the relation between BSI and GJT was evident in Experiment 1 where metalinguistic information of the rule was not directly provided, but it was not in Experiment 2 where the rule was explicitly presented. Further investigation is needed to evaluate these possible explanations.

Interestingly, when learning a more difficult rule in Experiment 2, participants' performance was predicted by individual differences in the incidental condition. Less proactivity produced better performance in the incidental condition. Even if there were evidence of incidental learning (compared to the untrained control group), these results were not found for Experiment 1 nor the easy dative rule in Experiment 2. Hence, a more flexible and less demanding type of control seems to facilitate L2 rule acquisition in highly demanding situations. This pattern supports the hypothesis that lower, and more flexible levels of control can facilitate learning in some situations (Thompson-Shill et al., 2009). Hence, successful incidental learning can also be related to the more flexible usage of less proactive goal-maintenance strategies and more reactive stimulus-driven strategies. Top-down proactive control develops during childhood, in parallel with PFC development (Cragg & Nation, 2010), and it seems to enhance cognitive performance. However, under certain circumstances, the development of the PFC and top-down strategies may produce situations where *more* becomes *less* in the context of successful language acquisition (Newport, 1990). Specifically, Thompson-Schill et al. (2009) highlight the involvement of the PFC in rule-driven intentional learning when the rule can be rapidly represented in WM (similar to this study's easy dative rule in Experiment 1). However, when WM is exceeded (as it might have happened in Experiment 2), low PFC involvement and low participation of costly executive control strategies may enhance learning. In some situations, strong cognitive control can be detrimental to successful language learning. This has been empirically found using TMS (Smalle et al., 2017) and tDCS (Friederici et al., 2013) in adults, showing that stimulation in the dorsolateral--PFC during incidental learning displays a beneficial effect of the hypoactivation of this area (Smalle et al., 2017).

Conclusion

In conclusion, it has been found that complex interactions between extrinsic (learning strategies and difficulty) and intrinsic (EFs) factors have a key role in the learning process. When learning an easy rule, explicit-intentional strategies facilitate learning at a higher level than incidental strategies; these strategies seem to be enhanced in people with higher proactive control. This advantage is no longer present when learning a complex rule, and incidental strategies seem to be enhanced by low levels of proactive control. These results are significant, as L2 learning involves both easy and difficult rules in contexts with different levels of difficulty. Therefore, to achieve successful rule-learning, different learning strategies and flexible executive control must be implemented.

Chapter 5. The role of L2 proficiency and proactive control in new grammar learning

Abstract

Bilingualism seems to be advantageous when trying to learn a new language. Previous linguistic experience seems to provide learners with tools that benefit learning; however, evidence of this benefit on new grammar learning is scarce. Extrinsic (complexity) and intrinsic (executive control) factors have been related to new grammar learning in monolinguals. In the present study, we aimed to assess the role of second language (L2) proficiency and proactive control in the explicit context of learning with variable complexity. Eighty-one Spanish–English bilinguals, varying in proficiency, learned *Japañol* (Japanese syntaxis and Spanish lexicon) in an explicit context with metalinguistic explanations, and the complexity of the sentences was manipulated (with/without subordinate clause). Individual differences in English proficiency were measured with the Michigan English Language Institute College Entrance Test (MELICET) test, and individual differences in proactivity were measured with the AX-CPT task. The participants learned the rule during five consecutive training sessions. Immediately and 2 weeks after (delayed) the last session, participants

performed a GJT, where they answered if the presented sentences were grammatically correct in *Japañol*. Overall, participants had better performance when answering to simple compared to complex sentences and in the immediate than the delayed test. The results showed that proficiency significantly modulated performance in both the immediate and delayed tests. Participants with low L2 proficiency had better performance when answering to simple sentences compared to complex ones. Additionally, in the immediate test, when answering to complex sentences, participants with high proficiency were found to have better performance than participants with low proficiency. Finally, proactive control was found to be a significant modulator in the immediate test but not in the delayed one. More proactivity significantly predicted better performance when answering to both simple and complex sentences. These results suggest that proactive control and proficiency, and not just previous experience, are key factors in successful grammar learning under explicit learning conditions.

Introduction

Learning a third language (L3) is assumed to be less costly than learning a second language (L2). The literature suggests that the L2 learning experience provides learners with tools that facilitate L3 learning processes (see Hirosh & Degani, 2021 for a review). These tools include greater metalinguistic abilities (Jessner, 2008), better use of learning strategies (Kemp, 2007), and better resolution of native language (L1) interference (Bartolotti & Marian, 2012; 2019). However, this benefit seems to depend on proficiency in the already-learned language (see Cenoz, 2013 for a review) and on the recruitment of cognitive control processes (Bogulski et al., 2019). These benefits have primarily been studied when learning L3 vocabulary (e.g., Antoniou et al., 2016; Bartolotti et al., 2011; Bartolotti & Marian, 2012; Bice & Kroll, 2019; Bjork & Kroll, 2015; Bogulski et al., 2019; see Grey, 2020 for a review).

However, there is much less evidence of how being bilingual can affect grammar learning (Grey et al., 2018). Few studies using different procedures have explored the role of bilingualism in L3 grammar learning by comparing monolingual with bilingual/multilingual groups (Cox, 2017; Grey et al., 2018; Lado, 2008; Nation & Mclaughlin, 1986; Nayak et al., 1990), and they seem to suggest that the facilitative effect of bilingualism over L3 grammar learning might depend on the complexity of the linguistic materials and the learning conditions (Cox, 2017; Lado, 2008; Nation & Mclaughlin, 1986). For example, Nation and Mclaughlin (1986) presented letter strings following the rules of artificial grammar to three groups of monolinguals, bilinguals, and multilingual participants. Learners in the rule-search explicit condition were asked to discover the regularities of the presented letter strings, while learners in the implicit condition did not receive instructions to search for regularities.

After the learning session, participants answered a GJT, where they were asked to judge whether or not new strings followed the regularities from the artificial grammar. The results showed that under the implicit condition, multilingual participants had better performance in the GJT than bilinguals and monolinguals, whereas no differences between the groups were found after the explicit learning condition. By contrast, Nayak et al. (1990) found that multilinguals had more benefits after the rule-search explicit condition than monolinguals when learning word order regularities in an artificial language (see Grey et al., 2018 for similar results). The inconsistency between the results of the two studies (Nation & Mclaughlin, 1986 and Nayak et al., 1990) was attributed to the use of learning material that differed in complexity (letter string vs. word order) across studies. Learners might benefit more from having strong metalinguistic abilities to search for a rule when learning an artificial language (that requires mapping between words and grammar rules) than when simply learning the regularities behind the letter string order (artificial grammar). In a recent paper using an artificial language under explicit learning conditions, Grey et al. (2018) found that bilingual learners needed less time to learn the regularities than monolinguals. Interestingly, in the low proficiency stages of the learning process, bilinguals showed similar brain patterns to those previously found in native speakers (P600, Friederici & Mecklinger,1996).

Grey et al. (2018) suggested that previous successful experience with explicit learning strategies facilitated bilinguals to acquire native-like processing of syntactic information at an earlier stage. Overall, these studies suggest that high proficiency in L2 facilitates L3 learning relative to learners with no previous L2 learning experience (monolinguals). However, it is not clear whether this benefit was simply present when comparing bi/multilingual to monolingual learners at the end of the "proficiency continuum" or if there was some variance associated with individual differences in L2 proficiency. While many people might have access to L2 instruction, not everyone necessarily achieves high proficiency levels. Thus, people with high L2 proficiency might prove to have better metalinguistic abilities (Cenoz, 2013), but it is also possible that lower levels of proficiency and even the mere continuous exposure to an L2 environment give an advantage to learners as compared to people who have not previous experience with any language (Bice &

Kroll, 2019). The continuous nature of L2 proficiency has not been previously considered as an individual difference variable when learning an L3. Hence, we aimed to assess the role of L2 proficiency in L3 grammar learning and the extent to which taking L2 knowledge as a continuous variable might help clarify the differences in language learning between monolinguals and bilinguals.

Research on differences between monolinguals and bilinguals during L2 language performance has been traditionally associated with experience in recruiting cognitive control processes to solve competition between languages (Bogulski et al., 2019; Morales et al., 2013). According to the DMC framework (Braver, 2012), proactive and reactive control might be involved in many different situations. Concretely, proactive control, as an anticipatory goal selection, has a key role when monitoring distracting events even before they occur, minimizing interference from the environment, whereas reactive control acts as a corrective mechanism over any interference that could affect the goal (Braver, 2012). Proactive control is related to L2 proficiency as a modulatory factor (Mishra et al., 2012; Vega-Mendoza et al., 2015) and as a compensatory tool during language comprehension, reducing costs in L2 processing (Pérez et al., 2019).

Recently, Rivera et al. (in press) reported results indicating that proactive control benefited the learning of grammar rules under intentional conditions, where participants were asked to learn the regularities (grammar rules) of the presented sentences, although they were not informed of the actual rule (metalinguistic information). Interestingly, proactive control was not associated with explicit learning if the participants were informed of the actual rule to learn metalinguistic information before being presented with the sentences.

These patterns of results might suggest that proactive control is involved when participants are instructed to search for and learn regularities, but they are not told about the specific rule or regularity that they should learn, forcing them to test different hypotheses while reading the sentences (see Rivera et al., 2022; for similar results in older adults). However, it is also possible that under explicit conditions, when participants are informed about the rule and they should maintain it while reading the sentence, WM might be overloaded and mask the hypothetical benefits associated with the use of proactive strategies (Rivera et al., in press; Wiemers & Redick, 2018). Hence, these two hypotheses remain to be tested.

An additional finding in Rivera et al.'s experiment (in press) was that the role of proactive control on grammar learning was modulated by the characteristics of the material to be learned, so that the implication of proactive control was more evident when learning an easy than a more difficult grammar rule (see Gao & Ma, 2021 for similar results). Hence, it appears that the role of individual differences in successful learning might be modulated by extrinsic factors for the learner.

The role of complexity (the difficulty of the learning material) can be explained from the assumptions of the DP model (Ullman, 2016). According to the model, learning under explicit conditions might be affected by both the complexity of the material and the time of testing. Explicit learning involves declarative memory, which is characterized by conscious engagement of cognitive resources during the learning process. Thus, difficult materials and/or conditions might compromise these resources, which might even be overloaded. In line with this, previous results have reported that learning associated with explicit conditions depends on the complexity of the rule (Rivera et al, in press; Tagarelli et al., 2016). Specifically, the benefits associated with explicit/intentional learning appear to be strongly present when learning easy but not difficult material, both in natural (Rivera et al., in press) and semi-artificial languages (Rivera et al., 2022). In addition, explicit learning has been shown to be time dependent. Declarative knowledge decays at a faster rate than procedural knowledge, whereas procedural learning takes more time to consolidate but remains for a longer time (Ullman, 2004). Thus, it has been shown that learning under explicit conditions generates successful results at early stages of the learning process; however, those benefits are not long lasting (Ullman, 2016), suggesting that with time there is a decline in the retrieval of the declarative information acquired during learning (Ullman et al., 2020). However, previous research has manipulated time over the learning process (beginning, middle, or end of the training process), but to the best of our knowledge, no study has been directed to investigate the role of time of testing after the learning phase has ended (but see Rivera et al., in press). Because the complexity of the materials might modulate learning, we introduced complexity of the sentences (simple vs. complex) and time of testing (immediate and two weeks after the last training session) as variables in our study.

Thus, the purpose of the present study was to investigate the role of L2 proficiency and proactive control as intrinsic modulatory factors of grammar learning in explicit learning conditions. In addition, we manipulated the complexity of the sentences in the learning materials and the time of testing. We asked participants to learn a “Spanish dialect,” Japañol, over 5 days. Japañol is a semi-artificial language created with a Spanish lexicon and following Japanese syntax (see

Rivera et al., 2022 for details). Specifically, Japañol follows two rules: case markers and word order (i.e., the verb always goes at the end of the sentence). During each learning session, we explicitly presented participants with the metalinguistic information regarding the case markers and asked them to learn the rule by paying attention to the sample sentences in Japañol. During the learning sessions, participants were asked about the presence/absence of a case marker after each sentence. In addition, the complexity of the material was manipulated so that the rule appeared in simple (without subordinate clause) or complex sentences (with subordinate clause). After the fifth learning session (immediate) and two weeks later (delayed), the participants were asked to perform a GJT with grammatical and ungrammatical new sentences according to the case marker rule. We calculated a *d'* index representing the capacity of the participants to discriminate between grammatical (hits) and ungrammatical (false alarms) new sentences, showing the extent to which participants learned the rule (see method for details). Following this procedure, we expected to find better performance when answering to simple sentences compared to complex ones in the GJT, as has been previously indicated in the literature (Rivera et al., in press; Tagarelli et al., 2016). Regarding the testing time, we expected to find a decline in performance in the delayed time compared to the immediate time.

To explore the role of proficiency in the learning process, we tested late Spanish–English bilinguals from Spain. Proficiency was measured using the Michigan English Language Institute College Entrance Test (MELICET) as an objective proficiency measure previously used to assess proficiency in English literacy (see Kaan et al., 2020 and López-Rojas et al., 2022, for distinctions between low and high proficiency using this test). In this experiment, participants were not required to have a specific L2 language level for participation, and proficiency varied from low to high levels (see participants section for more details). We expected proficiency to modulate language learning since previous results have shown differences between monolinguals and bilinguals when explicitly learning new grammar (Grey et al., 2018). Specifically, we expected better learning (larger d') for higher L2 proficiency levels.

Finally, to explore the role of individual differences in cognitive control, participants performed the AX-CPT task (Braver & Barch, 2002), and we calculated the Behavioral Shift Index (BSI) for each participant (Braver, 2012). This index reflects the balance between proactive/reactive control at the individual and group levels. As mentioned, we were interested in disentangling the WM overload hypothesis from the hypothesis-testing-while-learning posed by Rivera et al. (in press). Thus, we hypothesized that if the role of proactive control was associated with WM overload, higher BSI scores (toward proactivity) would predict better performance when answering to simple questions compared to complex sentences. However, if the role of proactive control was only present when participants needed to test hypotheses in order to learn the regularities without metalinguistic information, no significant interactions would be found between BSI and *d'*, since participants were always told of the rule and no hypothesis testing was needed during the learning process.

Methods

Participants

The sample size for this experiment was estimated following the estimation calculated by Rivera et al. (in press, experiment 2). With 1,000 simulations, the simulation suggested a sample size of 80 to achieve 80% statistical power using the simr package in R (Brysbaert & Stevens, 2018). A total of 81 participants completed the experiment (M = 22.3; SD = 3.2). As a requirement, all participants were native speakers of Spanish who acquired English after the age of 4 (M = 6.29; SD = 2.3), with variable proficiency (from B1 to C1 according to the European Common Framework), as reported in a self-assessment questionnaire (using a 1–10 scale; in speaking, M = 7.18; SD = 1.84; reading, M = 8.22; SD = 1.59, and listening M = 7.89; SD = 1.71) and as was found in the MELICET test (with a score up to 50; M = 28.9; SD = 10.67). Participants received economic compensation for their participation. All tasks were programmed and ran on Gorilla.sc, an online platform for behavioral experiments (Anwyl-Irvine et al., 2020).

