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Acquisition of grammar in L2 under incidental learning conditions: The role of frequency and working memory

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ABSTRACT

Although frequency is recognized as an important factor in second language acquisition, it has remained relatively under-investigated in terms of its impact on the acquisition of grammatical knowledge under incidental learning conditions. This article reports the results of an experiment where 100 novice adult learners were exposed to a complex noun-adjective agreement pattern in Russian under 4 incidental learning conditions where type and token frequency of the stimuli were manipulated. The results support a “starting small” approach for productive knowledge acquisition; accuracy was greater in the low-type low-token condition, and low-token frequency was more significant than low-type frequency. Working memory was differentially involved in production of acquired knowledge in different conditions and not engaged where learning was facilitated by frequency.

Introduction

Previous research into incidental learning conditions has demonstrated that adults can successfully acquire knowledge in such conditions (Leung & Williams, 2011; Morgan-Short et al., 2010; Rebuschat & Williams, 2011; Williams, 2005). Nevertheless, the general assumption in the L2 acquisition literature is that successful L2 acquisition after the critical period, specifically the acquisition of grammatical knowledge, follows an explicit learning mode. That is, the processing of the input is understood to take place with conscious cognitive involvement and with the intention to figure out the underlying regularities (Leow, 2000; Robinson, 2005; Schmidt, 1993; Scheffler, 2008). Therefore, in order to understand differences in incidental learning and explicit learning conditions, it is important to understand the contribution of factors such as frequency. We begin with a brief discussion of research into incidental learning and the role of frequency within this. The body of the paper then reports on an investigation into the acquisition of a noun-adjective agreement pattern in Russian under different incidental learning conditions in which type and token frequency are manipulated.

In the present paper, we focus on incidental learning conditions defined as a learning environment in which learners are unaware that they are receiving training, that will be followed by a test phase, and where participants are asked to understand the meaning of sentential stimuli without receiving feedback on their performance (Rebuschat & Williams, 2011). In contrast, we understand implicit learning as a process during which learners derive knowledge unintentionally from a complex rule-governed stimulus domain without becoming aware of the knowledge acquired (Reber, 1967); implicit knowledge is the outcome of such learning process (“unconscious knowledge that subjects are generally not aware of possessing” (Rebuschat & Williams, 2011, p. 4))

Acquisition of L2 grammatical knowledge under incidental learning conditions

According to the Fundamental Difference Hypothesis (FDH, Bley-Vroman, 1988), incidental learning processes are no longer available for the acquisition of an L2 grammar in adulthood. The FDH implies that after a certain critical period an L2 grammar has to be learned explicitly in order to be learned successfully. This assumption was supported by research on immigrant adult learners of English as L2 who performed worse on grammaticality judgment tests if they were immersed in the language environment after puberty (DeKeyser, 2000; Johnson & Newport, 1989). Further support emerged from the findings of studies directly comparing the effectiveness of L2 grammatical knowledge acquisition in incidental and explicit modes of learning (Robinson, 1997; Rosa & O'Neil, 1999); these demonstrated that explicit (Rosa & O'Neil, 1999) or instructed (Robinson, 1997) conditions lead to higher levels of knowledge intake.

Nevertheless, research on the acquisition of grammatical knowledge under incidental learning conditions showed that learners can successfully acquire such knowledge without being explicitly taught the rule. In these studies, participants learning an artificial or semi-artificial grammars via incidental exposure performed at above chance levels on post-tests measuring knowledge retention (Williams, 2005; Rebuschat & Williams, 2011; Tagarelli et al., 2011). These studies however generally explored the comprehension domain and very little research so far have focused also on the acquisition of productive knowledge under incidental exposure (Brooks & Kempe, 2013; Hama & Leow, 2010). A focus on production is important to understand how language is acquired in natural settings. We note Hama and Leow (2010), who made various methodological changes (such as including think-aloud protocols and oral presentation of the stimuli) to the study by Williams (2005), in which learners acquired determiner-noun agreement rules (according to animacy and distance) in a semi-artificial language under incidental learning conditions, and specifically extended it

with the addition of a production task. The results indicated that unaware participants performed significantly above chance in productive knowledge acquisition only on distance items, both trained and new, but not on animacy items. At the same time, other studies demonstrated that receptive and productive knowledge of some grammatical aspects of an L2 (gender agreement in particular) can be acquired to similar levels of proficiency under incidental and explicit training conditions. The study of Morgan-Short et al. (2010) employing an artificial language as material, demonstrated that although participants in the incidental and explicit learning conditions exhibited different ERP patterns, both groups showed significant learning effects and “there were no significant group differences” (p. 171).

It is worth stressing, however, that research within the incidental learning paradigm, has generally focused on artificial or semi-artificial languages. Very little research has addressed the acquisition under incidental exposure of a new natural language unfamiliar to learners (Chen et al., Brooks & Kempe, 2013). Other relatively under-researched areas in second language acquisition (SLA) are the role of type and token frequency, and of working memory. In the present study we addressed these issues and investigated whether productive knowledge acquisition of a grammar pattern in a natural language would be differentially affected by the learning condition (explicit vs. incidental) by type and token frequency, and by working memory.

Frequency and L2 knowledge acquisition

Developmental studies have demonstrated that frequency appears to be a crucial factor boosting language learning in children, which is primarily incidental (Abbot-Smith et al., 2004; Brandt, et al., 2011; Kidd et al., 2006, 2010; Lieven & Tomasello, 2008; Matthews et al., 2005; Tomasello, 2003). According to the usage-based approach, token frequency helps

to initially register new grammatical constructions in a child's memory and then type frequency helps to generalize the acquired schema to novel items. Nevertheless, little is known about whether the same principles apply to learning grammar under incidental learning conditions in adults. Researchers who argue for the role of associative and cognitive learning in SLA believe that frequency impacts the learning of a second language in the same way as learning of a L1 (Hulstijn, 2005; Ellis 2002, 2006). However, those studies demonstrating that frequency fosters incidental learning of a second language grammar focused on languages that are at least partly known to the L2 learners (Barcroft, 2009; Lee, 2002). Little so far is known about the acquisition of a natural language grammar by novice adult learners never who have never been exposed to the language before, and whether frequency affects L2 knowledge acquisition through incidental exposure similarly to L1.

