*Bilingualism: Language and Cognition*

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# Second language acquisition of grammatical rules: The effects of learning condition, rule difficulty, and executive function

Marta Rivera, Daniela Paolieri, Antonio Iniesta, Ana I Pérez and Teresa Bajo

Mind, Brain, and Behavior Research Center (CIMCYC), Department of Experimental Psychology, University of Granada, Granada, Spain.

**Research Article**

The current research was completed thanks to financial aid provided by the Sistema Nacional de Garantía Juvenil y del Programa Operativo de Empleo Juvenil de la Junta de Andalucía to Marta Rivera and grants from the Ministerio de Ciencia, Innovación y Universidades-Fondos Feder to Dr. Teresa Bajo (PGC2018-093786-B-I00) and Dr. Daniela Paolieri (A-SEJ-416-UGR20 and PID2019-111359GB-I00/AEI/10.13039/501100011033), A-CTS-111-UGR18-Feder.Andalucía, P20.00107 Agencia de Desarrollo e Innovación de Andalucía to Dr. Teresa Bajo and MSCA-COFUND Athenea3i-2018 grant to Dr. Ana I. Pérez (754446).

**Cite this article:** Rivera M, Paolieri D, Iniesta A, Pérez AI, Bajo T (2023). Second language acquisition of grammatical rules: The effects of learning condition, rule difficulty, and executive function. *Bilingualism: Language and Cognition* **26**, 639–652. https://doi.org/10.1017/S1366728922000815

Received: 26 January 2022
Revised: 14 October 2022
Accepted: 4 November 2022
First published online: 18 January 2023

**Keywords:**
second language learning; individual differences; context of learning; proactive control; rule difficulty; executive functions

Address for correspondence: Marta Rivera, Mind, Brain and Behavior Research Center (CIMCYC), Profesor Clavera s/n, 18011 (Granada, Spain). Email: martarivz@ugr.es



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**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-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.

## 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, Faretta-Stutenberg, Brill-Schuetz, Carpenter & Wong, 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, van Heuven, Conklin & Tunney, 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, Yilmaz &

Novella, 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, Sanz, Steinhauer & Ullman, 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). Hence, 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, 2000, 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, Gao & King, 2013), general intelligence (Kempe, Brooks & Kharkhurin, 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), it has only begun to be empirically explored as providing 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; Dörnyei, 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, Mora & Daidone, 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, Hamilton, Coslett, Datta, Bikson & Thompson-Schill, 2013; Smalle, Panouilleres, Szmalec & Möttönen, 2017). Hence, 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, Mueller, Sehm & Ragert, 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 staff, 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 (Kapa & Colombo, 2014). 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, Tagarelli & Rebuschat, 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 to 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). 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 (Unsworth, Redick, Heitz, Broadway & Engle, 2009). Proactive control seems to be especially relevant in intentional

https://doi.org/10.1017/S1366728922000815 Published online by Cambridge University Press

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 English learning (information extracted from the LEAP-Q questionnaire (Marian, Blumenfeld & Kaushanskaya, 2007), but their English proficiency was very basic (participation requirement: proficiency 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)[1]. 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-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 was 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. They 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

https://doi.org/10.1017/S1366728922000815 Published online by Cambridge University Press

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, van Hell & Kroll, 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).

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, $p < .001$, $\mu = .10$ 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, $p = .25$, $\mu = .02$, nor the interaction between condition and time, $F$ (1, 73) = .04, $p = .84$, $\mu = .0005$, were significant (see Figure 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] |

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* $R2 = .04$; $\beta = 1.58$, $t = 2.09$, $p = .04$. More precisely, participants had better discrimination (d' = 1.46) if they showed higher BSI scores (more proactive).

## 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 they 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,

**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] |

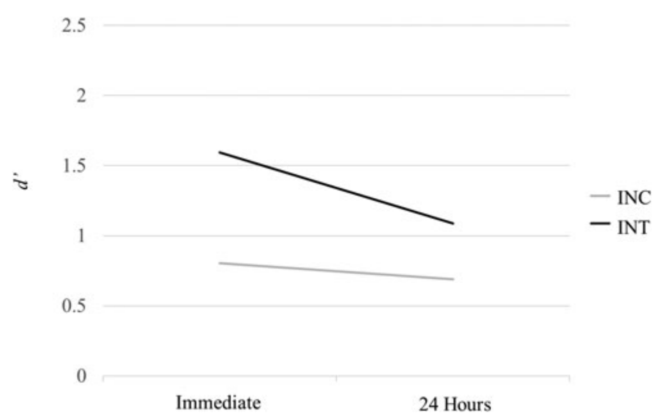


**Fig. 1.** Rule *learning d'* as a function of time (immediate and hours) x condition (INC-incidental and INT-intentional).