Materials

Experimental tasks: Learning and grammatical judgment tasks

Grammatical Rules and Learning Materials. A total of 500 sentences (100 sentences per day) were generated following two types of rules in a semi-artificial language system, Japañol (Spanish lexicon with Japanese syntax; Rivera et al., 2022). Japañol follows two specific rules from Japanese: 1) the case marker rule: there are three case markers depending on grammatical information: -ga for the subject, -o for the direct object, and -ni for the indirect object and 2) the word order rule: every sentence and clause ends with a verb, creating four different word orders grammatically correct. The word order structure can end up differentiating between simple sentences—Direct Object-Subject-Verb (OSV) and Direct Object-Subject-Indirect Object-Verb (OSIV)—and complex sentences involving subordinate clauses: Direct Object-Subject-[Subject-Verb]-Verb (OSSVV) and Direct Object-Subject-[Subject-Indirect Object-Verb]-Verb (OSSIVV). In all, 125 sentences were generated for each of the four word orders. Of the total of 500 sentences, half were plausible. The sentences were randomly presented, and all participants saw all sentences after 5 training days (100 sentences per day).

The participants were told that Japañol was a South American dialect of Spanish and that they were supposed to learn one specific rule (the case marker rule). Every day for 5 consecutive days, the participants started the session by reading the metalinguistic explanation of the rule. Once they read it, participants were instructed to read sentences and answer questions about the presence/absence (yes/no) of a specific case marker; half of the sentences had the specific marker asked in the question (participants answered "yes"), and the other half did not have it (participants answered "no"). Each sentence appeared on the screen for 10 s, and participants responded right after presentations. Although we did not record response times, participants were told to answer as quickly and accurately as possible.

Grammaticality Judgment Tasks. After the fifth day of training, participants were told that they would face a test on the just learned dialect and that all sentences presented during the 5 days were grammatically correct in the dialect. Participants needed to perform a grammaticality judgment test in which they had to respond (yes/no) to whether the sentences were grammatically correct. The test encompassed a total of 112 sentences: 32 were new sentences that followed the learned rules (new grammatical sentences), and the four word orders representing the rules were equally distributed (eight sentences per word order). Thirty-two were new sentences that did not follow the rule (new ungrammatical sentences), 16 missing a case marker and 16 having a case marker changed. Finally, 32 sentences were included as fillers. All sentences were randomly presented to the participants. Two different datasets were created with the same structure, and the order of presentation was counterbalanced between the participants and the testing sessions: immediately after the fifth learning session (Immediate) and 2 weeks later (Delayed).

Language proficiency measures

Language proficiency was measured using MELICET. In this test, participants had to complete 30 grammar questions and 20 cloze questions from a reading passage, with a total punctuation of 50 instances. Additionally, the participants responded to a self-assessment questionnaire based on the LEAP-Q questionnaire (Marian et al., 2007). They needed to provide some sociodemographic information as well as information about their educational level and style (public/private; monolingual/bilingual), and about their writing/reading/speaking skills, age of acquisition, and frequency of use in English. The results from this questionnaire were only used to describe the participants.

Cognitive Control Task: AX-CPT

In this version of the task (Ophir, et al., 2009), a set of 5 letters were shown in the middle of the screen following a specific presentation order, the first and the last one were printed in red, and the three middle ones were printed in black. The presentation of the letters created 4 different conditions: a) AX condition, when the first red letter presented was an “A” and the last red letter presented was an “X,” participants needed to answer ‘yes’; b) AY pattern, when the first red letter presented was an “A” but the last red letter presented was not an “X,” the correct answer was “no”; c) BX pattern, when the first red letter presented was not an “A” but the last red letter presented was an ‘X’, the correct answer was ‘no’; d) BY pattern, when neither the first letter was an “A” nor the last letter was an “X,” the correct answer was “no.” They also had to answer “no” during the middle letters (printed in black). The proportion of the patterns was 70% for the AX and 10% for any other pattern (AY, BX, or BY) from a total of 100 trials. This proportion is usually set to induce participants to pay attention to the context since it is highly predictive, and to use proactive control strategies. Participants performed a practice block representing the four experimental conditions in which participants were given feedback. After the practice block, they completed the experimental block (100 trials). Participants were asked to answer as quickly and accurately as possible. Trials were randomized for each participant. The letters were presented 300 ms in the center of the screen, with 4,900 ms between the presentation of the cue and the probe (printed in red), where the three distractor letters (printed in black) were presented for 300 ms with a 1,000 ms interval between them. The interval between trials was 1,000 ms.

Procedure

The experiment was divided into six sessions. Before each session started, participants logged into a zoom link where the researcher gave them instructions for the tasks and made sure that if anything went wrong, they would find the researcher in that zoom room, creating a "virtual laboratory." All tasks were programmed, and the experiment was run using Gorilla.sc (Anwyl-Irvine et al., 2020). During the first session, participants read and signed a consent form to participate in the experiment following the procedure evaluated and accepted by the ethics committee at University of Granada (817/CEIH/2019). Additionally, participants completed the self-assessment linguistic questionnaire and the MELICET test. Afterwards, they were told that the main goal of the experiment was to learn a dialect of Spanish for five consecutive days (including the first session). As mentioned, participants were explicitly informed about the case marker rule before presenting them with the sentences, and they were asked to respond (yes/no) whether a specific marker was in the sentence. The sentence remained on the screen for 10 seconds after a fixation point (300 ms). Then, the question appeared and remained on the screen until the participants' responded. To respond, the participants needed to press one of two keys on the keyboard (yes/no). For 5 consecutive days, participants were presented with 100 sentences per session and one cognitive task: the AX-CPT in the third session, and the alternating serial reaction time task (ASRT; Howard & Howard, 1997) in the fourth session. After the last learning session (the fifth), the participants were asked to answer an untimed GJT (Immediate). Finally, two weeks later, participants completed the delayed GJT and the CVMT task (Trahan &

Larrabee, 1988). Results from the ASRT and CVMT tasks are not reported in this paper since they were collected with a different aim, and they are the subject of another investigation.

Data analysis

Grammaticality Judgment Task

Performance was calculated following the detection theory (Hautus et al., 2021). First, the extent to which participants generalized the rule to new sentences was assessed by calculating a d' index: False Alarms (FA) on new ungrammatical sentences were subtracted from hits on new grammatical sentences (Rule-learning d'), indicating a more abstract representation of the rule. Differences from chance were calculated using a one-sample t-test between hits and FA (Table 1).

AX-CPT Task

For the AX-CPT, the data below 100 ms and 2.5 SDs over each participant's mean were filtered (Zirnstein, et al., 2018), for all participants (4.3%). Four participants lost more than 70% of their data, and one participant had AXerrors = 1. They were removed from the analysis. An index was calculated for the AX-CPT task, and the BSI was calculated as a combination of AY and BX trials (between errors and Response Time, RT; Braver et al., 2009). The index ranges from -1 to + 1, where scores near 0 show a balance between proactive and reactive control (1 more proactive/-1 less proactive).

English Proficiency Test – MELICET

Objective proficiency was calculated as the proportion of accuracy in the test. The variable was then normalized for the analysis.

Results

First, we analyzed the differences between FA and hits for each condition to assess overall learning, that is, whether participants were able to discriminate between grammatical and ungrammatical sentences. Results from the t-tests between FA and hits indicate that all participants discriminated between (new) grammatical and ungrammatical sentences beyond chance, both on simple and complex sentences (see the means and t-tests in Table 3).

Table 3.

Mean rates (SD) for d' scores. T-test reports for rule-learning d'

d' score	Explicit condition	
Rule Learning	Simple	Complex
Immediate	1.97(.86)	1.58(1.06)
t-test	$t\ (138) = 19.02$, $p < .001$, 95% CI [.52, .64]	$t\ (138) = 14.02$, $p < .001$, 95% CI [.42, .56]
Delayed	1.48 (1.55)	1.22(1.49)
t-test	$t\ (138) = 9.66$, $p < .001$, 95% CI [.35, .53]	$t\ (138) = 8.75$, $p < .001$, 95% CI [.29, .46]

Results of the ANOVA indicated that the main effect of Testing Time was significant, F (1, 206) = 12.04, p < .001. Better performance in the immediate GJT (M = 1.83; SE = .13) than in the delayed GJT (M = 1.41; SE = .13) was observed. The main effect of Complexity was also significant, F (1, 206) = 5.53, p =.02, with better performance when presenting the simple (M = 1.76; SE = .13) than the complex (M = 1.47; SE = .13) sentences. The interaction between Time and Complexity was not significant F (1, 183) < 1.

To explore the role of Language Proficiency (MELICET score) and Cognitive Control (BSI), and their interaction with sentence Complexity, independent linear mixed models were performed for each Testing Time (Immediate and Delayed GJT). The most complex model included two two-way interactions between Complexity and each of the continuous variables (MELICET score and BSI index). Participants were included as a random factor on the intercept.

We first fitted each model using the automatic function step from the stats-package, version 4.0.0 (R core 354 Team, 2020), specifying direction = “backward”. Thus, the most complex model started using maximum likelihood (ML). This function removes all meaningless predictors until it finds the model where all factors are statistically significant. The analyses were conducted using the lmer function of the lme4R-package, version 1.1-23 (Bates et al. 2015).

Immediate GJT

After fitting the model, the final model contained the main effect of BSI and the interaction between Complexity and MELICET score. Overall, the main effect of BSI showed that higher BSI predicts better performance (see figure 11). The main effect of Complexity and the interaction between Complexity and BSI were not significant (see table 11). However, the interaction between Complexity and MELICET scores showed significant differences between slopes ($\chi2$ = 5.19; *p = .02*). Participants with low proficiency had better scores when answering to simple than complex sentences. Additionally, proficiency positively predicted performance when answering to the complex ($\chi2$ = 9.76; *p = .003*) but not to the simple ($\chi2$ = 1.77; *p = .36*) sentences (see Figure 6).

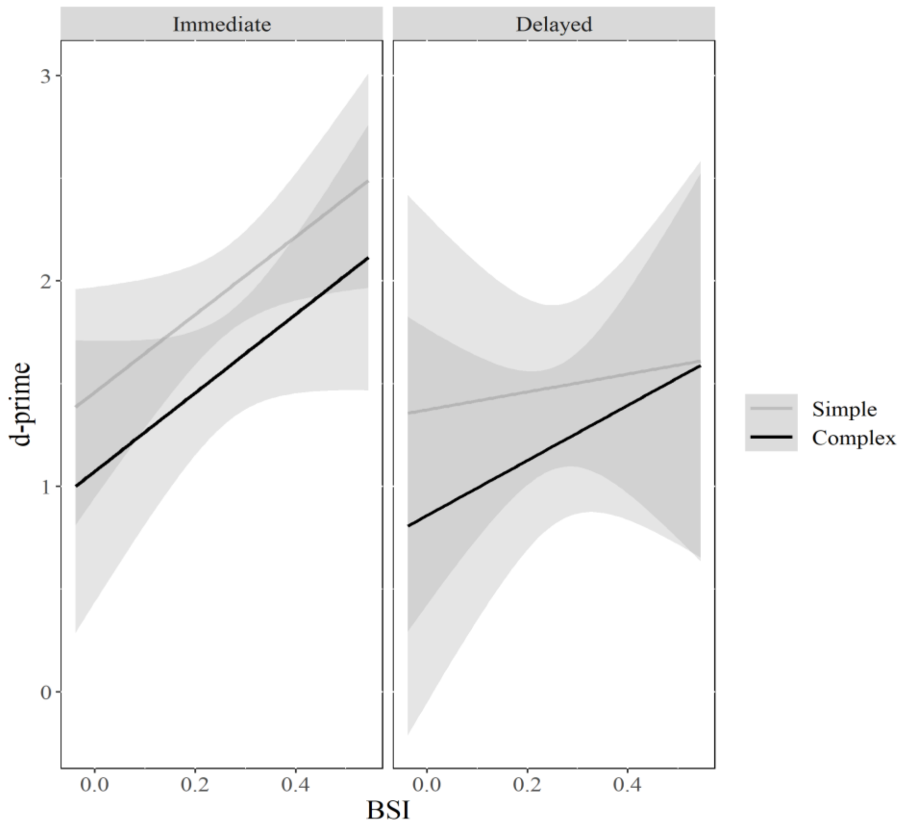

Figure 6. Rule-learning d' scores associated with BSI for simple and complex sentences for each GJT testing time. Highlighted areas represent Standard Error.

Delayed GJT

After fitting the model, the final model contained the interaction between Complexity and MELICET score, neither the main effect of BSI nor the interaction between Complexity and BSI was significant (see table 4).

While the main effect of Complexity was not significant, the interaction with the MELICET score showed a significant difference between slopes ($\chi 2$ = 4.98; *p = .02*). Showing that participants with low proficiency in L2 had better scores when answering to the simple than to the complex sentences, these differences were not evident for participants with high proficiency (see Figure 7).

Table 4.

Fixed effects from the LME model of rule learning d' per GJT time of testing.

Final model Immediate GJT					
Effect	Estimate	SE	T	CI 95%	p
Intercept	2.22	.19	11.34	1.84, 2.61	<.001***
BSI	1.66	.83	1.99	.02, 3.29	.04*
MELICET score	.35	.26	1.33	-.16, .87	.18
Complexity	-.05	.15	-.33	-.35, .25	.74
Complexity:MELICET score	.47	.21	2.28	.06, .88	.02*
Final model Delayed GJT					
Effect	Estimate	SE	T	CI 95%	p
Intercept	1.32	.33	3.94	.66, 1.98	<.001***
MELICET score	-.32	.45	-.72	-1.21, .55	.47
Complexity	.11	.18	.61	-.25, .47	.54
Complexity:MELICET score	.55	.25	2.23	.06, 1.04	.02

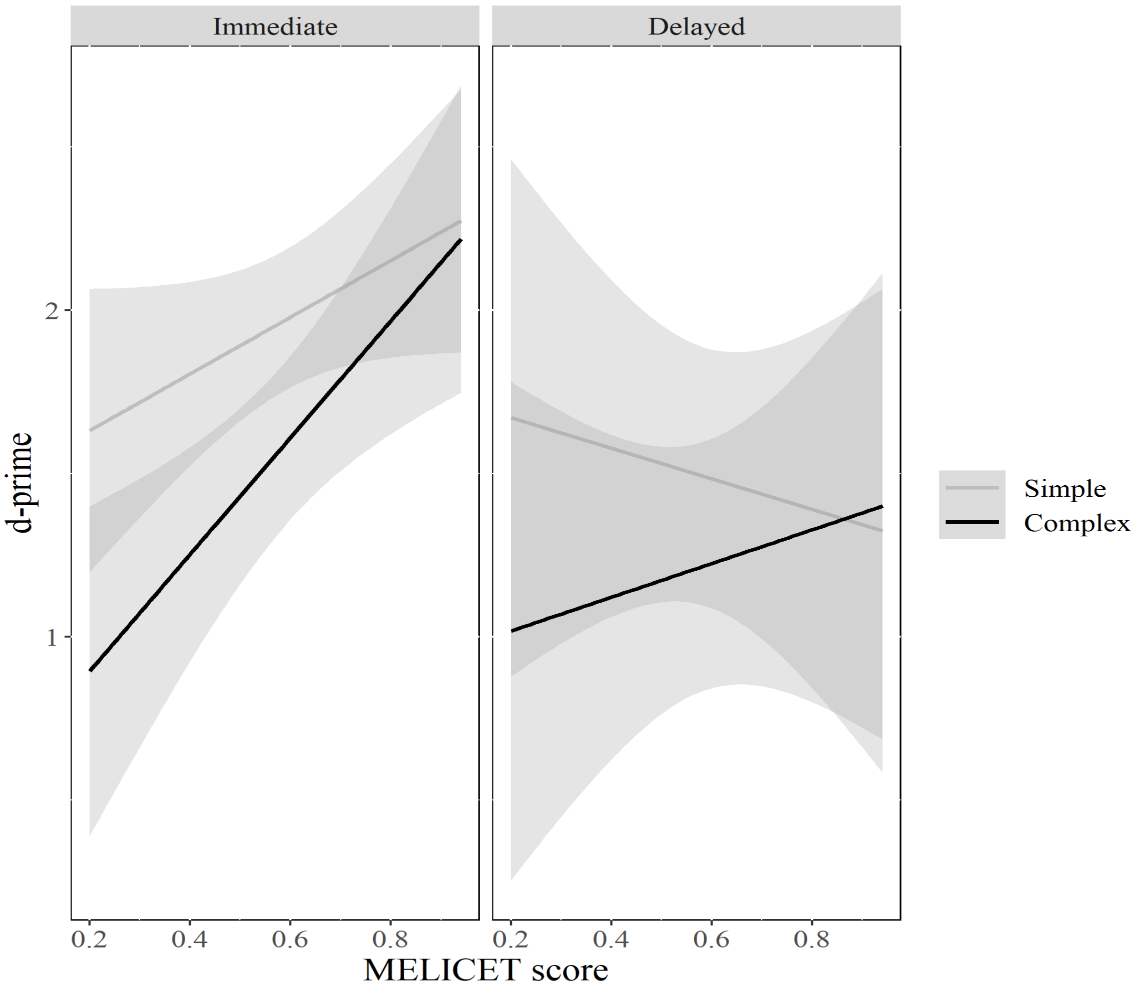

Figure 7. Rule-learning d' scores associated with MELICET score for simple and complex sentences for each GJT testing time. Highlighted areas represent Standard Error.