Frequency is considered by many as an important factor for L2 learning (Gass & Mackey, 2002; Ellis N., 2002; Hulstijn, 2005). It is believed that processes that guide the acquisition of an L2 are no different from those that guide the acquisition of any other type of information, as suggested by the Associative-Cognitive CREED hypothesis (Ellis, 2006). According to this hypothesis, high-frequency constructions are learned more easily than low-frequency ones through associative learning mechanisms, and there is ample evidence that humans are extremely sensitive to the frequencies of elements that co-occur together in the input (Ellis, 2002; Lieven, 2010; Saffran, 2003; Saffran et al., 1997). For the purposes of the present study, we have selected the noun-adjective agreement pattern as a prime example of the co-occurrence of inflectional endings.

The issue of type and token frequency and its role in the acquisition of grammatical knowledge has been raised by many usage-based theorists in regards to L1 acquisition, but has been under-investigated in relation to incidentally acquired L2 knowledge. The primacy of token frequency has been stressed in relation to exemplar-based learning; repeated

exposure and use of a given construction leads to the accumulation of a critical mass of tokens. Type frequency comes into play in the generalization of the acquired knowledge to new items and in the abstraction of schemas (Tomasello, 2000, 2008). Similarly, according to Bybee's (1985, 1988) network model, type and token frequency play crucial roles in establishing and maintaining complex morphological representations, where high token frequency facilitates entrenchment and type frequency prompts productivity.

In the artificial-grammar learning paradigm, the *fragment view* approach places a high importance on frequency as a mechanism that fosters tracking of strings of items in the input and storing them in the learner's memory as fragments. Researchers believe that when exposed to an artificial grammar during training learners are sensitive to the frequency with which certain symbols co-occur across the training strings (Johnstone & Shanks, 2001; Knowlton & Squire, 1992, 1994; Perruchet & Pacteau, 1990). Few empirical studies, nevertheless, have so far focused on how frequency impacts the acquisition of an unfamiliar natural L2 grammar through incidental learning (Robinson, 2005).

Previous research demonstrated that frequency positively affects acquisition of L2 vocabulary by adult learners under incidental learning conditions (Hamrick & Rebuschat, 2013; Rott, 1999). Researchers also provided evidence that frequency of exposure of adults to the input of familiar second language can boost acquisition of salient grammar forms through incidental learning exposure (Lee, 2002). Robinson (2005) examined how frequency affects acquisition by novice learners of natural language grammatical knowledge under incidental learning conditions. Japanese speakers were exposed to Samoan and were targeted for the learning of ergative marking rules in transitive sentences. There were nine sentences of different types each repeated 50 times during training. However, each verb was used only in one context and thus it was associated only with one word-order pattern. Participants' performance on grammaticality judgment post-tests showed high accuracy on old

grammatical sentences, but not on new grammatical and ungrammatical sentences, demonstrating that there was a failure to transfer knowledge gained during training to novel sentences.

Overall, research has shown that frequency has some positive impact on acquiring knowledge through incidental exposure. In the present study we aim to better understand how the manipulation of type and token frequency affects the acquisition of productive knowledge of a natural language agreement pattern under incidental learning conditions.

Working memory and learning through incidental exposure

At the same time, it is vital to know how the frequency interacts with the impact of other factors such as working memory (WM), which has generally been established as a necessary resource for successful acquisition of language knowledge, both L1 (Adams & Gathercole, 2010; Morra & Chamba, 2009) and L2 (Mackey et al., 2002; Miyake & Friedman, 1998, Speciale et al., 2004). Research has demonstrated that WM plays a crucial role in both the learning and retrieving of grammatical knowledge such as gender marking (Kempe, Brooks, & Kharkhurin, 2010). However, it is yet unknown whether WM resources would be differentially involved in the activation of knowledge acquired under incidental learning conditions where frequency had different facilitating effects.

Nevertheless, research that investigated the impact of working memory on incidental learning (Conway et al., 2011; Kaufman et al., 2010), using on-line tasks or post-test measures of the acquisition of knowledge in the incidental learning conditions (Brook & Kempe, 2013; Tagarelli et al., 2011), found no effect of working memory. Yang and Li (2012) explored the neural cognitive mechanisms underlying implicit and explicit learning of artificial grammar sequences. As part of this investigation, they measured participants'

phonological and working memory using a letter-number sequence task and the N-back working memory task, where participants were asked to press a response button to identify whether the letter presented was identical to a pre-specified letter in a given series of letters. They found that participant's WM differentially affected the two types of artificial grammar learning, with WM positively impacting performance in grammaticality judgements about the test sequences of the artificial grammar in the explicit learning condition, but not in the incidental one.

Tagarelli et al. (2011) studied the impact of working memory on the acquisition of L2 syntax in the incidental learning and explicit learning conditions. Native speakers of English who had no previous knowledge of German were assigned to one of two groups: incidental and rule-search. They then learned a semi-artificial language consisting of English words and German syntax and had to perform a grammaticality judgement test after training. As a measure of working memory participants completed the Operation Word Span task, where participants saw an equation and a word appearing on the computer screen. They had to read the word out loud, indicate whether the equation was correct, and later recall as many words presented as possible. Participants also completed a letter-number ordering task, where they had to repeat the numbers that had been previously presented to them by the experimenter in numerical order and repeat the letters in alphabetical order. The results showed that there was no significant difference between the incidental and rule-search groups on both working memory tests. Additionally, for the incidental learning group there were no correlations between accuracy on the grammaticality judgment test and performance on either of the two working memory tests. There was however a significant positive correlation between the accuracy on the grammaticality judgment tests and participants' performance on the letter-number ordering task in the rule-search group. Therefore, the study indicated that working memory did not appear to affect the ability to acquire knowledge of L2 syntax under the

incidental learning condition, but influenced the learning of L2 syntax under the explicit learning condition.