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[2]. 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, 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

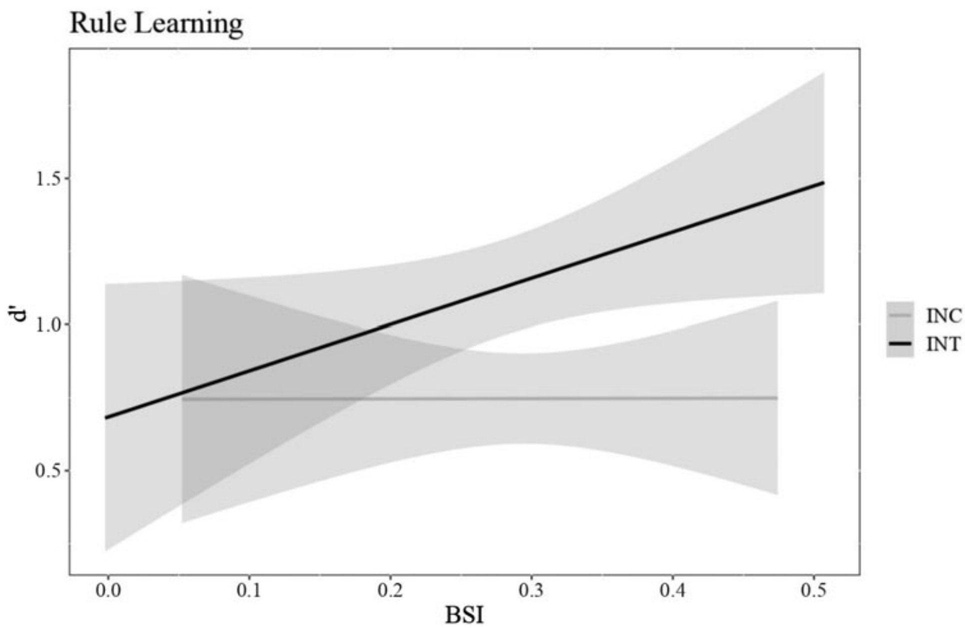


**Fig. 2.** Rule-learning d-prime scores associated with BSI for incidental (INC) and intentional (INT) conditions. Highlighted areas represent Standard Error.

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.

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**Dative alternation rule**

*Verbs with one syllable in the stem like **give** 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 **provide** 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*

**Fig. 3.** Metalinguistic explanations used in the explicit context for the dative *alternation* and pseudoclefts 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 100 ms 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).

ANOVA analyses of the effects of learning condition, type of rule, and time indicated a significant effect of condition, $F$ (1, 166) = 48.8, $p < .001$, $\mu = .22$ (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).

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, $\beta = -1.12$, $t = -3.59$, $p$ <.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* $R2 = .0002$; $\beta = -.37$, $t = -1.01$, $p = .314$ (see Figure 5).This effect was not significant for the explicit condition for the dative, $F$ (1, 143) = 1.728, $p = .19$, *adjusted* $R2 = .005$; $\beta = .55$, $t = 1.31$, $p = .2$ or the pseudocleft rule, $F$ (1, 106) = .24, $p = .6$, *adjusted* $R2 = -.007$; $\beta = -.23$, $t = -.49$, $p = .624$.