Discussion

The main goal of this experiment was to explore the role of both extrinsic (complexity and time) and intrinsic (individual differences in proficiency and proactive control) variables as modulatory factors of grammar learning under explicit conditions when learning a semiartificial language, *Japañol*. To do so, we tested explicit learning of one rule (case-marker) after receiving metalinguistic explanations and seeing sentences following that rule. The complexity of the material was manipulated by presenting simple (without subordinate clause) and complex (with subordinate clause) sentences both during learning and testing. Additionally, to test whether the effects of explicit learning were long lasting, participants performed the test both immediately and two weeks (delayed) after the last learning session. To account for the performance after learning, we calculated a *d'* index. Additionally, differences in proficiency and cognitive control were tested through different tasks.

First, regarding the role of extrinsic factors in L3 language learning, results showed that both complexity and time of testing affected performance in the GJT. Thus, participants showed better GJT performance when answering to simple (without subordinate clause) than to complex (with subordinate clause) sentences. The impairments associated with complex material when learning under explicit conditions have been previously reported by Tagarelli et al. (2016) (see Gao & Ma, 2021 for similar results), suggesting that the probability of explicitly learning regularities diminish for highly complex sentences (see Rivera et al., in press for similar conclusions). Additionally, the main effect of time of testing indicated better performance in the immediate compared to the delayed test. Thus, participants showed better GJT performance when being tested immediately after the last learning session than when they were tested two weeks later. This pattern suggests that learning under explicit conditions may lead to encoding and representing the grammatical regularities of the language in the declarative memory system which is usually associated with time decay (see Ullman, 2016 for similar conclusions). The independent effects of complexity and time suggest that the explicit learning procedure used in this experiment engaged declarative memory.

Second, we investigated individual differences and proactive control as intrinsic variables modulating language learning. Regarding proficiency, we found an interaction between proficiency and complexity for the immediate and delayed test. This interaction indicated that there were differences in performance for simple and complex sentences for participants with low L2 proficiency. Performance to simple sentences was better than performance for complex sentences. However, no differences were found for participants with high L2 proficiency (see figure 3). Additionally, L2 proficiency positively predicted performance when answering to complex sentences in the immediate test (but not when answering to simple sentences) indicating that L2 proficiency is a key variable in successful explicit learning (see Grey et al., 2018; Nayak et al., 1990 for similar results. Hence, our results seem to suggest that proficient knowledge of another language facilitates the use of metalinguistic information under explicit learning conditions and benefits learning. It is important to note that our participants had previous experience with explicit learning instructions since they all received English instruction during their school years. This suggests that the benefits associated with proficiency are not just due to participants receiving previous formal L2 training since all participants (low and high proficiency) underwent formal L2 language learning at school (although they varied in their further L2 experiences), but also to their better metalinguistic knowledge of how languages behave that can be used as a tool for language learning (Jessner, 2008; but see Nayak et al., 1990 for different conclusions).

Similarly, individual differences in proactive control were associated with better performance. However, differently from proficiency, BSI predicted GJT just in the immediate test, and independently of the complexity of the sentences. Specifically, higher scores in BSI (towards 1, proactive control) predicted better overall performance in the immediate GJT test. The fact that proactive control was recruited in conditions where participants did not have to continuously test hypotheses during learning (but see Morgan-Short et al., 2012), and where rule maintenance played a critical role, suggests that proactive control might be used for goal maintenance during learning and that this might be overloaded under very complex learning conditions. As mentioned, Rivera et al., (in press) reported proactive control to be related with learning in explicit conditions and simple sentences, and a reduction of this effect for complex sentences. Interestingly, participants in the Rivera et al., study learnt two rules (easy and difficult rule) during the learning phase, so the overall context was more complex than in the present experiment. Suggesting again that cognitive overload may underlie the presence or absence of proactivity effects. However, further research should be conducted to directly assess this interpretation by manipulating different difficulty levels and observing the relation between proactivity and learning. The fact that the role of proactivity was only evident in the immediate tests also suggests that proactive control predicts learning under conditions that mainly engage the declarative system as represented by the early moments after learning in a no too complex context (Ullman, 2016).

To summarize, we found that explicitly learning new grammar results in better performance when learning simple material and in early stages of the consolidation process. These results account for the recruitment of declarative memory in the process of learning, as proposed by the declarative/procedural model (Ullman, 2016). Additionally, we found that when declarative strategies are recruited, proactive control positively predicted successful learning. Hence it seems that both declarative and proactive strategies are interrelated in grammar learning. Finally, we found that proficiency also predicted successful learning in the immediate test and for complex material. In conclusion, this pattern seems to indicate that proficiency, and not just previous experience with language learning, is a key factor in successful explicit learning. However, the nature of the benefits associated with proficiency and cognitive control with successful grammar learning needs to be further explored.

Chapter 6. Cognitive and contextual factors modulating grammar learning at older ages[4]

Abstract

Second language learning has been shown more difficult for older than younger adults, however the research trying to identify the sources of difficulty and possible modulating factors is scarce. Extrinsic (learning condition and complexity) and intrinsic factors (executive control) have been related to L2-grammar learning in younger adults. In the present study, we aim to assess whether extrinsic and intrinsic factors are also modulating grammar learning in older adults. We compared the learning performance of younger and older adults in a L2 learning task. 162 Spanish native-speakers (81 young) learnt *Japañol* (Japanese syntaxis and Spanish lexicon) in either an intentional (metalinguistic explanation) or an incidental (comprehension of sentences) context. The complexity of the sentences was also manipulated by introducing (or not) a subordinate clause. Individual differences in proactivity were measured with the AX-CPT task. After the learning phase, participants

[4] The content of this chapter has been published as Rivera, M., Paolieri, D., Iniesta, A., Bajo, T. (2022). Cognitive and contextual factors modulating grammar learning at older ages. *Frontiers in aging neuroscience*, 979.

performed a Grammatical Judgment Task where they answered if the presented sentences were grammatically correct. No differences between older and younger adults were found. Overall, better results were found for the intentional-condition than for the incidental-condition. A significant interaction between learning context and the proactivity index in the AX-CPT task showed that more proactive participants were better when learning in the incidental-condition. These results suggest that both extrinsic and intrinsic factors are important during language learning and that they equally affect younger and older adults.

Keywords: Second Language Learning, Aging, Individual differences, Context of learning, Proactive Control.

Introduction

Learning a second language (L2) late in life has been shown to be a tool to access new social and cultural challenges in a globalized world (Pot, et al., 2019) as well as a source of cognitive enhancement (Bubbico et al. 2019). The benefits associated to language learning at older ages have been broadly studied, both after a brief exposure to a new language (Wong et al., 2019; see Nilsson et al., 2021 for a review) and after a lifetime of speaking more than one language (Bialystok et al., 2016; but see Papageorgiou et al., 2019 for a different view). However, the actual process of learning late in life and the differences to language learning in younger adults have been less investigated.

Aging is assumed to be related to cognitive decline (Park et al., 2002; Craik & Grady, 2009), due to structural changes in the brain (see Park & Reuter-Lorenz, 2008 for a review). Age-related impairments have been observed in executive functioning (EF, Craik & Bialystok, 2006; see Verssimo et al., 2021, for nuances), working memory (WM; Pliatsikas et al., 2019; Salthouse, 2009), declarative memory (Ullman, 2016; Ward et al., 2020) and intentional/explicit learning, where there is an intention to learn something (see Hedden & Gabrieli, 2004 for a review). However, the decline in incidental/implicit learning, that is learning without intention, is not so well documented (Ward et al. 2020). The existing studies have shown that implicit learning is less susceptible to aging than explicit learning (Ristin-Kaufmann & Gullberg, 2014); not only when motor skills are involved, but also during language learning (structural priming; Hardy et al., 2019; speech production; Muylle et al., 2021), and it is better preserved for older adults with greater cognitive abilities (Fu et al., 2020; Howard & Howard, 2013; Ward et al., 2020). Hence, the goal of this study is to investigate the possible role of cognitive abilities in intentional/explicit and incidental/implicit learning for older adults with a specifically focus on executive functions (EF), since previous studies with younger adults have shown that better EF skills might facilitate language learning (Kapa & Colombo, 2014).

EF refer to a domain-general set of mechanisms that control cognition and action to attain a specific goal (Miyake and Friedman 2012). An interesting theoretical framework in the context of aging (Braver and Barch 2002) and language use (Pérez, et al., 2018) is the Dual Mechanisms of Cognitive Control (DMC, Braver, 2012). According to this framework, two different cognitive control modes (proactive and reactive), as part of the EF set of mechanisms, may be put into work in different situations. Proactive control refers to anticipatory goal selection that minimizes interference before a distracting event occurs

(Braver 2012) and it is highly related to working memory (Unsworth et al. 2009). Reactive control can be understood as a late correction mechanism operating in a bottom-up manner to avoid interference once it has occurred. The interaction between these two control modes is dynamic so that people might differ in their use of the two control modes, and some situations may favor one mode over the other (Mäki-Marttunen, Hagen, and Espeseth 2019). Crucially, the AX-CPT (AX-Continuous Performance task; Ophir et al., 2009) has been designed to assess individual differences in the relative balance between proactive and reactive control. In this task, participants need to answer to a pair of cue/probe. Participants answer 'yes' when the cue is an A, and the probe is an X (AX trials) and 'no' in any other situation. Proactive and reactive control preference is calculated thanks to the combination of the AY (A-Cue, Y-probe) and BX (B-cue, X-probe) trials. For instance, BX trials can benefit from proactive but not reactive control and the opposite is found for AY trials, that benefit from reactive but not proactive control.

Differences in proactivity/reactivity as measured by the AX-CPT task have been related to age (Braver and Barch 2002), and therefore, they might also be related to older and younger differences in grammar learning. Results comparing younger and older performance in the AX-CPT task have shown that younger adults typically rely on proactive control more than older adults who tend to use more reactive control strategies (Braver et al. 2009). This pattern has been attributed to the high cognitive demand associated to proactive control (Braver 2012) and the difficulties of older adults to maintain the relevant contextual information needed to reduce contextual interference in advance (Braver & West, 2008; Xiang et al., 2016). Therefore, contrary to younger adults, older adults may compensate their reduced ability for proactive strategies by using more reactive strategies when learning a new language. Additional studies have found that older adults with a cognitively active daily live (reading, playing instruments, having high education…), hence with high cognitive reserve, might use the same strategies than younger adults both cognitively (Stern, 2009) and during learning (Gajewski et al. 2020). As mentioned, proactive control has been related to language use (Pérez, et al., 2018) and to language learning (Rivera et al, in press), and, it is, then, possible, that variations in cognitive control may play a key role predicting grammar learning in incidental/implicit and intentional/explicit learning contexts. If this was the case, the pattern of individual differences in grammar leaning might differ for younger and older adults. However, no study to date has tested the influence of proactive/reactive strategies during grammar learning in older adults.

Many of the studies comparing incidental/implicit and intentional/explicit language learning in young adults have used semi-artificial and artificial grammar learning (AGL) where participants are assumed to learn grammatical rules implicitly or explicitly. During AGL, participants are exposed, and sometimes instructed, to memorize letter sequences that follow a particular rule (Reber 1967). After the learning phase, participants are informed that the sequences followed rules and they are asked to classify new letter sequences as grammatical or ungrammatical based on this information. In many cases, participants are not informed or aware of the regularities conforming the grammatical rule while being exposed to them (implicit/incidental learning), whereas in intentional/explicit conditions, they might be informed about the existence of a rule or even explicitly informed of the specific nature of the rule and asked to learn it for further testing. Overall, studies using semi-artificial and artificial grammar learning (see Goo et al., 2015 for a meta-analysis) report that participants (usually young adults) obtain better results from intentional than incidental learning, suggesting that metalinguistic knowledge enhances learning.

Interestingly, experiments comparing older and younger adults in artificial grammatical learning have shown that older adults show impaired performance during intentional learning relative to the younger adults, however, these differences are reduced or not evident during incidental learning (Kürten et al. 2012). For instance, Midford and Kirsner (2005) created four conditions in which the complexity of the artificial grammar and the explicit or implicit nature of the instruction was varied. Across experiments these conditions were tested in older and younger adults: a) in the first experiment, the presented letter strings conformed a complex grammar system, and participants did not receive instructions or explanations about the rules; b) in the second experiment, the same complex grammar system was used but participants received detailed instructions to understand the grammar structure; c) in the third experiment, the presented strings conformed a simple grammar system, and participants did not receive instructions about the rules; and d) in the last experiment, the strings conforming the simple grammar system were presented, and participants received instruction with detailed explanation about the grammatical system. After the training phase, all participants performed a test judging whether the presented sequences were or not grammatically correct, and finally, they were asked to report the strategies that they might have used during the test (memory/guessing). Overall, younger adults were more accurate than older adults. Additionally, they found an interaction between age and grammatical rule-complexity, indicating that younger adults were more accurate when learning an easy grammar rule than older adults, however, these differences were not evident for difficult grammar learning. An additional interaction between grammatical rule-complexity and instructions also indicated better performance when explicit instructions were given for simple grammar learning than when participants were not given learning instructions (implicit), however, these differences were not found for complex grammar learning.

The similar performance of older and younger participants in the implicit learning of complex grammatical rules suggests that implicit learning might be preserved in older adults (Midford and Kirsner 2005). Additionally, analyses of self-reported strategies indicated that both groups used explicit strategies (memory) when the rule was easy or explicitly presented. However, they tended to use implicit strategies (guessing) when the rule was complex or implicitly presented. This pattern also suggests that older adults are less effective than younger adults in their use of explicit strategies, but that implicit strategies might be efficiently used by the older adults since learning differences with the younger adults where not evident in conditions where these strategies were required (implicit complex conditions) and used (Midford and Kirsner 2005). More recent data also indicate that older adults seem to relay more on incidental than intentional learning strategies (see Wagnon et al., 2019 for a review). Since older adults have a notable decay in declarative memory, the differences between younger and older adults in language learning might also be related to the cognitive resources available to the participants, so that age related impairments in cognitive resources might reduce the efficacy of intentional strategies in explicit/intentional learning conditions (Ingvalson et al., 2017).