Similar results of no effect of WM on knowledge acquisition under incidental learning conditions were also found by Brooks and Kempe (2013). In contrast to other studies (Conway et al., 2011; Kaufman et al., 2010; Tagarelli et al., 2011; Yang and Li, 2012), which focused on the comprehension of artificial languages, Brooks and Kempe (2013) investigated the acquisition of productive knowledge of Russian gender and case agreement patterns by novice learners through incidental exposure over six sessions. However, in line with previous research WM was not a significant predictor of knowledge acquisition in these studies.

The present study

The present study explores the acquisition of productive knowledge of a noun-adjective agreement pattern in Russian through incidental learning by adults. Like Brooks and Kempe (2013), we address the acquisition of grammatical knowledge in a natural language. Previous research that explored the acquisition of knowledge in the incidental learning condition generally used artificial or semi-artificial languages. It is however important to employ a natural language in order to gain a better understanding of how adults acquire a second language in a natural L2 learning environment. The main aim is to explore how frequency affects productive knowledge acquisition of the agreement pattern under the incidental learning condition. This can then be compared to knowledge acquisition under the explicit learning condition by novice adult learners. Russian was chosen as, differently from English, it requires overt marking of gender agreement between nouns and adjectives, a novel

morpho-syntactic pattern for native speakers of English. The questions posed in the study are the following:

- 1) Is the acquisition of productive knowledge of an agreement pattern in the incidental learning conditions affected by the manipulation of type and token frequency?
- 2) Is there a correlation between working memory skills and the acquisition of the productive knowledge of a gender agreement pattern in the incidental learning conditions?
- 3) What is the difference as a function of learning condition (explicit vs. incidental) in the productive knowledge acquisition?

Design

In this experiment we investigated the acquisition of noun-adjective agreement under incidental learning conditions and manipulated the type and token frequency of feminine and masculine nouns in four different cases: nominative, dative, instrumental and genitive. An explicit learning condition was also included to compare the effectiveness of knowledge acquisition with the incidental learning condition. Previous SLA research demonstrated that an explicit learning condition was generally more effective for L2 grammar knowledge acquisition than an incidental condition (DeKeyser, 1995; Ellis, N., 1993; Norris & Ortega, 2000; Robinson, 1996). These studies used metalinguistic explanations of the rule as a method of training in the explicit learning condition. We also provided metalinguistic information about the rule during training in the explicit learning condition instead of using a rule-search condition which allows room for a degree of implicitness during learning. Thus, incidental and explicit learning conditions were intentionally kept distinct in terms of experimental design to make our study more informative for second language learning

practices and to bring the lab research closer L2 learning in natural settings, where learners are usually taught the grammatical rule. Moreover, the explicit learning condition in the present study was treated as base-line comparison condition for the knowledge acquired under incidental learning conditions, based on the findings from previous research that explicit learning condition is generally more effective.

Performance accuracy was measured using comprehension and production tasks. In the comprehension task we also measured reaction times based on the definition of implicit knowledge as being automatic and easy to activate (Shiffrin & Schneider, 1977) and according to previous research identifying timed tasks as a suitable measures for implicit knowledge (Ellis R., 2005). Since participants in all conditions performed at ceiling in comprehension and no statistically significant difference between the conditions was found (comprehension accuracy, $p = .10$; RT , $p = .37$), we will not further discuss the issue of receptive knowledge acquisition in the present paper.

Participants

One hundred undergraduate students (25 males and 75 females) were included in the study (age range 18-38). Participants received 10% credit or £5 payment for their participation. Sixty-eight of the participants had some beginner or intermediate knowledge of a classroom-taught foreign language (French, Spanish, German, Urdu, Panjabi, Ancient Greek, Latin, Japanese, Arabic, Chinese, Welsh, Swedish, Italian, Dutch, Irish, Afrikaans). None of the participants had ever studied Russian or any other Slavic language, and none of them had any advanced knowledge of a language with grammatical gender agreement, or of linguistics or psychology. Participants were randomly allocated to one of the five conditions, for a total of 20 in each condition.

Materials

The materials of the study were Russian words (6 animate nouns, 4 adjectives, 3 prepositions *k, ot, s* ‘towards, away from, with’ and the particle *eto* ‘this’. The stimuli were matched for imageability and number of syllables. All the nouns were animate and stereotypical characters were chosen (e.g. *volshebnik* ‘magician’). In addition, only nouns and adjectives that fell into the inflectional paradigm of cases represented in Table 1 were selected.

[Insert Table 1]

The training sentences contained noun-adjective agreement in nominative, dative, instrumental and genitive cases singular. The instrumental case was of particular interest, as it creates a pattern of similar endings between the adjective and the noun, and was thus considered to be salient in the context of the other cases and potentially easier to learn through incidental exposure. The other cases were selected on the basis of imageability, i.e. how easy it would be to create a series of slides to tell a story. Each slide contained a picture and a Russian sentence, such as:

[Insert Figure 1]

[Insert Table 2]

Depending on the incidental learning condition, participants viewed a different number of types and tokens and thus a different number of experimental slides. Each type was represented by a story about a feminine or a masculine character that consisted of 4 slides presented sequentially. Each story was randomized. The number of types and slides presented to the participants in each condition are presented in Table 3.

[Insert Table 3]

WM tests

Operation Span and Reading Span tests (Unsworth et al., 2005) were used as measures of WM. These tests require participants to remember letters in the order presented and either solve an arithmetical operation or judge the semantic plausibility of an English sentence. The participant is presented with one arithmetical operation or sentence at a time. During each trial an arithmetical problem or sentence is presented and then a letter immediately follows. The arithmetical problem / sentence – letter pairs are presented in sets of 3 to 7 items. After each complete set participants have to recall letters in the order presented. Trials consist of 3 sets of each set-size, with the set-sizes ranging from 3 - 7. The order of presentation of each set size is random for each participant. Altogether participants are presented with 75 letters and 75 arithmetical problems or sentences.