## 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

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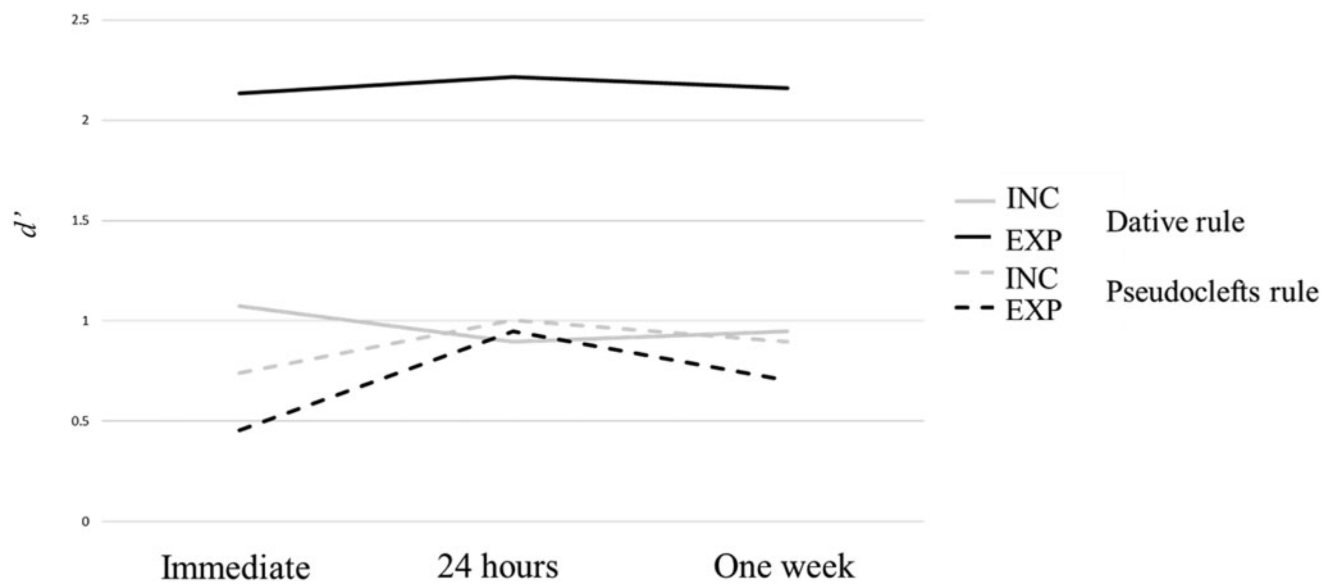


**Fig. 4.** Rule *learning d' index* as a function of time (immediate and hours), condition (INC-incidental and EXP-explicit), and rule (dative and pseudoclefts).

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. (2013; 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 they 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, Steinhauer, Sanz, and Ullman (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, 2018).

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 not to the use of previous language knowledge in the absence of learning.

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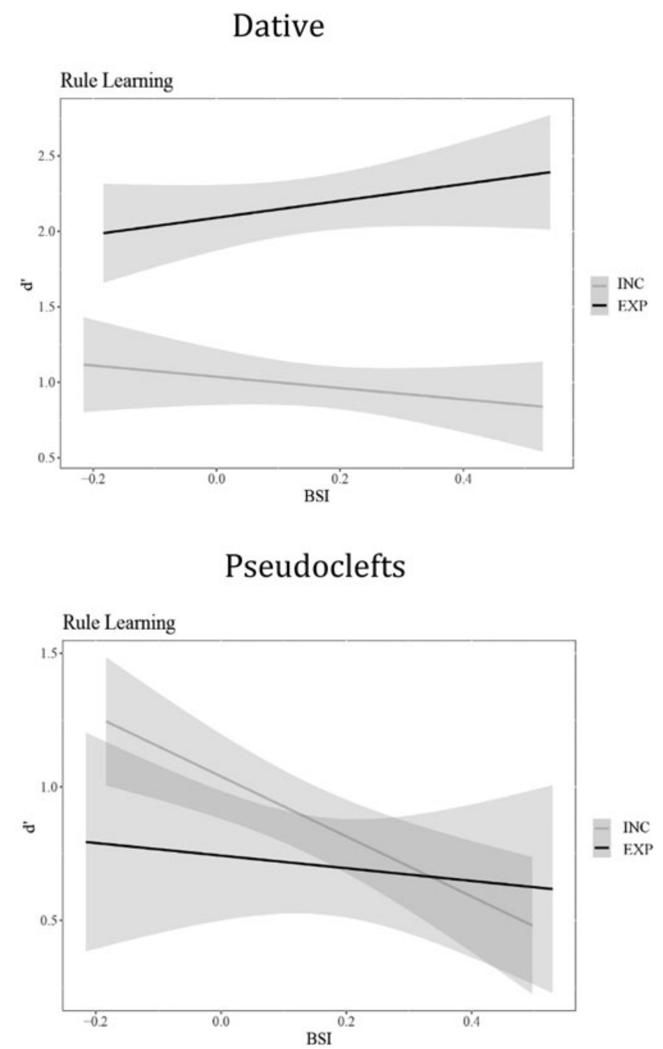


**Fig. 5.** Rule-learning d-prime associated with BSI for incidental (INC) and explicit (EXP) conditions, for the dative (right) and pseudoclefts (left) rules. Highlighted areas represent Standard Error.

## 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 a 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 100 ms 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

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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, 2018 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, 2001, 2004). 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 and 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), its 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-Schill 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.

**Supplementary Material.** For supplementary material accompanying this paper, visit https://doi.org/10.1017/S1366728922000815

Supplementary material includes experimental material (learning and testing material) of Experiment 1 and 2.

**Acknowledgement.** Funding for open access charge: Universidad de Granada.

**Data Availability Statement.** The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Notes

[1] 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.

[2] 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.

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