Individual differences in cognitive abilities might, then, be an important factor modulating grammar learning in incidental and intentional conditions. Individual differences in cognitive processes (Luque and Morgan-Short 2021), including WM (Faretta-Stutenberg and Morgan-Short 2018), declarative/procedural learning/memory skills (M. Fu and Li 2021; Morgan-Short et al. 2012) and EFs (Kapa & Colombo, 2014; Rivera et al., in press) have been related to language learning in young adults. Since there have been found age related differences in the cognitive control (Braver & West, 2008), in the present study we will focus on proactive cognitive control as a possible source of individual differences that might underlie the age-related differences in grammar learning.

The main goal of this experiment was to investigate whether differences between younger and older adults would be observed during intentional and incidental learning of a semi-artificial grammar. Additionally, we wanted to explore the influence of extrinsic (instruction and difficulty of the grammatical rules) and intrinsic factors (individual differences in proactive/reactive control) in the learning process and whether the influence of these factors change between the two age groups. With this aim, we presented older and younger participants semi-artificial simple and complex sentences following a rule of the semi-artificial grammar Japañol: Spanish lexicon with Japanese syntax (see Maie & Dekeyser, 2020 for a similar procedure using English lexicon with Japanese syntax called Japlish). In the incidental condition, participants were presented with the sentences and asked to answer comprehension questions about them, whereas in the intentional condition, they were informed about the rule before being presented with the sentences. The rules appeared in simple (without subordinate clause) or in complex sentences (with subordinate clause). After the learning session, participants were asked to perform a Grammatical Judgment test (GJT) with grammatical and ungrammatical new sentences. These sentences were used to calculate a rule-learning d' index representing the capacity of the participants to discriminate between grammatical (hits) and ungrammatical (false alarms) new sentences, and therefore, the extent to which participants have learnt the rule. As it was previously found by Midford and Kirsner (2005), we expected better performance in the intentional than in the incidental condition. More importantly, we predicted that younger adults in the intentional conditions would have better performance (higher rule-learning d') than older adults for both simple and complex sentences, whereas in the incidental conditions, the differences between younger and older adults might not be evident, especially for complex sentences (where procedural strategies are expected).

In addition, to explore the role of individual differences, participants were asked to perform the AX-CPT task (Braver and Barch 2002) and we calculated the BSI index for each participant (see below for a detailed explanation of how BSI is calculated; Braver, 2012). This index reflects the balance between proactive/reactive control at an individual and group level. As mentioned, previous research has shown differences between younger and older adults in the task with younger adults showing better performance and better proactive control (Braver et al. 2009). Similarly, Rivera et al. (in press) in the context of grammatical learning task, showed that proactive control was positively related to rule-learning in an intentional context where participants were informed of the presence of a regularity (although the particular rule was not explicitly stated). Even though the conditions of the present experiment were different to this previous study (Rivera et al., in press), we hypothesized that proactivity would be related to better intentional learning which requires maintaining the explicit goal to learn the rule in mind (proactive control). We also expected that, overall, older adults would show reduced proactive control as compared to their younger counterparts, and that this, in turn, might be related to reduced performance under intentional conditions. If this was the case, we would also observe that the differences between older and younger adults would diminish for older participants with higher proactive control.

Our predictions regarding incidental conditions were less precise since proactive and reactive control might play different roles during incidental learning. On the one hand, proactive control has been related to enhanced responsiveness to contextual cues which might also help to detect language regularities even under incidental conditions. On the other hand, proactive control is cognitively demanding, and it might only be put to work when participants attempt to learn the materials in a motivated and intentional manner and not when participants' attention is focused on understanding the sentences in the incidental condition. In the latest situation, the less demanding reactive control might be advantageous.

Method

Participants

The sample size for this experiment was calculated a priori to estimate the sample. The expected power of fixed-effects was calculated a priori using the simr package in R (Brysbaert and Stevens 2018). The effect-size was planned on a pilot study with 10 participants, and the minimum requirement was estimated through powerCurve function (alpha=0.4). With 1,000 simulations, the simulation showed a sample size of 134 to achieve 100% statistical power. A total of 162 participants completed the experiment; 81 old adults (M=66; SD=4.7) and 81 young adults (M=21.4; SD=4.8). As a requirement, all of them were native speakers of Spanish with low proficiency in any other second language (B1 or lower according to the European Common Framework), as reported in a self-assessment questionnaire. Participants in each age group were randomly assigned to either the intentional or the incidental learning condition. No differences in age and formal education were found between participants in any of the conditions (all ts<1; see table 5). Additionally, to rule out any possible mild cognitive impairments in older adults, we tested them with an online adaptation of the Seven minutes test (7MT) (Solomon et al., 1998; Spanish version; Ser Quijano et al., 2004) (from a maximum of 45 points: M=28.59; SD=8.26; being 22 or less is a sign of decline). In addition, we created a Sociodemographic and Daily Life questionnaire (based on Scarmeas & Stern, 2004), to assess their cognitive reserve (M = 2.34; SD = 1.18; from a maximum score 5); no differences between conditions of learning, $t < 1$. Overall, our older participants were cognitively active in their daily life. Although the mean cognitive reserve score was medium, 92% of them assured to read in their daily basis. Participants received course credit for their participation, or a raffle ticket for a 25€ card on an online shopping website. All tasks were programmed and ran in Gorilla.sc, an online platform for behavioral experiments (Anwyl-Irvine et al. 2020)

Table 5.

Socio-demographic information extracted from the LEAP-Q questionnaire. Mean (SD) of age and years of formal education for young and old participants

Group	Condition	Age	Formal education (Years)	Cognitive Reserve
Young	Intentional	22.7 (35.28)	17.58 (3.92)	-
	Incidental	20.1 (1.20)	17.41 (2.07)	-
Old	Intentional	66.68 (4.86)	23.68 (15.75)	2.34 (1.11)
	Incidental	65.3 (4.56)	20.27 (11.16)	2.35 (1.27)

Materials

Experimental Tasks: Learning and Grammaticality Judgement Test

Grammatical Rules and Learning Materials. A total of 100 sentences were generated following two types of rules in a semi-artificial language system. Our semiartificial language Japañol (Spanish lexicon with Japanese syntax) is an adaptation of Japlish (English lexicon with Japanese syntaxis) previously used in other experiments (Williams & Kuribara, 2008). We used the rules used by Maie and Dekeyser (2020) in their simple and complex word order modification. According to these rules, every sentence and clause ends with a verb and there are three case markers depending on grammatical information: -ga for the subject, -o, for the direct object, and -ni for the indirect object. Four different word orders are grammatically correct in Japanese. Two of these word orders were included in simple sentences of the forms: Direct Object-Subject-Verb, (OSV) and Direct Object-Subject-Indirect Object-Verb (OSIV); the other two word orders were included in complex sentences involving subordinate clauses: Direct Object-Subject-[Subject-Verb]-Verb (OSSVV) and Direct Object-Subject-[Subject-Indirect Object-Verb]-Verb (OSSIVV). Twenty-five sentences were generated for each of the four word-orders. From the total of 100 sentences, half of the sentences were plausible. The sentences were randomly presented, and all participants saw all sentences during the training phase (See Appendix 1 for examples).

For both intentional and incidental learning contexts, participants were told that Japañol was a South American dialect of Spanish. In the incidental condition, participants were told to read the sentences one by one and respond (yes/no) whether the presented sentence was plausible. They were told that the purpose of this task was to know if the 'dialect' was easy to understand for native speakers of Spanish. In the intentional condition, the word order and case marker rules were explicitly explained to the participants before asking them to read the sentences one by one and to respond a question about the presence/absence (yes/no) of a specific feature of the rule after each sentence; half of the sentences had the specific feature asked in the question (participants answered "yes") and the other half did not have it (participants answered "no") (see Figure 1). Each sentence appeared on the screen for 10 seconds and participants responded right after presentations. Although we did not record response times, participants were told to answer as fast and accurate as possible.

Grammaticality Judgement tasks (GJT). After training, participants in the incidental condition were told that the sentences were grammatically correct and that they all followed the rules of the dialect. Additionally, all participants were told that they needed to perform a grammaticality judgment test where they had to respond (yes/no) whether the sentences were grammatically correct. The test encompassed a total of 112 sentences: 32 were previously studied during the training phase (studied; half were plausible); 32 were new sentences that followed the learned rules (new grammatical plausible sentences; all were plausible). For both, studied and new grammatical sentences, the four word-orders representing the rule were equally distributed (eight sentences per word order). Finally, 48 were new sentences that did not follow the rules (new ungrammatical sentences) with eight sentences violating each of the four learned word orders, eight missing a case marker and eight having a case marker changed. All sentences were randomly presented to the participants.

Executive function tasks

AX-CPT task. As mentioned, the AX-CPT tasks has been widely used to assess proactive and reactive control strategies (Locke and Braver 2008). In this version of the task (Ophir, et al., 2009), a set of 5 letters were shown in the middle of the screen following a specific presentation order, the first and the last one were printed in red, and the three middle ones were printed in black. The presentation of the letters created 4 different conditions: a) AX condition, when the first red letter presented was an ‘A’ and the last red letter presented was an ‘X’, participants needed to answer ‘yes’; b) AY pattern, when the first red letter presented was an ‘A’ but the last red letter presented was not an ‘X’, the correct answer was ‘no’; c) BX pattern, when the first red letter presented was not an ‘A’ but the last red letter presented was an ‘X’, the correct answer was ‘no’; d) BY pattern, when neither the first letter was an ‘A’ nor the last letter was an ‘X’, the correct answer was ‘no’. They also had to answer ‘no’ during the middle letters (printed in black). The proportion of the patterns was: 70% for the AX; and 10% for any other pattern (AY, BX or BY), from a total of 100 trials. This proportion is usually set to induce participants to pay attention to the context since it is highly predictive, and to use proactive control strategies. Participants performed a practice block representing the four experimental conditions where participants were given feedback. After the practice block, they completed the experimental block (100 trials). Participants were asked to answer as fast and accurately as possible. Trials were randomized for each participant. The letters were presented 300ms in the center of the screen, with 4900ms between the presentation of the cue and the probe (printed in red) where the 3 distractor letters (printed in black) were presented for 300ms with a 1000ms interval between them. The interval between trials was 1000ms.

Procedure

Due to restrictions as a result of the COVID-19 pandemic, all tasks were programmed, and the experiment was run using Gorilla.sc, an online platform for behavioral experiments (Anwyl-Irvine, et al., 2020). The experiment was divided in two sessions. During the first session, participants learned the rules. As mentioned, in the incidental condition, participants were told to read each sentence and respond if the sentences were or not plausible. In the intentional condition, participants were explicitly informed about the rules before presenting them with the sentences and they were asked to respond (yes/no) whether a specific feature of the rule was in the sentence (see figure 8). For both intentional and incidental conditions, the sentence remained on the screen for 10 seconds after a fixation point (300ms). Then, the question appeared, and remained on the screen until the participants' response. To respond, participants needed to press the mouse over one of the two boxes that appeared on the screen (yes/no boxes; see figure 8). Finally, the AX-CPT and the control tasks were presented in the second session. Before each session, participants were contacted by phone to walk them through the Gorilla platform and make sure that if anything went wrong, they would call the researcher.

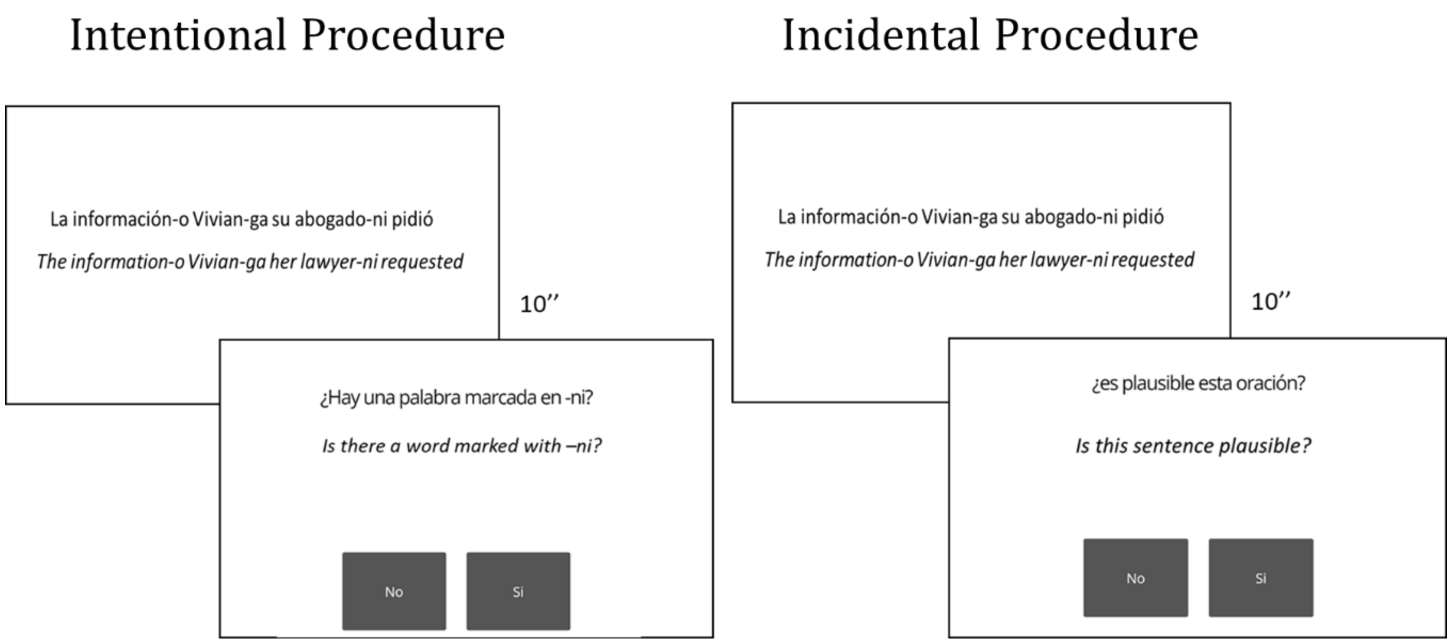

Figure 8. Learning task conditions: Incidental and Intentional

Data Analysis

Grammaticality Judgment Task

Performance was calculated through discrimination d' scores (Hautus, et al., 2021). The extent to which participants generalized the rule to new sentences was assessed by calculating a d' index: False Alarms (FA) on new-ungrammatical sentences were subtracted from hits on new-grammatical sentences (Rule-learning d'), indicating more abstract representation of the rule. Secondly, and for sake of completeness, a d' was calculated for the studied sentences, by subtracting FA on new-ungrammatical sentences from hits on studied-grammatical sentences (Episodic-recognition d'); this represents knowledge of the exact sentences they were trained with. Studied implausible sentences (n=16) were considered as fillers and not included in the analyses. Differences from chance were calculated using one-sample t-test between hits and FA (Table 6). Additionally, following signal detection theory (Hautus et al., 2021), we calculated the response criterion index (β) as a measure of response bias. High values of β indicate that participants are using a conservative criterion for "yes" response, whereas lower β values indicate a more lenient criterion when responding "Yes".