The two WM tasks were obtained from the Attention and WM Lab at Georgia Institute of Technology. They have been used in a number of previous studies (Redick et al., 2012; Turner & Engle, 1989; Unsworth & Engle, 2008).

Procedure

Participants were randomly assigned to one of two conditions: the explicit learning condition or the incidental learning condition. The experiment consisted of a pre-training phase in which participants were administered the two WM tests. In the pre-training phase they also undertook vocabulary learning and were tested on this. The pre-training phase was followed by a training phase in which participants either received explicit instruction on the noun-adjective agreement rule in the four cases and the two genders, or were exposed to varying types and tokens of actual sentences as a function of frequency condition (high type-high token, high type-low token, low type-low token, low type-high token). Finally, the test phase immediately followed the training phase and participants were tested on their productive knowledge of noun-adjective agreement.

Pre-training

WM Tests. Participants completed the two WM tasks delivered via E-Prime 2 (Psychology Software Tools, Pittsburgh, PA), Operation Span (OS) and Reading Span (RS). During the OS test participants were presented with simple arithmetical operations such as $(2*1) + 1 = 3$, and were asked to judge their correctness as soon as possible by clicking a true or false box on the computer screen. Immediately after each operation an English letter appeared on the screen and participants were instructed to memorize the letters in the order in which they were presented. At the end of each set of trials participants were asked to recall the English letters in the correct order by ticking the appropriate box on the screen with a mouse click. Also participants were instructed to keep their accuracy on the arithmetical operation at least 85% and received feedback on how many letters they recalled. The real trials were preceded by a set of practice trials. During the practice session, the mean time that each participant

required to solve an arithmetical operation was recorded by a computer program, which was then used during the presentation of the real trials. If the participants took more than their average time plus 2.5 SD to solve the equation, then the program automatically moved on and the trial was recorded as an error.

In the RS task participants were presented with semantically plausible and semantically anomalous English sentences on the computer screen and were asked to judge the semantic plausibility of the sentences by clicking a true or false box on the computer screen. After each sentence an English letter appeared on the screen and participants were instructed to memorize the letters in the order they were presented. The procedure for the RS test was similar to that for the OS test.

Vocabulary Test. Participants memorized 6 Russian nouns, 4 adjectives, 3 prepositions (*k* ‘towards’, *ot* ‘away from’, *s* ‘with’) and the particle *eto* ‘this is’. The nouns and the adjectives were presented in the singular form and in the nominative case and masculine gender. The transliterations of the Russian words were presented in the Latin alphabet alongside an English translation and a matching picture, see Figure 1. After the memorization phase participants completed a vocabulary test. Participants had to score at least 85 % on the vocabulary test to proceed to the training phase.

Training

Participants were divided into five conditions: 4 incidental learning conditions (high type-high token frequency, high type-low token frequency, low token-high type frequency, low token-low type frequency) and an explicit learning condition.

As an initial part of training, participants in the incidental learning conditions saw one sequence of pictures with Russian sentences involving a stereotypical character of masculine gender and one involving a stereotypical feminine character like the one represented in Figure 1. Each sequence consisted of four sentences including a noun-adjective string in four cases (Nominative, Dative, Instrumental and Genitive) and four semantically corresponding pictures. Participants were thus given one example of a story with a character of each gender and were told that the character was of either masculine or feminine gender, but they were not explicitly told about the case-marking pattern. We also checked that participants correctly understood the motion of the characters depicted in the pictures. Participants were told that subsequently in the training phase they would view similar stories about similar characters.

During the training phase participants in the incidental learning conditions then saw sequences of pictures depicting actions performed by stereotypical feminine and masculine characters, and the corresponding sentences in Russian. They saw four pairs of pictures and sentences like those initially presented. Participants were instructed to look at each picture, read each sentence and try to understand its meaning. The presentation of the stories was randomized.

Participants in the explicit learning condition were presented with two examples of the noun- adjective agreement in all four cases for each gender together with the translations and the relevant metalinguistic explanation. They were asked to memorize the rule and were informed about the subsequent testing. The time spent by participants during the training phase in the explicit condition and the incidental learning conditions was the same.

Testing

The production task was “filling-the-gap” task. Participants saw pictures with Russian sentences similar to the ones they were exposed to during training and had to provide the missing ending of the adjective. There were 30 grammatical Russian sentences (15 new and 15 old) and the order of presentation of new and old blocks of sentences was counterbalanced among the participants. Participants in the incidental learning conditions were told that they would next see sentences and pictures similar to the ones they had seen previously, whereas participants in the explicit learning condition were told that they would be tested on the previously learned rule.

Debriefing

Participants completed all tasks in one session which lasted approximately 60 minutes, and were debriefed at the end of the experiment. If the participant could verbalize the metalinguistic rule of noun-adjective agreement or simply stated that the ending of the word changed depending on the movement of the character associated or the gender of the character, they were classified as “aware”. If the participant stated that they did not notice anything, they were classified as “unaware”. On the basis of this classification there were 28 aware and 52 unaware participants in the incidental learning conditions. Since investigating the role of awareness in knowledge acquisition was however not the focus of the present study, and employing verbal reports for measuring awareness was one of its limitations, we do not report separate results for aware and unaware participants.

Results

Frequency and production in incidental learning conditions

Overall performance on the production task in all the conditions, including the explicit learning condition, was below chance. Accuracy was measured on old and new items for the four cases (Nominative, Dative, Instrumental and Genitive) and two genders (feminine and masculine).

A distinction was made between complete production of the adjectival endings (where the full ending was reproduced correctly), and incomplete production (where the ending was partially reproduced). For the incomplete production, a participant received a point if, for instance, instead of providing the complete adjectival ending *-aya* for the agreement in the feminine gender Nominative case a participant produced an incomplete ending *-a* or *-ya*.