Executive Function Tasks

For the AX-CPT, the data below 100ms and 2.5 SDs over each participant's mean were filtered (Zirnstein, et al., 2018), for young (5.4%) and old (3.5%) adults. An index was calculated for the AX-CPT task, the Behavioral Shift Index (BSI) was calculated as a combination of AY and BX trials (between errors and Response Time, RT; Braver et al., 2009). The index goes from -1 to +1, where scores near 0 show a balance between proactive and reactive control (1 more proactive/-1 less proactive).

Results

First, we analyzed the differences between False Alarms and Hits for each condition to assess overall learning, that is if participants were able to discriminate between grammatical and ungrammatical sentences. Results from the t-tests between FA and hits, indicate that young participants discriminated between grammatical (new) and ungrammatical sentences beyond chance, both on simple and complex structures after incidental and intentional learning. However, old adults were not able to discriminate beyond chance on complex structures after incidental learning (see means and t-tests on Table 6).

Rule learning d' main model

Analyses on rule learning were performed using linear mixed-effects models. We first fitted each model using the automatic function step from the stats-package, version 4.0.0 (R core Team, 2020), specifying direction = "backward". Thus, the most complex model started with using maximum likelihood (ML). This function removes all meaningless predictors until it finds the model where all factors are statistically significant. The analyses were conducted using the lmer function of the lme4R-package, version 1.1-23 (Bates et al. 2015).

Table 6.

Mean rates (SD) for d' scores and t-tests between hits and FA.

		Young Group		
d' score	Incidental condition		Intentional condition	
	simple	*complex*	*simple*	*complex*
Rule Learning	.88 (1.43)	.25 (.70)	2.81 (1.49)	1.74 (1.23)
T-test	*t* (43) = 4.57, *p* < .001, 95% CI [.13, .34]	*t* (43) = 2.82, *p* =.007, 95% CI [.02, .15]	*t* (36) = 12.37, *p* < .001, 95% CI [.59, .82]	*t* (36) = 8.92, *p* < .001, 95% CI [.39, .63]
Episodic Recognition	.97 (1.42)	.26(.69)	2.70 (1.53)	1.80 (1.49)
T-test	*t (*43) = 5.06, *p* < .001, 95% CI [.15, .37]	*t* (43) = 11.89, *p* = .013, 95% CI [.01, .14]	*t* (36) = 11.35, *p* < .001, 95% CI [.57, .82]	*t* (36) = 7.43, *p* < .001, 95% CI [.37, .65]
		Old Group		
	simple	*complex*	*simple*	*complex*
Rule Learning	.36 (.98)	-.12 (.60)	2.21 (1.61)	.63 (1.11)
T-test	*t* (45) = 3.48, *p* = .001, 95% CI [.05, .19]	*t* (45) = -.761, *p* =.451, 95% CI [-.06, .02]	*t* (34) = 8.07, *p* < .001, 95% CI [.40, .67]	*t* (34) = 3.44, *p* =.002, 95% CI [.07, .30]
Episodic Recognition	.38(.87)	.13 (.64)	2.23 (1.62)	.53 (1.31)
T-test	*t* (45) = 4.38, *p* < .001, 95% CI [.07, .20]	*t* (45) = 1.606, *p* = .115, 95% CI [-.01, .09]	*t* (34) = 8.221, *p* < .001, 95% CI [.42, .71]	*t* (34) = 2.37, *p* = .023, 95% CI [.02, .28]

To explore the role of the different factors on rule learning, condition (intentional/incidental), age (young/old), rule-complexity (simple/complex) and BSI (continuous variable) were included in the model as fixed factors. Participants were included as a random factor on the intercept. After fitting the model, the final model contained the interaction for condition and rule-complexity, condition and age, and condition and BSI (see table 7).

Table 7.

Fixed effects from the LME model of rule learning d'.

Final model					
Effect	Estimate	SE	t	CI 95%	p
Intercept	-.24	.20	-1.21	-.63, .14	.22
Condition	1.12	.31	3.61	.51, 1.72	<.001***
Complexity	.60	.12	4.80	.35, .84	<001***
Age	.26	.23	1.13	-.19, .72	.25
BSI	1.07	.61	1.75	-.12, 2.26	.08·
Condition:Complexity	.71	.19	3.84	.35, 1.08	<.001***
Condition:Age	.81	.35	2.29	.12, 1.51	.02*
Condition:BSI	-2.08	.91	-2.28	-3.88, -.29	.02*

* $p < .05$; *** $p < .001$

Overall, participants showed better performance in the intentional (M = 1.95; SE = .13) than in the incidental condition (M = .41; SE = .12) and rules in simple sentences (M = 1.56; SE = .12) were learned better than rules in complex sentences (M = .64; SE = .12). No significant main effect of age was found. All significant main effects were modulated by higher level interactions (see table 8). The learning condition x rule-complexity interaction showed better performance for the simple sentences both in the intentional, t (144) = -8.84, p < .001 and incidental, t (144) = -4.11, p < .001 conditions. However, the differences between simple and complex sentences were larger in the intentional (1.31) than in the incidental (.6) condition. The learning condition x age interaction showed better performance for young participants than for older adults in the intentional t (144) = -3.96, p < .001, but not in the incidental condition, t (144) = -1.11, p = .68. Crucially, the learning condition was also modulated by a higher interaction with BSI, where the differences between slopes were significant ($\chi 2$ = 4.98; p = .02). In the incidental condition, BSI was close to significance, t (138) = 1.96 p= .05. However, no significant significance was found in the intentional condition, t (138) = -.43 p= .067. As can be seen in figure 9, larger BSI scores (BSI towards 1) predicted higher d' learning scores in the incidental condition. As seen in Figure 10, this pattern of results was similar for younger and older participants since the three-way interaction with age was not significant.

Table 8.

d' mean and Standard Deviation per condition of learning, age group and complexity.

Intentional condition			
	Young	Old	Overall
Simple	2.9 (.19)	2.16 (.22)	2.6 (.15)
Complex	1.77 (.19)	.57 (.22)	1.29 (.15)
Overall	2.34 (.17)	1.38 (.21)	
Incidental condition			
	Young	Old	Overall
Simple	.90 (.18)	.49 (.19)	.71 (.14)
Complex	.26 (.18)	-.05 (.19)	.11 (.14)
Overall	.58 (.15)	.22 (.17)	

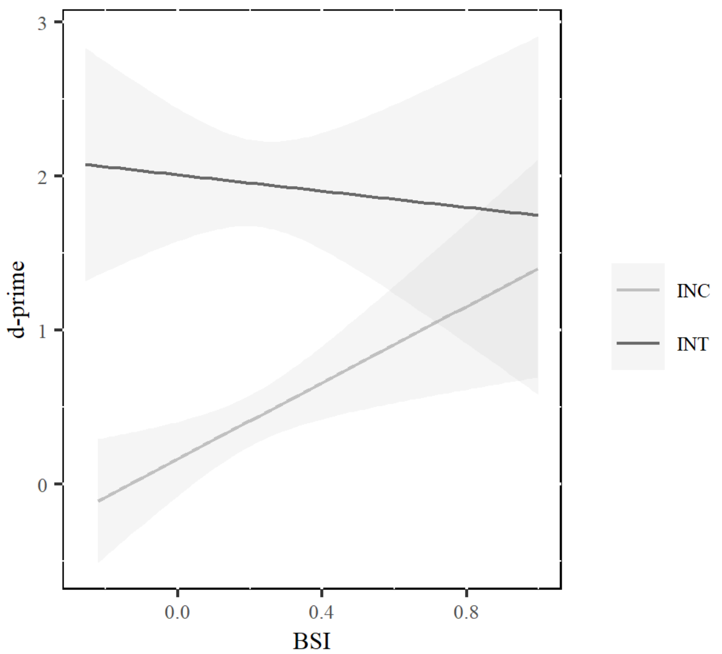

Figure 9. Rule-learning d’ scores associated to BSI for incidental (INC) and intentional (INT) conditions. Highlighted areas represent Standard Error.

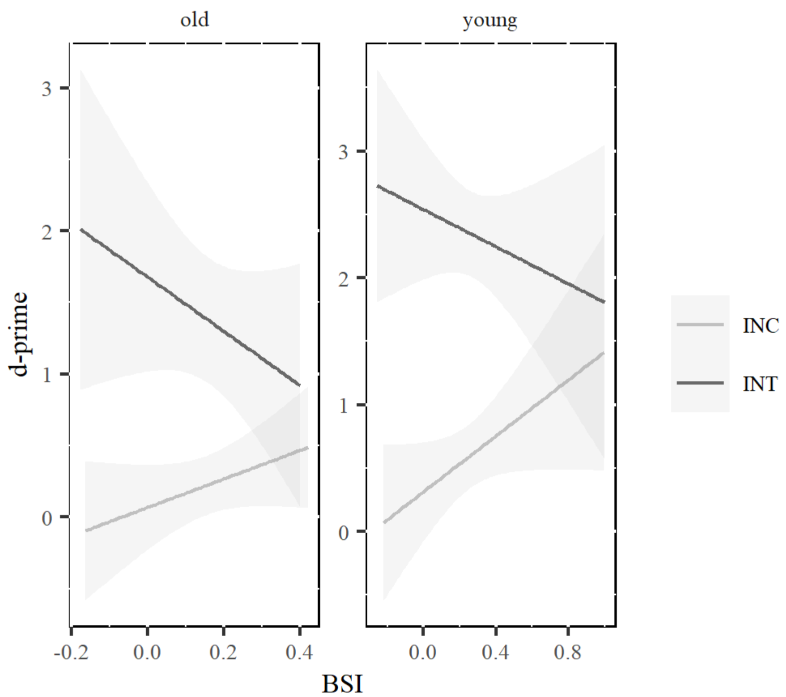

Figure 10. Rule-learning d’ scores associated to BSI for incidental (INC) and intentional (INT) conditions, in younger (right) and older (left) adults. Highlighted areas represent Standard Error.

Rule learning β main model

No significant main effects of condition, age, complexity, or BSI were found. However, the three-way interaction between learning condition x age x complexity (see Table 9) showed that in the intentional condition, the younger group has a more conservative criterion ($M = 7.99$; $SD = .95$) than the older group ($M = 2.08$; $SD = 1.16$) when learning the more difficult sentences $t(62) = 3.8$, $p = .001$. In contrast, no differences were found between younger and older participants for the incidental condition $t(148) = -1.12$, $p = .67$. When learning simple sentences, no significant differences were found for the intentional $t(63) = -.18$, $p = .99$ nor the incidental $t(148) = -.54$, $p = .94$ condition.

Table 9.

Fixed effects from the LME model of rule learning β.

Final model					
Effect	Estimate	SE	t	CI 95%	*p*
Intercept	.17	.66	.26	-1.12, 1.47	.79
Condition	1.91	1.04	1.83	-.12, 3.95	.07
Complexity	-.37	.89	-.42	-2.11, 1.37	.68
Age	.42	.91	.47	-1.35, 2.21	.67
Condition:Complexity	-1.49	1.39	-1.07	-4.2, 1.22	.28
Condition:Age	5.48	1.38	3.97	2.77, 8.18	<.001***
Complexity:Age	-.22	1.22	-.18	-2.61, 2.16	.85
Condition:Complexity:Age	-5.41	.84	-2.94	-9.01, -.18	.003**

* p < .05; *** p < .001

Discussion

The main goal of this experiment was to explore the role of both extrinsic (complexity and time) and intrinsic (individual differences in proficiency and proactive control) variables as modulatory factors for grammar learning under explicit conditions when learning a semi-artificial language, Japañol. To do so, we tested the explicit learning of one rule (case marker) after receiving metalinguistic explanations and seeing sentences following that rule. The complexity of the material was manipulated by presenting simple (without subordinate clause) and complex (with subordinate clause) sentences both during learning and testing. Additionally, to test whether the effects of explicit learning were long lasting, participants performed the test both immediately and 2 weeks (delayed) after the last learning session. To account for performance after learning, we calculated a d' index. Additionally, differences in proficiency and cognitive control were tested using different tasks.

First, regarding the role of extrinsic factors in L3 language learning, the results showed that both complexity and time of testing affected performance in the GJT. Thus, participants showed better GJT performance when answering to simple sentences (without subordinate clause) compared to complex (with subordinate clause) ones. The impairments associated with complex material when learning under explicit conditions have been previously reported by Tagarelli et al. (2016) (see Gao & Ma, 2021 for similar results), suggesting that the probability of explicitly learning regularities diminishes for highly complex sentences (see Rivera et al., in press for similar conclusions). Additionally, the main effect of time of testing indicated better performance in the immediate test compared to the delayed test. Thus, participants showed better GJT performance when being tested immediately after the last learning session than when they were tested two weeks later. This pattern suggests that learning under explicit conditions may lead to encoding and representing the grammatical regularities of the language in the declarative memory system, which is usually associated with time decay (see Ullman, 2016 for similar conclusions). The independent effects of complexity and time suggest that the explicit learning procedure used in this experiment engaged declarative memory.

Second, we investigated individual differences and proactive control as intrinsic variables that modulate language learning. Regarding proficiency, we found an interaction between proficiency and complexity for the immediate and delayed tests. This interaction indicated that there were differences in performance for simple and complex sentences for participants with low L2 proficiency. Performance for simple sentences was better than performance for complex sentences. However, no differences were found for participants with high L2 proficiency (see Figure 10). Additionally, L2 proficiency positively predicted performance when answering to complex sentences in the immediate test (but not when answering simple sentences), indicating that L2 proficiency is a key variable in successful explicit learning (see Grey et al., 2018; Nayak et al., 1990 for similar results. Hence, our results appear to suggest that proficient knowledge of another language facilitates the use of metalinguistic information under explicit learning conditions and benefits learning. It is important to note that our participants had previous experience with explicit learning instructions, since they all received English instruction during their school years. This suggests that the benefits associated with proficiency are not just due to participants receiving previous formal L2 training, since all participants (low and high proficiency) underwent formal L2 language learning at school (although they varied in their further L2 experiences), but also to their better metalinguistic knowledge of how languages behave. This knowledge can be used as a tool for language learning (Jessner, 2008; but see Nayak et al., 1990 for different conclusions).

Similarly, individual differences in proactive control were associated with better performance. However, in contrast to proficiency, BSI predicted GJT only in the immediate test, and independently of the complexity of the sentences. Specifically, higher scores in BSI (toward 1, proactive control) predicted better overall performance in the immediate GJT test. The fact that proactive control was recruited in conditions where participants did not have to continuously test hypotheses during learning (but see Morgan-Short et al., 2012) and where rule maintenance played a critical role suggests that proactive control might be used for goal maintenance during learning and that this might be overloaded under very complex learning conditions. As mentioned before, Rivera et al. (in press) reported proactive control being related to learning in explicit conditions and simple sentences and a reduction of this effect for complex sentences. Interestingly, participants in the Rivera et al. study learned two rules (the easy and difficult rules) during the learning phase, so the overall context was more complex than in the present experiment. This suggests again that cognitive overload may underlie the presence or absence of proactivity effects. However, further research should be conducted to directly assess this interpretation by manipulating different difficulty levels and observing the relationship between proactivity and learning. The fact that the role of proactivity was only evident in the immediate tests also suggests that proactive control predicts learning under conditions that mainly engage the declarative system as represented by the early moments after learning in a not too complex context (Ullman, 2016).

To summarize, we found that explicitly learning new grammar results in better performance when learning simple material and in the early stages of the consolidation process. These results account for the recruitment of declarative memory in the process of learning, as proposed by the DP model (Ullman, 2016). Additionally, we found that when declarative strategies were recruited, proactive control positively predicted successful learning. Hence, it seems that both declarative and proactive strategies are interrelated in grammar learning. Finally, we found that proficiency also predicted successful learning in the immediate test and in complex material. In conclusion, this pattern seems to indicate that proficiency, and not just previous experience with language learning, is a key factor in successful explicit learning. However, the nature of the benefits associated with proficiency and cognitive control in successful grammar learning needs to be further explored.

PART 3:

General discussion and conclusions

Chapter 7. General discussion and conclusions

Given the social, educational, and professional relevance of proficient multi-language use in our society, as well as the great challenge that language learning sometimes presents during adulthood, this dissertation focused on understanding grammar learning in adults and the role of different intrinsic (i.e., individual differences in cognitive abilities) and extrinsic (i.e., learning condition) factors in grammatical rule learning. These extrinsic and intrinsic factors and their interactions have been identified as key during language learning, specifically in vocabulary and artificial grammar learning. In our experimental section, we developed a frame in which different factors (interacting between them) were investigated with the aim of understanding the relation between cognitive individual differences and successful grammar learning in adult learners.

To test grammar learning, we measured the capacity of the learners to generalize the regularities from the learning phase to new sentences. In particular, we calculated a discrimination index (d' scores) that represented the capacity of our participants to differentiate new grammatical from new ungrammatical sentences during a GJT. The results of the experimental section will now be summarized to create a complete picture of the implications of the results in the language learning research field. To facilitate understanding, we first discuss the results associated with the main effects and simple interactions between the extrinsic factors, and then focus on the role of individual differences under different learning environments.

The role of extrinsic factors

Following the DP model (Ullman, 2004;2016;2020), the role of extrinsic factors is essential to recruit the cognitive strategies to successfully acquire a language, and they have been extensively studied in the language learning literature (see Spada & Tomita, 2010 for a meta-analysis on the topic). Hence, the results derived from the manipulation of the learning condition, the to-be-learned material, or the testing time are important to frame the role of cognitive abilities in successful grammar learning. Across experiments, we manipulated the learning condition, the difficulty/complexity of the to-be-learned material, and the testing time, and some interesting conclusions were extracted from the manipulation and interactions.

From simple exposure to receiving metalinguistic information about the to-be-learned material, the results of our experiments regarding learning conditions provide additional evidence to the already existing literature on the relative advantage of intentional/explicit over incidental/implicit learning conditions and to the interaction with other extrinsic factors (DeKeyser, 2005; Goo et al., 2015; Williams, 2009). Thus, across conditions and in different experiments, we varied the explicitness of the instructions given to the learners. Therefore, in some experiments, in the incidental condition (Experiments 1, 2, and 4), participants were given instructions to comprehend a set of sentences during the learning phase, and to answer (yes/no) to comprehension questions on the presented sentences, without awareness of a subsequent test on the grammatical regularities present in those sentences, whereas in the intentional condition (experiment 1), participants were asked to read a set of sentences in English and to learn the regularity that all of them were sharing. Hence, participants' attention was focused on discovering the regularities shared by the sentences. Additionally, in the explicit condition (Experiments 2, 3, and 4), participants were informed at the beginning of the training that the goal of the learning session was to learn some rules, and they were also provided with metalinguistic information conforming to the rules to learn. Hence, we manipulated the awareness and information that the participants received to learn the rules.

Overall, participants under the intentional and explicit conditions performed better in the GJT than participants in the incidental condition. These results are in line with the literature on language learning, showing that when an adult is given explicit instructions to learn, they have better learning results than when they are not aware of the learning process (Goo et al., 2015 for similar conclusions). However, in Experiment 2 (Chapter 4), the results indicated that this main effect was modulated by an interaction with difficulty. In experiment 2, the difficulty was manipulated by presenting easy or difficult English rules to the learners (as rated by experts). As in previous experiments, we found that learning under explicit conditions generated significantly better learning, as measured by GJT performance, than learning under incidental conditions, but this advantage was only present when learning easy rules, and not when learning difficult rules.

Previous studies in the literature have also indicated that differences in difficulty/complexity are less evident under incidental than under intentional/explicit learning conditions, suggesting that demanding difficult materials and rules seems to recruit procedural memory where less effortful cognitive processes are engaged (Ullman, 2016). Interestingly, in Experiment 4 (Chapter 6), where we manipulated the complexity of the sentences and participants learned two rules in Japañol, both explicit and incidental learning were better for simple sentences than for complex sentences, but the differences were reduced in the incidental condition. The overall pattern of results and the difference between Experiments 2 and 4 regarding complexity and learning condition might have to do with the nature of the to be learned materials. Thus, whereas in Experiment 2, the sentences were from a language with low familiarity for the participants, in Experiment 4, Japañol was used, which is based on the L1 lexicon of our participants (Spanish). This might have generated some awareness for participants even though they were in an incidental condition, thus reducing the differences between the two learning conditions. Hence, the characteristics of the to-be-learned material might also be important in modulating the relationship between complexity and learning conditions.

Finally, we manipulated the testing time. Hence, across experiments, grammatical knowledge through the GJT was assessed immediately after the learning session (Experiments 1, 2, 3, and 4), after 24 h (Experiments 1 and 2), or 1 week (Experiment 2) or two weeks (Experiment 4) from the last learning session. Comparisons across experiments indicated no differences for the shorter delays between training and test (Experiments 1 and 2), that is, from periods ranging from 24 hours to a week. However, there were differences when comparing the immediate test with the 2-week delayed GJT test (Experiment 3), where we found significantly better performance for the immediate GJT after the learning session than for the 2-week delayed GJT. This effect of time was not general since differences between the 2-week delay and the immediate test only appeared when learning of the rules was explicit. This pattern suggests that, as predicted by the procedural/declarative framework, declarative knowledge is more prone to be acquired under explicit conditions, and once acquired, it is more susceptible to decay with time than procedurally acquired knowledge (incidental conditions). Our pattern also suggests that declarative knowledge does not have a fast decay since we only found its effect after a 2-week delay. However, more research is needed to pinpoint the relationship between the level of acquisition after training, declarative knowledge, and decay with time.

The role of intrinsic factors

A second relevant aspect of our results has to do with the interaction between the extrinsic factors (discussed in the previous section) and intrinsic factors, such as individual differences in proactive/reactive control, previous linguistic experience, and aging. Extensive evidence associates individual differences in successful language learning with the role of personality traits (Derakhshan et al., 2022), motivation to learn (Pawlak et al., 2022), differences in DP memory (Morgan-Short et al., 2014), or WM (Faratta-Stutenberg & Morgan-Short, 2018). For instance, research on the role of declarative and procedural memory skills in grammar learning has found differences in the recruitment of declarative or procedural strategies to be affected by extrinsic factors for the learner (Carpenter, 2008; Hamrick, 2015; Morgan-Short et al., 2014). However, there has been little research on the role of executive control and language learning, despite the large body of research that relates executive control and bilingualism (Bialystok, 2010; Bobb et al., 2013; Kroll, 2015; Pliatsikas & Luk, 2016).

According to the DMC framework (Braver, 2012), two modes of executive control, proactive and reactive control, vary between people and contexts. These two types of control might be involved in different ways when learning a new language. Thus, proactive control is assumed to be involved in the early selection and monitoring of relevant information toward the goal, and it might be key in maintaining the goal of "learning a new rule" when instructed and in monitoring the sentences for regularities. Likewise, reactive control is assumed to oversee corrective mechanisms when there is competition with the given goal, reacting to a grammar error after being committed, and it has been portrayed as a predictor of L2 proficiency (Luque & Morgan-Short, 2021).

As mentioned, proactive and reactive control have been shown to vary depending on some features of the context and of the individual. For example, a large number of studies have shown that younger adults are more prone to use the more effortful proactive control mode, whereas older adults often use the less demanding reactive control mode (e.g., Braver & Brach, 2002). Similarly, language experience has been shown to modulate proactive/reactive control so that proficient bilinguals seem to better adjust their control strategies to the demands of the task (e.g., Morales et al., 2013, 2015). The fact that proactive and reactive control may be differentially involved in different language learning and may also vary with language experience and age makes it relevant to investigate the possible interaction of these variables during language learning. For this reason, an important goal of our experimental section was to shed light on these interactions.

In the present section, we summarize the relevant findings of the four experiments involved in this dissertation and the theoretical implications of these results for the language learning literature. We will discuss the role of individual differences in proactive/reactive control, previous linguistic experience, and aging in different learning environments as intrinsic modulatory factors. Importantly, we will discuss the role of those intrinsic factors in interaction with the different extrinsic factors that we found relevant for new grammar learning: learning condition, difficulty/complexity, and testing time.

Proactive/reactive control and learning conditions

To facilitate understanding, we plotted a summary of the main results regarding these variables in Figure 11. From more to less information provided to our learners, we employed three different learning conditions in our experiments: explicit (Experiments 2, 3, and 4), intentional (Experiment 1), and incidental (Experiments 1, 2, and 4) learning condition. Across the experiments, we observed complex interactions between our extrinsic and intrinsic variables. To organize our discussion, we will present our results in different subsections corresponding to different learning conditions.

Intentional/explicit learning conditions

According to the declarative/ procedural learning model (Ullman 2001, 2004; 2016; 2020), the intention to learn involves the declarative system. Hence, we assumed that instructions to learn either by themselves (intentional conditions) or accompanied by further information about the to-be-learned rules (explicit conditions) engaged the declarative system.

Consequently, our overall prediction was that strong proactive control would facilitate the maintenance of the goal (to learn the rule) and the goal-relevant information. However, the results from our experiments showed a more complex and nuanced pattern. In Experiment 1, participants in the intentional condition were instructed to learn the regularities underlying the structure of a set of sentences in English, although they were not informed of the particular form of these regularities. In this condition, and as expected, higher BSI (more proactive control) was associated with better performance in the GJT. However, in experiment 2, where we introduced two rules (easy and difficult) and participants were provided with information about the specific rule to learn (explicit condition), BSI was not related to rule learning (performance in GJT).

Following these unexpected results, we hypothesized that the different learning patterns between Experiments 1 and 2 might be due to two possible factors in which the two experiments differed. First, it was possible that the more difficult context of Experiment 2, where two rules have to be learned, increased the cognitive demands (the rules have to be maintained in mind to identify them during the presentation of the sentences), and this increment may have discouraged the engagement of the costlier proactive strategies and reduced the influence of proactive control. Second, it was also possible that proactive control might be differentially involved when people needed to monitor the sentences to identify possible grammatical regularities without really knowing the features defining the rule. That is, under the intentional condition of Experiment 1, because participants did not know the specific rule to learn, they might have been testing different hypotheses during the presentation of the sentences, and this hypothesis testing process might be facilitated by proactive control. Because the two hypotheses (high cognitive demands or hypothesis testing) might explain the pattern of results, in Experiment 3, participants were asked to learn one of the rules of the Japañol language, and they were provided with explicit information about the rule to be learned in this new language (Japañol). Our predictions were that if hypothesis testing underlies the relation between intentional/explicit learning and proactive control, proactive control would not be predictive of learning. Contrary to this prediction, the results indicated that proactive control did predict grammar learning in Japañol. Hence, these results contradict the "testing hypothesis" explanation since participants were explicitly instructed and informed of the specific features of the rule to be learned and suggest that the cognitive load might be a better explanation of the pattern of results obtained. Thus, with simpler contexts and rules, proactive control seems to predict intentional learning independently of whether participants need to identify the rule or are given previous information about it.

The fact that in the more difficult conditions of Experiments 2 and 4, the relation between proactive control and learning was not evident provides support for this hypothesis. Since proactive control is highly dependent on WM (Mäki-Marttunen et al., 2019), proactive control might not be recruited in high WM-demanding conditions. Although this interpretation provides an account of our data, further research with different difficulty/complexity manipulations is needed to better explore the influence of cognitive control during language learning with and without an overloaded WM system.

Incidental learning condition

Interestingly, according to the DP model (Ullman, 2001, 2004, 2016, 2020), the role of difficulty/complexity is tight up with the recruitment of the procedural memory system during learning, which is also related to the absence of intention and awareness during the learning process.

However, the hypotheses related to the role of cognitive control under implicit/incidental conditions were less clear. Since learning under implicit/incidental conditions is understood as an effortless process of learning that does not involve attention toward the to-be-learned regularities, the role of proactive control might be less evident under these circumstances, where perhaps the recruitment of reactive control is more useful.

In our experiments, the incidental condition was defined by the instructions to the participants to comprehend the sentences, and by the lack of information regarding the rule or the goal to learn the grammar rule (in English or Japañol). Across experiments, proactive/reactive control showed different patterns in our incidental conditions.

Thus, Experiments 1 and 2 indicated that proactive/reactive control interacted with the complexity of the rules. Hence, when learning easy rules in English, cognitive control did not play a role in incidental grammar learning, as measured by the GJT. However, when learning a difficult rule, lower proactivity was associated with better grammar learning (experiment 2). As mentioned, proactivity might be recruited as a mechanism to maintain a goal (i.e., comprehend and answer questions about the sentences) and to focus on the information relevant to the goal, which in the case of our incidental condition was "the meaning of the sentence" (Braver, 2012). It could be that participants with high proactive control strategies paid attention to the meaning at the cost of sentence structure, as it was part of the "goal-irrelevant" information. Hence, when they were asked later to discriminate between grammatical and ungrammatical sentences in the GJT, they might have a harder time than low-proactive individuals. By contrast, participants with less proactive and less focused type of control may perceive both the meaning and the form of each sentence at the same level, and then, they might be able to acquire the grammatical regularities in the sentences to a greater extent than participants with high proactive control. However, because learning easy rules does not need extra resource recruitment to be achieved, cognitive control did not affect learning success (see Tagarelli et al., 2016 for similar results).

Although this interpretation is in line with previous results by Tagarelli et al. (2016), we were puzzled by the results in Experiment 4, where high proactivity was found to benefit the incidental learning of two rules in Japañol. Proactive control has also been associated with context monitoring to anticipate interference from irrelevant information to the goal (Braver, 2012). Hence, it might also be possible that the recruitment of proactive control made the participants get involved in unconscious learning of regularities, resulting in better learning of the regularities than participants with less proactive resources available.

In an attempt to explain these conflicting results, we propose that they can be explained if we take into account the nature of the languages. In Experiment 2, we used a language with low familiarity to the participants, whereas in Experiment 4, the language involved the lexical information of the participants' native language. Hence, it is possible that our learners of Japañol suffered from strong interference from Spanish, and this might recruit proactive control to avoid interference. Research on bilingualism has found that proactive control was implicated in L1 language control when using an L2 (Green & Abutalebi, 2013). In the same way, if participants are aware of these similarities and have available cognitive resources, it could be the case that controlling the activation of the competing L1 is one of their goals during the learning phase. Then, even if they are not asked to learn the regularities of Japañol, learners acquire them thanks to their use of proactive strategies to control the similarities between this language and Spanish. In that case, participants with strong proactive control might be testing hypotheses on the differences and similarities between both languages to a greater extent than those without strong proactive control (see Morgan-Short et al., 2012 for similar conclusions). Obviously, these explanations are post-hoc and speculative, and they need to be put to a test before establishing stronger conclusions; however, they provide a framework for the complex interaction between extrinsic and intrinsic factors in language learning.