[Insert Figure 2]

[Insert Figure 3]

We first conducted statistical analyses of production accuracy scores between the incidental learning conditions. In the incidental learning conditions aware and unaware participants were not separated, but both included in the analyses. The data were analyzed using logistic regression in R (Generalized Linear Model (GLM), employing the R Commander software package (R Development Core Team, 2009, version 2.15.3)). We checked for normality and homogeneity by visual inspections of plots of residuals against fitted values. Throughout the paper, we present MCMC-estimated p-values that are considered significant at the $\alpha = 0.05$ level. To investigate production accuracy of adjectival endings the following factors were included in the model as fixed effects: Condition, RS Total score and OS Total score. The

variable of Condition had four levels according to the incidental learning conditions. The binomial family of GLM with the logit link function was used because the variable was dichotomous. The low type low token frequency condition was chosen as a reference category because of theoretical interest. The variables to be included in the model were selected on the basis of theoretical importance and the Bayesian information criterion (BIC).

Complete Production

The analysis demonstrated that participants in the low type low token frequency condition performed significantly better than participants in all other incidental learning conditions.

[Insert Table 4]

We also conducted separate comparisons between each incidental learning condition using the following model: Condition (fixed effect), Subject (random effect). A significant difference in production accuracy was found between all the incidental learning conditions, except between low type high token and high type low token frequency conditions.

[Insert Table 5]

Incomplete Production

The analysis showed that participants in the low type low token frequency condition performed better than in the high type high token frequency condition. Separate analyses also

demonstrated that in other incidental learning conditions participants produced endings more accurately than in the high type high token frequency condition.

[Insert Table 6]

[Insert Table 7]

Old vs. New Items

In addition, the analysis comparing the old and new items in each condition demonstrated that participants performed significantly more accurately on old rather than new items in the production of complete endings. The same was not true, however, for the production of incomplete endings.

[Insert Table 8]

[Insert Table 9]

Production in the explicit learning condition

To compare the effectiveness of productive knowledge acquisition in the explicit learning condition as compared to the incidental learning conditions we conducted separate comparisons between the explicit condition and each incidental learning condition using the model: Condition (fixed effect), Subject (random effect).

Participants in the explicit learning condition produced both complete and incomplete endings more accurately than in each incidental learning condition.

[Insert Table 10]

[Insert Table 11]

WM and knowledge acquisition under incidental learning conditions

Having found a significant positive effect of WM on production accuracy by conducting a logistic regression analysis, we then conducted a series of two-tailed Pearson correlation tests to further explore the relationship between participants' scores on the WM tests and productive knowledge acquisition in each incidental learning condition. To gain a better understanding of this relationship, separate correlations were conducted for two scores arising from both WM tests: OS/ RS total score, which was calculated for all the letters recalled by participants in the order they were presented, and OS/ RS score, which was calculated for all the letters recalled without taking into account the order.

Performance on production in the explicit learning condition was positively correlated with the OS test scores, whereas performance on production in the incidental learning conditions positively correlated with the RS test scores.

[Insert Table 12]

[Insert Table 13]

Discussion

In line with previous L2 acquisition research our findings suggest that an explicit learning condition is generally more effective for the acquisition of L2 grammatical knowledge than the incidental (DeKeyser, 1995; Ellis, N., 1993; Hulstijn & de Graaff, 1994; Norris & Ortega, 2000; Robinson, 1996) our results demonstrate that participants in the explicit learning conditions exhibited better knowledge retention in production than participants in the incidental learning conditions.

With respect to the role of frequency, our first finding is that at the initial stages learners are starting small in production and that token frequency has a more significant effect for productive knowledge acquisition than type frequency. Overall, learners who were exposed to fewer types and fewer tokens exhibited the highest level of accuracy in production among all the incidental learning conditions. Learners exposed to fewer types and higher tokens exhibited the second highest accuracy rate. These results are in line with the notion that “less is more” and first language acquisition studies proposing the primacy of token frequency over type (Newport, 1990; Tomasello, 2000, 2008) and exemplar-based learning assumptions (Braine & Brooks, 1995; Brooks, Tomasello, Dodson & Lewis, 1999; Ellis, 2002, 2006, 2014; Tomasello, 2000, 2008). Similarly, they are supported by cognitive approaches to L2 learning and the event-based view that posits the importance of tokens over types for the categorization of the input information (Ellis, 2002). They also fit in with the implications of some research on artificial language learning, where adults learned better morphology and meaning when initially presented with small segments of language rather than the full complex system (Kersten & Earles, 2001). Thus, in our experiment those learners who were exposed to few examples (low type low token frequency condition) could retain and produce the knowledge better, compared to those who had been exposed to high number of examples (high type high token frequency condition).

Another explanation could also be that the acquisition of a grammatical pattern in beginner adult learners is based on memorization. Taraban (2004) showed that while learning an artificial grammar adults tend to memorize rather than regularize the structure. Similarly, in the study by Robinson (2005) participants accepted chunks of ungrammatical letter strings presented with high frequency as correct, which may imply that high frequency items may appear more salient during the process of forming memory representations. Thus, as suggested by a fragment-view approach, learners track the frequency of the items co-occurring in the input and store them in memory as fragments (Johnstone & Shanks, 2001; Knowlton & Squire, 1992, 1994; Perruchet & Pacteau, 1990). Such piecemeal memorization is present in our findings: learners started with the production of an incomplete ending indicating the knowledge of a given agreement pattern, before producing a complete morphological form (e.g. incomplete form *-a-* before complete ending *-aya-*). In addition, the production of complete endings (the full morphological form) was better for the trained (old) rather than the new items. However the learners were able to generalize the knowledge acquired in the incidental learning conditions when producing an incomplete morphological form indicating gender and case agreement (incomplete endings). Thus, it could be the case that, because productive knowledge acquisition is a more cognitively demanding task, a learner would memorize small chunks of information exemplified by frequently occurring tokens. In contrast, in the comprehension task, where participants were asked to perform a recognition grammatical judgment task, accuracy was at ceiling.

The second finding was that WM resources were engaged during activation of grammatical knowledge acquired during incidental exposure in production. WM was engaged when the learner was confronted by a complex agreement rule varying as a function of gender and case. However, when the facilitating factor of frequency came into play, adults were able to automatically activate acquired knowledge during the production task, without

engaging WM. The learners in the low type low token frequency condition did not recruit WM and also performed the most successfully among the learners in all other incidental learning conditions.