In sum, our results in the incidental condition suggest that when we do not have the intention to learn, proactive/reactive control might be recruited depending on the nature of the language to be learned (difficulty of the rules or strong L1 interference). Hence, when the language is not based on the participants' L1 and the rules to learn are difficult, recruiting reactive control is more beneficial than recruiting proactive control. On the other hand, when the language is based on the participants' L1, the recruitment of proactive control benefits from testing the differences between both languages and controlling the interference associated with the L1. Further research should be directed to replicate this pattern and further support our underlying assumptions.

The recruitment of proactive/reactive control has been found to be modulated by other factors intrinsic to the learner. For instance, individual differences in linguistic experience (learning an L2) are related to the efficient use of both proactive and reactive control (Morales et al., 2013, 2015), and research comparing younger and older adults has concluded that, while younger adults tend to use proactive strategies when needed, older adults are prone to use reactive strategies even when proactive control would be more beneficial (Braver & Barch, 2002). Hence, since linguistic experience and aging constitute populations with different experiences using cognitive control, we decided to explore their role during new grammar learning. In the next sections, we discuss the results found for individual differences in previous linguistic experience and aging.

Previous linguistic experience

As mentioned, previous linguistic experience provides the learner with the efficient use of proactive/reactive strategies, and with tools that facilitate language learning, as can be the ability to reflect on the regularities of a language to be learned (Jessner, 2008) or to inhibit competitors from the L1 (Bogulski et al., 2019). Hence, we hypothesized that the learner's previous linguistic experience might have a beneficial key role when learning a new grammar under explicit conditions. Hence, in addition to the role of proactive/reactive control, the role of previous linguistic experience was explored in Experiment 3, where participants were exposed just to the explicit learning condition and needed to learn one rule in Japañol. Since all our participants had formal education in L2 (English), in this experiment, we focused on the interaction between L2 proficiency (measured with the MELICET test) and successful L3 grammar learning.

Differences between multi/bilingual and monolingual participants have already been explored in the context of language learning (Cox, 2017; Grey et al., 2018; Nation & Mclaughlin, 1986; Nayak et al., 1990). However, they have always been studied as a categorical variable (monolingual vs. bilingual). Because numerous studies have shown that different bilingual experiences and proficiency may act as a "continuum" and predict performance in different tasks, we decided to assess language proficiency and take it as a continuum to predict L3 grammar learning. The results of Experiment 3 indicated that individual differences in L2 proficiency interacted with the complexity of the sentences to predict successful grammar learning (performance in the GJT task). On the one hand, lower proficiency was found to better predict GJT performance for simple sentences than for complex ones both in the immediate and delayed tests. Additionally, proficiency was found to predict learning for complex sentences in the immediate test. Thus, more proficiency in the L2 benefited participants in learning the rules associated with complex sentences. Hence, previous L2 language experience appears to be used as a tool for explicit language learning (Jessner, 2008).

These results are the first to show the role of proficiency as a continuum for participants with the same previous experience, and they are, therefore, quite relevant to the field. However, there are a number of questions that need further investigation. First, it would be important to test whether the benefits are only present when the L2 and L3 learning conditions match (i.e., explicit L2 learning – explicit L3 learning) or whether the acquired metalinguistic knowledge is also useful under incidental conditions. Likewise, it would be interesting to test whether a population that learned their L2 in an incidental manner (i.e., heritage speakers) would have successful learning under explicit conditions or, on the contrary, the absence of explicit recruitment of metalinguistic resources during L2 learning would lead to them having no benefits as compared with people learning their L2. Hence, our finding of a relationship between language experience and L3 language learning can help open up a new line of research on the modulatory role of L2 proficiency as related to the learning condition of both L2 and L3.

Aging

According to the literature, aging is a relevant variable in the recruitment of proactive/reactive control. Specifically, it seems that older adults tend to use reactive strategies more than younger adults (Braver & Barch, 2002) due to a cognitive decline (Marcotte & Ansaldo, 2014). Hence, since proactive strategies are effortful, people with cognitive decline are more prone to recruit less effortful reactive strategies to perform a given task independently of whether the requirements of that task would benefit from the use of proactive strategies. Since we found proactive/reactive control to have a different role in new grammar learning under different conditions, we aimed to explore the possible effect of aging (a population that tends to use reactive strategies) in grammar learning. Hence, we hypothesized that aging would be a relevant variable during new grammar learning. More specifically, following previous literature, we expected younger adults to be significantly better when learning new rules under explicit conditions than older adults, and to find that these differences would be reduced under incidental conditions, where proactive control may be less relevant.

The role of aging was explored in Experiment 4, where participants were exposed either to the incidental or explicit (labeled as intentional in the paper, Chapter 6) learning condition to learn two rules in Japañol. The results of the experiment showed differences in aging in terms of learning condition. Younger adults were able to better learn the regularities than older adults under the explicit learning condition; however, no differences in aging were found under the incidental learning condition. Similar results were found by Midford and Kirsner (2005), who showed better performance in the GJT for younger than older adults under an intentional learning condition. In contrast to Midford and Kirsner's results, we found that older adults obtained some benefits from being exposed to the metalinguistic information of the regularities in the explicit learning condition, showing better learning under the explicit than the incidental learning conditions.

Specific to our older adult population was that all of them were cognitively active (cognitive reserve), which might benefit their recruitment of cognitive resources in the explicit learning condition. Therefore, while the older adults had less proactive control than the younger adults, both groups had the same influence of proactive/reactive control in the learning process. Hence, although we expected an interaction between proactive/reactive control and the aging group and that older adults would depend on reactive control to a higher extent than younger adults when learning the new rules, we did not find this interaction probably because the older adults in our experiment had available resources to recruit proactive control due to their high cognitive reserve. Thus, older and younger adults had similar benefits when recruiting proactive control during the incidental learning of Japañol.

Hence, we might conclude that having an active lifestyle in aging benefits grammar learning under explicit conditions and the presence of proactive control strategies during incidental conditions. However, more studies are necessary to test the real implication of cognitive reserve in grammar learning and to see to what extent learning under incidental conditions, more than under explicit conditions, could generate successful learning in populations with a cognitive decline associated with low cognitive reserve.

Conclusions

As learning a new language is a struggle for some adults but not for others, this work aimed to explore the complex interaction between intrinsic and extrinsic factors for the learner when learning new grammar. The main goal of this experimental work was to frame how successful grammar learning was associated with the recruitment of cognitive control under different learning conditions. While cognitive control is an essential tool in memory, attention, and learning, this dissertation is the first attempt to uncover it as an important variable in new grammar learning and one of the first steps to consider cognitive control abilities to be relevant when designing a language course program. Hence, perhaps implementing cognitive control training to be more efficient in the recruitment of proactive/reactive strategies when needed might be, in the long term, beneficial to generate successful grammar learning under different circumstances.

Interestingly, cognitive control can be modulated by the differences associated with the learner. For instance, previous linguistic experience has been found to benefit the flexible recruitment of cognitive control (Morales et al., 2013, 2015), while aging is associated with a decline in the recruitment of proactive control (Braver & Barch, 2002). Thus, as we explored the role of those differences in adult learners, we found previous linguistic experience (L2 proficiency) to benefit and aging to impair new grammar learning under explicit conditions. Therefore, we conclude that in a classroom-like setting (explicit learning), differences between learners may be present to a larger extent than in an immersion-like setting (incidental learning).

The conclusions extracted from this dissertation open the door to a better understanding of the role of proactive and reactive control in new grammar learning, but more importantly, this evidence needs to be treated as an example of the complexity associated with successful learning in adult populations.

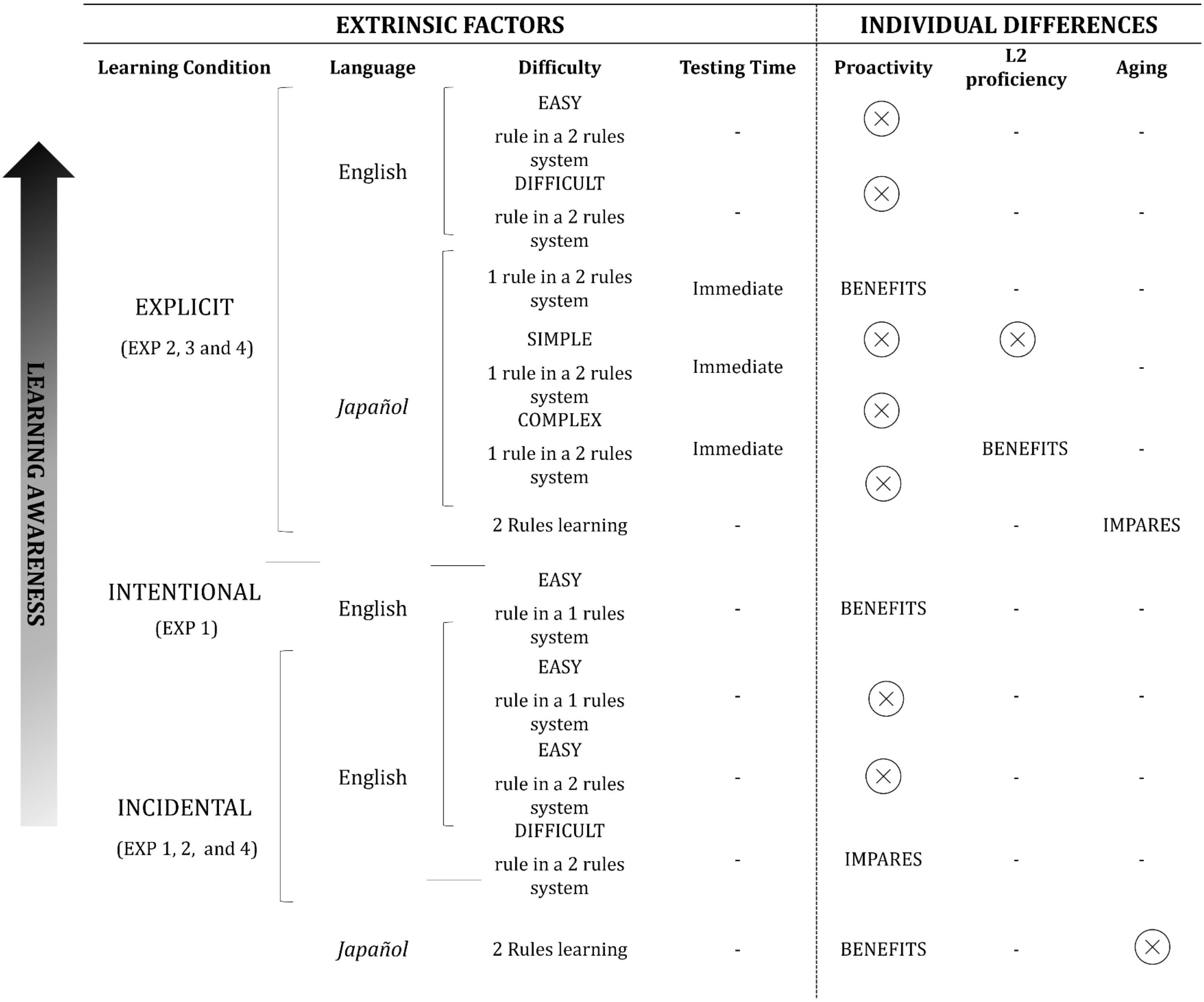

Figure 11. Summary of the role of individual differences in grammar learning (as measured by d' discrimination index in the GJT) in terms of the interaction with the extrinsic factors manipulated in this dissertation.

Capítulo 8. Resumen y conclusiones

En la sociedad actual el aprendizaje de idiomas resulta imprescindible en el desarrollo educativo, profesional, y social. En especial, en España el aprendizaje de inglés se ha instalado como prioritario, lo que ha dado lugar al desarrollo de programas de educación multi/bilingües en los ciclos de educación primaria y secundaria. Sin embargo, el aprendizaje de idiomas durante la adultez se ha observado más complejo y asociado a una gran variabilidad en las experiencias percibidas entre aprendices (Carroll, 1990; Fillmore, 1982; Luque and Morgan-Short, 2021; Wong et al., 2017).

Entre los factores encontrados para modular el éxito en aprendizaje de idiomas en adultos se han encontrado algunos factores intrínsecos, como diferencias individuales en motivación por el aprendizaje (Ellis, 2004; Pawlak, 2021; Pawlak et al., 2022) o diferencias asociadas a las habilidades cognitivas de las/los aprendices, como pueden ser las diferencias en inteligencia general (Kempe, Brooks, & Kharkhurin, 2010) o en memoria de trabajo (Faretta-Stutenberg & Morgan-Short, 2018). Por otro lado, factores del ambiente como las condiciones de aprendizaje, también se han observado relevantes en el proceso de aprendizaje de un idioma (Dekeyser, 2008) y en interacción con los factores intrínsecos (Wong et al., 2017). Es decir, el entorno en el que se produce el aprendizaje parece afectar a los procesos cognitivos encargados de dicho aprendizaje.

Desde un punto de vista teórico, el modelo Declarativo/Procedimental (modelo DP; Ullman, 2001; 2004; 2016; 2020) sugiere que dos sistemas asociados a la memoria a largo plazo, el sistema declarativo y el sistema procedimental (Eichenbaum, 2010; Eichenbaum & Cohen, 2001) están implicados en el aprendizaje de idiomas. En general, el sistema de memoria declarativa se encuentra implicado en el aprendizaje y conocimiento de hechos y eventos (ej., recordar la fecha de inicio de la segunda república en España) y el sistema de memoria procedimental se asocia al aprendizaje y mantenimiento de procedimientos adquiridos como hábitos y habilidades (ej., montar en bicicleta o conducir).

En relación con el aprendizaje de idiomas, Ullman (2001) propone que ambos sistemas están encargados de diferentes aspectos en el proceso de aprendizaje y, además el uso de un sistema u otro varía en función de las características del ambiente. Desde esta perspectiva, el sistema declarativo se asocia al aprendizaje de vocabulario y de la información arbitraria asociada a las irregularidades del idioma (ej. las frases hechas o los verbos irregulares). Además, el reclutamiento del sistema declarativo se produciría en un ambiente donde quien aprende es consciente de lo que debe aprender y tiene intención de aprenderlo, como ocurre en el aprendizaje de idiomas reglado (Morgan-Shot et al., 2012). Por otro lado, el sistema procedimental se asocia con el aprendizaje gramatical (ej. El orden de las palabras en una oración o la formación de del pasado en los verbos regulares) en condiciones donde las reglas se aprenden por simple exposición al idioma, sin intención explícita de aprender dichas regularidades o cuando lo que queremos aprender es demasiado complejo (Ullman, 2004; 2006). Por tanto, el sistema procedimental se recluta en ambientes donde la comprensión del idioma es el objetivo principal, como ocurre en un período de inmersión en un país donde se habla dicho idioma (Morgan-Short et al., 2014). Además, ambos sistemas difieren en el tiempo necesario para el aprendizaje: mientras que el sistema declarativo produce un aprendizaje rápido y cuyo conocimiento es fácil de olvidar, el sistema procedimental se basa en un aprendizaje que necesita mucha exposición y es lento, pero cuyo conocimiento se mantiene a largo plazo. Por tanto, la información almacenada en el sistema declarativo decae con facilidad desde el momento posterior al fin del aprendizaje (Hamrick, 2015).

De la misma manera que el modelo DP sugiere que los sistemas de memoria a largo plazo pueden ser reclutados en función de las condiciones de aprendizaje, el objetivo de esta tesis ha sido explorar cómo interfiere el control cognitivo en el aprendizaje de reglas gramaticales en función de las características del ambiente. Desde el punto de vista del *Dual Mechanisms Framework* (Braver, 2012), el control cognitivo puede variar entre control proactivo y reactivo. Por un lado, el control proactivo estaría encargado de la selección temprana y continuada de la información más relevante para la consecución de un objetivo concreto (ej., mantener las instrucciones de aprender una nueva regla gramatical), mientras que el control reactivo sería responsable de actuar frente a un evento que ocurre para interferir con el objetivo concreto de la tarea (ej., corregir un error gramatical). Ambos tipos de control se han visto relacionados con la consecución exitosa de diferentes objetivos, pero el reclutamiento del control proactivo o reactivo depende de las características de las tareas (ej. Cómo de compleja es esa tarea) o los recursos que la persona que aprende tiene disponibles (Braver et al., 2009). Sin embargo, ningún estudio hasta la fecha ha explorado cómo estas formas de control están asociadas al aprendizaje de idiomas, por lo que el objetivo principal de esta tesis es entender el rol del control proactivo y reactivo en el aprendizaje de una nueva gramática.

Objetivos y consecución de los experimentos

Para la consecución de nuestros objetivos, diseñamos cuatro experimentos donde manipulamos diferentes contextos de aprendizaje en función de las instrucciones que recibían las/los participantes (condición de aprendizaje), la dificultad o complejidad del material que debían aprender, y el momento en el que se el test de conocimiento (prueba de juicio gramatical) desde la fase de aprendizaje. Además, medimos las diferencias en control cognitivo usando una tarea que capta el uso de las estrategias proactivas y reactivas, la tarea AX-CPT (Ophir et al., 2009).

En total generamos tres condiciones de aprendizaje manipulando la información que recibían quienes debían aprender: en primer lugar, en la condición de aprendizaje incidental, los/las participantes eran instruidas para leer y responder a una pregunta de comprensión por cada oración que se les presenta en un determinado idioma. En la condición de aprendizaje intencional, las/los participantes eran informadas de que todas las oraciones que iban a ver seguían las mismas reglas gramaticales y que el objetivo de la tarea era aprender dichas regularidades. Por último, en la condición explícita, las/los participantes obtenían un texto explicativo de las reglas que debían aprender durante la tarea antes de comenzar a leer las oraciones que seguían dichas regularidades. Tras el aprendizaje, las/los participantes debían realizar una prueba de juicio gramatical (GJT) donde debían elegir si las oraciones que se les presentaban (que no habían sido presentadas previamente) eran gramaticalmente correctas o incorrectas. Esta prueba podía hacerse inmediatamente después, 24 horas después, una semana después, o dos semanas después de la fase de aprendizaje, en función del experimento. Para medir el aprendizaje, calculamos un índice de discriminación (d-prima) que nos permitió cuantificar la capacidad de las/los participantes para distinguir las oraciones que seguían las reglas gramaticales que aprendieron de aquellas que no.

En el primer y segundo experimentos de esta tesis, agrupados dentro del estudio titulado *Adquisición de reglas gramaticales en un segundo idioma: Los efectos de las condiciones de aprendizaje, dificultad de la regla, y funciones ejecutivas* (en el capítulo 4), exploramos el rol del control cognitivo (proactivo/reactivo) en adultos jóvenes mientras aprendían regularidades de un idioma natural: el inglés. En concreto estábamos interesadas en examinar el rol de las estrategias de control cuando las instrucciones generaban condiciones de aprendizaje incidentales, intencionales, o explícitas y la dificultad de las reglas había sido manipulada. En el primer experimento un grupo de participantes fue expuesto al aprendizaje incidental y otro al aprendizaje intencional de una regla fácil en inglés. En el segundo experimento, manipulamos la dificultad de las reglas y los participantes podían aprender una regla fácil (la misma que en el primer experimento) o una difícil, según fue juzgado por un grupo de expertos. Cada regla era presentada en la condición de aprendizaje incidental o explícita, y cada grupo de participantes veía cada una de las reglas en una condición diferente ya que la presentación de las reglas estaba bloqueada y contrabalanceada entre participantes. En estos experimentos esperábamos encontrar que las condiciones de aprendizaje mediarían el rol de control proactivo/reactivo y que habría diferencias en la importancia de uno de los dos tipos de control asociado a la dificultad de las reglas gramaticales. En primer lugar, como en el caso de otros estudios, esperábamos que el aprendizaje de las reglas iba a ser mejor en las condiciones intencional y explícita que en la incidental. Además, esperábamos que el rol del control proactivo iba a ser más evidente en la condición intencional del experimento 1 donde los participantes saben que deben aprender una regla, pero no tienen información acerca de ella. Por lo que el control proactivo sería necesario para detectar las regularidades.

En el tercer experimento, titulado *El rol del dominio en un segundo idioma (L2) y el control proactivo en el aprendizaje de una nueva gramática* (capítulo 5) el objetivo era doble: por un lado, queríamos entender la relación entre control cognitivo y aprendizaje de idiomas observada en los dos primeros experimentos y por el otro, queríamos explorar el rol de las diferencias individuales asociadas a la experiencia lingüística (nivel de dominio de un segundo idioma) para predecir el aprendizaje de una nueva gramática. El rol de estas diferencias individuales (en control y experiencia lingüística) fue explorado durante el aprendizaje explícito de una regla gramatical en *Japañol*, un idioma semiartificial formado por el léxico del español y dos reglas sintácticas del japonés. Con respecto al rol del control proactivo esperábamos encontrar que, en el caso de ser reclutado tan solo para de un proceso de detección de regularidades, no encontraríamos una relación entre control proactivo y aprendizaje explícito de una regla gramatical. Sin embargo, si el rol del control está asociado a la sobrecarga de la memoria de trabajo, al solo presentarse una regla de las dos existentes, encontraríamos que el control proactivo tendría un rol en este proceso de aprendizaje.

En segundo lugar, con respecto al rol de la experiencia lingüística, experimentos previos han mostrado que afecta al aprendizaje de idiomas, incluso cuando la experiencia con ese idioma es solo contextual (Bice y Kroll, 2019). Por ejemplo, Bice y Kroll (2019) encontraron que hablantes monolingües de inglés viviendo en un contexto donde otros idiomas aparte del inglés son hablados (ej., California, donde hay una gran afluencia de hispanohablantes) tenían un mejor aprendizaje de vocabulario en finlandés (idioma nuevo) que hablantes monolingües de inglés viviendo en un contexto donde solo se habla inglés (ej., Pensilvania). Además, se ha observado que los/las bilingües tienen un mejor aprendizaje de vocabulario en un tercer idioma (L3) que hablantes monolingües aprendiendo una L2 (Cenoz, 2003; Bartolotti et al., 2011). Por otro lado, investigación comparando multilingües, bilingües, y monolingües aprendiendo la gramática de un nuevo idioma, ha llegado a diferentes conclusiones en función de la condición de aprendizaje. Por ejemplo, se ha observado que los multilingües tienen mejores resultados en el aprendizaje implícito de una gramática artificial que bilingües y monolingües (Nation y Mclaughlin, 1986). Pero Nayak et al. (1990) encontraron que los multilingües tenían mejores resultados después de aprender de manera explícita las regularidades de un idioma artificial (resultados similares fueron encontrados por Grey et al., 2018). Sin embargo, la comparación entre grupos de personas con (multilingües y bilingües) y sin (monolingües) experiencia previa en una L2, podría estar enmascarando el verdadero rol de la experiencia lingüística ya que los grupos constituyen los extremos del continuo que es el dominio de un idioma. Por ello, en este experimento, tratamos el dominio de la L2 como una variable continua y esperamos que prediga el aprendizaje exitoso de la nueva gramática.

Por último, en el experimento 4 titulado *Factores cognitivos y contextuales modulando el aprendizaje gramatical en edades avanzadas* (capítulo 6) el objetivo principal era explorar las diferencias entre adultos jóvenes y mayores (de 60 años) para explicar las diferencias asociadas al uso de estrategias cognitivas, así como la interacción entre control proactivo y reactivo, y las condiciones de aprendizaje en los dos grupos. Mientras que el aprendizaje en edades avanzadas se asocia con beneficios sociales (Pot et a., 2019) y cognitivos (Nilsson et al., 2021), el aprendizaje se encuentra amenazado por el deterioro cognitivo en funciones ejecutivas (Verssimo et al., 2021) y memoria (Pliatsikas et al., 2019). Además, las personas mayores ponen en uso estrategias reactivas para intentar paliar las dificultades para mantener información relevante (Braver y Barch, 2002) mientras que las jóvenes suelen usar estrategias proactivas (Braver, 2012). Estas diferencias pueden estar afectando al uso de estrategias implícitas en el aprendizaje que parecen estar más preservadas que las estrategias explicitas (Hardy et al., 2019). Algunos estudios explorando diferencias en aprendizaje gramatical en mayores han concluido que estos son menos efectivos que las personas jóvenes cuando usan estrategias explicitas, pero no implícitas (Wagnon et al., 2019). Sin embargo, esta relación está poco estudiada en la literatura y por ello, en este último estudio manipulamos las condiciones de aprendizaje para observar las diferencias entre jóvenes y mayores, así como el posible rol del control proactivo o reactivo. En este experimento esperábamos encontrar diferencias en aprendizaje entre jóvenes y mayores en la condición explícita, pero no en la incidental, como se ha encontrado anteriormente en la literatura. Además, esperábamos encontrar que las personas mayores dependerían en mayor medida de las estrategias reactivas que los adultos jóvenes durante el aprendizaje, especialmente en la condición incidental.

Resultados

En general, en estos experimentos, encontramos que en las condiciones intencional y explicita el aprendizaje era mejor que en la condición incidental (experimentos 1, 2, y 3). Estos resultados han sido previamente observados en la literatura, mostrando que cuando proporcionamos instrucciones de aprendizaje los resultados son mejores que cuando no (Goo et al., 2015). Adicionalmente, en el experimento 2, encontramos que estos beneficios asociados a la condición explícita, solo se mantenían durante el aprendizaje de la regla fácil, no de la difícil. Estos resultados sugieren que el aprendizaje de material más demandante (difícil) se adquiere mediante el sistema procedimental, donde es necesario emplear menos esfuerzo a nivel cognitivo. En el experimento 4 (capítulo 6), sin embargo, manipulamos la complejidad de las oraciones que se presentan en *Japañol* y encontramos que los/las participantes aprendían mejor con oraciones simples que complejas tanto en la condición explícita como incidental. Aunque las diferencias en aprendizaje entre oraciones simples y complejas eran menores en la condición incidental. Estas diferencias en resultados pueden deberse a que, mientras en el experimento 2 los/las participantes aprendían un idioma desconocido (el inglés), en el experimento 4 aprendían un idioma basado en su idioma nativo (el español), lo que podría generar en los participantes cierta conciencia de la necesidad de aprender incluso en la condición incidental.

Con respecto al momento en el que se realizaba la prueba, solo encontramos resultados significativos en el experimento 3 (capítulo 5). Específicamente, encontramos que los/las participantes que habían aprendido en una condición explícita una regla gramatical del *japañol* tenían mejores resultados en la GJT inmediatamente después de la sesión de aprendizaje que en que GJT dos semanas después. No encontramos diferencias cuando la prueba era 24 horas o una semana después de la sesión de aprendizaje. Este patrón de aprendizaje sugiere, tal y como predice el modelo declarativo/procedimental, que el conocimiento declarativo se suele adquirir en condiciones explícitas y que, una vez adquirido, es más susceptible de decaer con el tiempo.

Con respecto al rol de las diferencias individuales, encontramos que el control cognitivo, la experiencia previa aprendiendo un idioma y la edad, interactuaban de manera diferente con el aprendizaje en función de las condiciones del ambiente de aprendizaje. En concreto encontramos que una alta capacidad para mantener activo el objetivo de la tarea e inhibir la información irrelevante para esa tarea antes de que interfiera (alto control proactivo), predecía mejores resultados en el aprendizaje (medido con una GJT) cuando se les informaba a los/las aprendices que debían aprender una regla gramatical, pero no tenían acceso a información sobre esa regla (condición intencional; experimento 1). Además, encontramos que el control proactivo también beneficia el aprendizaje cuando se proporciona información sobre la regla a aprender (condición explícita), en condiciones donde la carga de memoria de trabajo es baja (solo se debe aprender una regla; experimento 3) pero no cuando la memoria de trabajo estaba sobrecargada (se deben aprender dos reglas; experimentos 2 y 4). Adicionalmente, cuando el objetivo de la tarea no era el de aprender las regularidades, si no el de comprender las oraciones que se presentaban (condición incidental), el rol del control cognitivo era diferente. Concretamente, un control menos focalizado y estrategias para reaccionar ante una interferencia una vez ha ocurrido (control reactivo), beneficiaba el aprendizaje de una regla difícil en inglés (experimento 2). Sin embargo, cuando los/las participantes debían aprender dos reglas gramaticales en *Japañol*, un mayor control proactivo beneficiaba los resultados de aprendizaje (experimento 4).

Con respecto a la experiencia previa aprendiendo un idioma (L2), en el experimento 3 encontramos que diferencias individuales en el nivel de dominio en ese idioma interactuaban con la complejidad de las oraciones para predecir el aprendizaje exitoso de la gramática. En concreto, personas con bajo nivel de dominio en el idioma tenían mejores resultados aprendiendo con oraciones simples que complejas. Adicionalmente, un mayor nivel de dominio predecía un mejor aprendizaje en oraciones complejas. Por tanto, la experiencia aprendiendo una L2 parece ser beneficiosa en el uso de estrategias para aprender una nueva gramática de manera explícita en condiciones complejas.

Por último, con respecto al envejecimiento, en el experimento 4 encontramos que los adultos jóvenes tenían mejores resultados en el aprendizaje de las regularidades que los adultos mayores en la condición explícita, pero no en la incidental, como ya se había encontrado en la literatura (Midford y Kirsner, 2005). Sin embargo, a diferencia de lo encontrado anteriormente, en este experimento vimos que las personas mayores se beneficiaban de la información que recibían sobre las regularidades ya que tenían mejores resultados en la condición explícita que en la incidental. Estos resultados pueden deberse a que las personas mayores de nuestro experimento tenían una vida cognitivamente activa (leían, estudiaban, jugaban a juegos de ingenio…) y esto podría haber influido en que usasen estrategias de aprendizaje más costosas y útiles en el aprendizaje explícito. De hecho, tanto jóvenes como mayores con mayor control proactivo tenían mejores resultados de aprendizaje.

Conclusiones

Estos resultados, aunque inconcluyentes, son los primeros en demostrar la importancia del rol del control cognitivo durante el aprendizaje inicial de reglas gramaticales en diferentes idiomas. Adicionalmente, el control cognitivo puede ser modulado por diferencias asociadas a quien aprende. Por ejemplo, la experiencia lingüística se asocia con un beneficio en el uso flexible del control proactivo y reactivo (Morales et al., 2013; 215) y el envejecimiento se asocia con un declive en el control proactivo (Braver & Barch, 2002). Por tanto, cuando exploramos el rol de estas dos poblaciones encontramos que, mientras la experiencia lingüística beneficiaba el aprendizaje explícito de una regla gramatical, el envejecimiento lo empeoraba. De estos resultados podemos concluir que, en un contexto de aprendizaje similar al que se recibe formalmente en una clase (aprendizaje explícito), las diferencias entre aprendices a nivel cognitivo estarán presentes en mayor medida que en un contexto de aprendizaje de inmersión (aprendizaje incidental). Finalmente, podemos concluir que el rol del control cognitivo es relevante en diferentes condiciones de aprendizaje y por ello la compleja interacción entre control y factores extrínsecos debe continuar siendo explorada.

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