These findings are in line with previous research that demonstrated that verbal WM is involved in the learning of words through incidental exposure in the absence of facilitating factors such as visual cues (Duyck et al., 2003). Similarly, the study by Misyak and Christiansen (2012) exploring the relationship between statistical learning of adjacent and nonadjacent dependencies and verbal working memory found a positive correlation with WM.

Also, different types of WM may be engaged in knowledge acquisition under incidental and explicit learning conditions. In the present study learners in the incidental learning conditions were acquiring grammar together with meaning and thus their scores correlated with the Reading Span test scores, whereas learners in the explicit learning condition were memorizing the grammar rule and thus their scores correlated with the Operation Span scores. This fits with previous studies on the acquisition of grammatical knowledge through explicit and incidental learning, where participants' performance on post-tests in the explicit learning (rule-search) condition correlated with Operation Span (Tagarelli et al., 2011), and research on sentence processing and reading in adult L2 learners where a correlation with Reading Span was found (Alptekin & Ercetin, 2009; Harrington & Sawyer, 1992; Juffs, 2004; Jeaser, 2007). The finding of this experiment may be explained by the nature of natural language learning. During such learning a lexical meaning processing would take place, which implicates the involvement "of declarative memory for words and events" and makes the critical distinction between artificial and natural language (Robinson, 2010, p.260).

When it comes to incidental learning, our findings support the assumption that L2 adult learners are guided by the same principles of associative and cognitive learning as L1 learners, with frequency being a crucial mechanism of learning, as suggested by the Associative-Cognitive CREED proposal of Ellis (2006). Also, according to Bybee's network model of the acquisition of complex morphology (1985; 1988), both type frequency, understood as the frequency of a morphological pattern, and token frequency, the frequency of exemplars, play an important role in establishing and maintaining representations of the newly acquired associations. High frequency morpho-syntactic structures become more entrenched and easier to access as a whole; in the high token condition where learners were exposed to fewer types, we did indeed report the highest learning effect in production (Hooper, 1976, Bybee, 1985). Similarly to research by Ellis et al. (2014), entrenchment guided by high token frequency of a particular item occurring within a construction helped adults to access it more easily.

However contrary to Bybee's proposal, in this experiment high type frequency did not increase productivity by strengthening the schema and increasing its chances of being applied to new items in production. Thus, it can be assumed that acquisition of productive knowledge of the noun-adjective agreement pattern in the present experiment was based on memorization and followed the trend of piecemeal exemplar-based learning, with token frequency playing a more important role than type frequency (Ellis, 2002; Tomasello, 2000, 2008). This however, may be happening only at the initial stages of learning. In the later stages, when the representations are formed, type frequency may come into play as a factor helping to generalize the acquired knowledge to new items.

The asymmetry of the frequency effect in comprehension and production may also have to do with the general asymmetry between receptive and productive levels of knowledge (ceiling effect in comprehension and below chance, very poor, in production) in all the

incidental learning conditions. This asymmetry between the levels of knowledge and different frequency effects in receptive and productive knowledge acquisition could be explained by the general established assumption that comprehension precedes production in language acquisition (Clark & Hecht, 1982; Fraser et al., 1963; DeKeyser & Sokalski, 1996; Winitz et al., 1981). At the same time, such an asymmetry between production and comprehension is also exemplified by the engagement of WM during acquisition of patterns in incidental learning conditions with different involvement of frequency. Our findings suggest that the impact of frequency is more important for production, as a more cognitively demanding task than comprehension, and that frequency appears to be one of the facilitating mechanisms of knowledge acquisition through incidental exposure that helps a learner to stay away from engaging WM resources. In contrast to previous studies focusing on comprehension (Conway et al., 2011; Kaufman et al., 2010; Tagarelli et al., 2011) and findings by Brooks and Kempe (2013) investigating productive knowledge acquisition as measured after the six sessions, WM was engaged by beginner learners (exposed to the pattern in one session) during production in the present study. This may support the assumption by Kaufman et al. (2010), who suggested that a learner might resort to WM only at the initial stages of learning under incidental learning conditions. Since our participants were tested after a single hour-long session, it would be desirable for future research to conduct a longitudinal study in order to investigate whether a learner may still resort to WM after multiple exposures and whether performance on production would improve.

References

- Abbot-Smith, K., Lieven, E., & Tomasello, M. (2004). Training 2;6-year-olds to produce the transitive construction: the role of frequency, semantic similarity and shared syntactic distribution. *Developmental science*, 7 (1), 48-55.
- Alptekin, C, & Ercetin, G. (2009). Assessing the relationship of WM to L2 reading: Does the nature of comprehension process and reading span task make a difference? *System*, 37, 627-639.
- Barakat, B., Seitz, A., & Shams, L. (2013). The effect of statistical learning on internal stimulus representations: Predictable items are enhanced even when not predicted. *Cognition*, 129, 205–211.
- Barcroft, J. (2009). Effects of synonyms generation on incidental and intentional L2 vocabulary learning during reading. *TESOL Quarterly*, 43(1), 79-103.
- Bialystok, E. (1981). The role of linguistic knowledge in second language use. *Studies in Second Language Acquisition*, 4, 31-45.
- Bley-Vroman, R. (2002). Frequency in production and comprehension, and acquisition. *Studies in Second Language Acquisition*, 24,209-213.
- Braine, M., & Brooks, P. (1995). Verb argument structure and the problem of avoiding an overgeneral grammar. In M. Tomasello & W. E. Merriman (Eds.), *Beyond names for things: Young children's acquisition of verbs* (pp. 352–376). Hillsdale, NJ: Erlbaum.
- Brandt, S., Verhagen, A., Lieven, E., & Tomasello, M. (2011). German children's productivity with simple transitive and complement-clause constructions: Testing the effects of frequency and variability, *Cognitive Linguistics*, 22 (2), 325–357.
- Brooks, P., & Kempe, V. (2013). Individual differences in adult foreign language learning: The mediating effect of metalinguistic awareness . *Memory & Cognition*, 41 (2), 281-296.
- Brooks, P., Tomasello, M., Dodson, K., & Lewis, L. (1999). Young children's overgeneralizations with fixed transitivity verbs. *Child Development*, 70 (6), 1325–1337.

- Bybee, J. (1985). *Morphology: A study of the relation between meaning and form*. Philadelphia, PA: John Benjamins.
- Bybee, J. (1988). Morphology as lexical organization. In M. Hammond & M. Noonan (Eds), *Theoretical morphology*. San Diego, CA Academic Press.
- Chen, W., Guo, X., Tang, J., Zhu, L., Yang, Zh., & Dienes, Z., (2011). Unconscious structural knowledge of form–meaning connections. *Consciousness and Cognition*, 20, 1751–1760.
- Clark, E., Hecht, B. (1982). Learning to coin agent and instrument nouns. *Cognition*, 12, 1-24.
- Conway, C., Baurnschmidt, A., Huang, S., & Pisoni, D. (2011). Implicit statistical learning in language processing: Word predictability is the key. *Cognition*, 114 (3), 356-371.
- DeKeyser, R. (1995). Learning second language grammar rules: An experiment with a miniature linguistic system. *Studies in Second Language Acquisition*, 17, 379-410.
- DeKeyser, R. (2000). The robustness of critical period effects in second language acquisition. *Studies in Second Language Acquisition*, 22, 499-533.
- DeKeyser, R., & Sokalski, K. (1996). The differential role of comprehension and production practice. *Language Learning*, 46 (4), 613–642.
- Duyck, W., Szmalec, A., Kemps, E., & Vandierendonck, A. (2003). Verbal WM is involved in associative word learning unless visual codes are available. *Journal of Memory and Language* 48, 527–541.
- Ellis, N. (2002). Frequency effects in language processing: A review with implications for theories of implicit and explicit language acquisition. *Studies in Second Language Acquisition*, 24, 143-188.
- Ellis, N. (2005). At the interface: dynamic interactions of explicit and implicit language knowledge, *Studies in Second Language Acquisition*, 27, 305–352.

- Ellis, N. (2006). The associative-cognitive CREED. In *Theories in Second Language Acquisition: An introduction*, B. VanPatten and J. Williams (eds). Cambridge: CUP.
- Ellis, R. (2005). Measuring implicit and explicit knowledge of a second language: a psychometric study. *Studies in Second Language Acquisition*, 27 (2), 141-17.
- Ellis, N., O'Donnell, M., & Romer, U. (2014). The processing of verb-argument constructions is sensitive to form, function, frequency, contingency and prototypicality. *Cognitive Linguistics*, 25 (1), 55-98.
- Fraser, C., Bellugi, U., & Brown, R. (1963). Control of grammar in imitation, comprehension, and production. *Journal of Verbal Learning and Verbal Behavior*, 2 (2), 121-135.
- Frensch, P., & Runger, D. (2003). Implicit learning. *Current Directions in Cognitive Science*, 12 (1), 13-18.
- Gass, S., & Mackey, A. (2002). Frequency effects and second language acquisition. *Studies in Second Language Acquisition*, 24 (2), 249-260.
- Hama, M. & Leow, R. P. (2010). Learning without awareness revisited. *Studies in Second Language Acquisition*, 32 (3), 465-491.
- Hamrick, P., & Rebuschat, P. (2013). Frequency effects, learning conditions, and the development of the implicit and explicit knowledge. *Measured language: Quantitative approaches to acquisition, assessment, processing, and variation*, J. Connor-Linton & L. Amoroso (Eds.). Georgetown University Press: Washington, D.C.
- Harrington, M., & Sawyer, M. (1992). L2 WM capacity and L2 reading skill. *Studies in Second Language Acquisition*, 14, 25-38.
- Hooper, J. (1976). Word frequency in lexical diffusion and the source of morphophonological change. Current progress in historical linguistics, ed. by William Christie, 96-105. Amsterdam: North-Holland.

- Hulstijn, J. (2005). Theoretical and empirical issues in the study of implicit and explicit second-language learning. *Studies in Second Language Acquisition*, 27, 129-140.
- Hulstijn, J., & de Graaff, R. (1994). Under what conditions does explicit knowledge of a second language facilitate the acquisition of implicit knowledge? A research proposal. *AILA Review*, 11, 97-112.
- Hummel, K. M. (2009). Aptitude, phonological memory, and second language proficiency in nonnovice adult learners. *Applied Psycholinguistics*, 30, 225-249.
- Jeaser, M. (2007). Learner-based factors in L2 reading comprehension and processing grammatical form: Topic familiarity and WM. *Language Learning*, 57 (2), 229-270.
- Johnson, J. S., & Newport, E. L. (1989). Critical period effects in second language learning: The influence of maturational state on the acquisition of English as a second language. *Cognition Psychology*, 21, 60–99.
- Johnstone, T., & Shanks, D. (2001). Abstractionist and processing accounts of implicit learning. *Cognitive Psychology*, 42, 61–112.
- Juffs, A. (2004). Representation, processing and WM in a second language. *Transactions of the Philological Society*, 102 (2), 199-225.
- Kaufman, S., Deyoung, C., Gray, J., Jiménez, L., Brown, J., & Mackintosh, N. (2010). Implicit learning as an ability. *Cognition*, 116 (3), 321-340.
- Kempe, V., Brooks, P., & Kharkhurin, A. (2010). Cognitive predictors of generalization of Russian grammatical gender categories. *Language Learning*, 60 (1), 127-153.
- Kersten, A., & Earles, J., (2001). Less really is more for adults learning a miniature artificial language. *Journal of Memory and Language*, 44 (2), 250–273.
- Kidd, E., Lieven, E., Tomasello, M. (2006). Examining the role of lexical frequency in children's acquisition and processing of sentential complements. *Cognitive Development*, 21, 93-107.

- Kidd, E., Lieven, E., Tomasello, M. (2010). Lexical frequency and exemplar-based learning effects in language acquisition: Evidence from sentential complements. *Language Sciences*, 32, 132-142.
- Knowlton, B., & Squire, L. (1992). Intact artificial grammar learning in amnesia: Dissociation of classification learning and explicit memory for specific instances. *Psychological Science*, 3, 172–179.
- Knowlton, B., & Squire, L. (1994). The information acquired during artificial grammar learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20, 79–91.
- Lee, J. (2002). The incidental acquisition of Spanish. *Studies in Second Language Acquisition*, 24 (1), 55-80.
- Leow, R. (2000). A study of the role of awareness in foreign language behavior. *Studies in Second Language Acquisition*, 22, 557-584.
- Leung, J. & Williams, J. (2011). The implicit learning of mappings between forms and contextually derived meanings. *Studies in Second Language Acquisition*, 33 (1), 33-55.
- Lieven, E. (2010). Input and first language acquisition: Evaluating the role of frequency. *Lingua*, 120, 2546-2556.
- Lieven, E., & Tomasello, M. (2008). Children's first language acquisition from a usage-based perspective: In P. Robinson and N. Ellis (eds). *Handbook of Cognitive Linguistics and Second Language Acquisition* (pp. 168-196).
- Mackey, A., Philp, J., Egi, T., Fujii, A., & Tatsumi, T. (2002). Individual differences in working memory, noticing interactional feedback and L2 development. In P. Robinson (Ed.), *Individual differences and instructed language learning* (pp. 181–209). Philadelphia: Benjamins.

- Masoura, E., & Gathercole, S. (2005). Contrasting contributions of phonological short-term memory and long-term knowledge to vocabulary learning in a foreign language. *Memory* 13 (4), 422–429.
- Morgan-Short, K., Sanz, C., Stainhauer, K., & Ullman, M.T. (2010). Second language acquisition of gender agreement in explicit and implicit training conditions: An event-related potential study. *Language Learning*, 60 (1), 154-193.
- Matthews, D., Lieven E., Theakston, A., & Tomasello, M. (2005). The role of frequency in the acquisition of English word order. *Cognitive Development*, 20 (1), 121–136.
- Misyak, J., & Christiansen, M. (2011). Statistical learning and language: An individual difference study. *Language Learning*, 69 (1), 302-331.
- Miyake, A., & Friedman, N. (1998). Individual differences in second language proficiency: Working memory as “language aptitude.” In A. F. Healy & L. E. Bourne (Eds.), *Foreign language learning: Psycholinguistic studies on training and retention* (pp. 339–364). Mahwah, NJ: Lawrence Erlbaum Associates.
- Morra, S., & Camba, R. (2009). Vocabulary learning in primary school children: Working memory and long-term memory components. *Journal of Experimental Child Psychology*, 104, 156–178.
- Morgan-Short, K., Faretta-Stutenberg, F., Brill-Schuetz, K., Carpenter, K., & Wong, P. (2014). Declarative and procedural memory as individual differences in second language acquisition. *Bilingualism: Language and Cognition*, 17 (1), 56-72.
- Newport, E. (1990). Maturational constraints on language learning. *Cognitive Science*, 14, 11–28.
- Norris, J., & Ortega, L. (2000). Effectiveness of L2 instruction: A research synthesis and quantitative meta-analysis. *Language Learning*, 50, 417-528.
- Reber, A. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior*, 6, 317-327.

- Rebuschat, P., & Williams, J. (2011). Implicit and explicit knowledge in second language acquisition. *Applied Psycholinguistics*, pp. 1-28.
- Redick, T.S., Broadway, J.M., Meier, M.E., Kuriakose, P.S., Unsworth, N., Kane, M.J., & Engle, R. W. (2012). Measuring WM capacity with automated complex span tasks. *European Journal of Psychological Assessment* 28, 164-171.
- Perruchet, P., & Pacteau, C. (1990). Synthetic grammar learning: Implicit rule abstraction or explicit fragmentary knowledge? *Journal of Experimental Psychology: General*, 119, 264–275.
- Robinson, P. (1997). Generalizability and automaticity of second language learning under implicit, incidental, enhanced, and instructed conditions. *Studies in Second Language Acquisition*, 19, 223-247.
- Robinson, P. (2005). Cognitive abilities, chunk-strength, and frequency effects in implicit artificial grammar and incidental L2 learning: replications of Reber, Walkenfeld, and Hernstadt (1991) and Knowlton, and Squire (1996) and their relevance for SLA. *Studies in Second Language Acquisition*, 27, 235-268.
- Robinson, P. (2010). Implicit Artificial Grammar and Incidental Natural Second Language Learning: How Comparable Are They? *Language Learning*, 60 (2), 245–263.
- Roehr, K. (2008). Linguistic and metalinguistic categories in second language learning. *Cognitive Linguistics*, 19 (1), 67–106.
- Rosa, E., & O'Neill, M. (1999). Explicitness, intake and the issue of awareness: Another piece to the puzzle. *Studies in Second Language Acquisition*, 21, 511-556.
- Rott, S. (1999). The effect of exposure frequency on intermediate language learners' incidental vocabulary acquisition and retention through reading. *Studies in Second Language Acquisition*, 21(4), 589-619.

- Saffran, J. (2003). Statistical language learning: Mechanisms and constraints. *Current Directions in Psychological Science*, 12, 110-114.
- Saffran, J., Newport, E., Aslin, R., Tunick, R., & Barrueco, S. (1997). Incidental language learning: Listening (and learning) out of the corner of your ear. *Psychological Science*, 8, 101-105.
- Scheffler, P. (2008). The natural approach to adult learning and teaching of L2 grammar. *International Review of Applied Linguistics in Language Teaching*, 46 (4), 289-313.
- Schmidt, R. (1993). Awareness and second language acquisition. *Annual Review of Applied Linguistics*, 13, 206-226.
- Speciale, G., Ellis, N., & Bywater, T (2004). Phonological sequence learning and short-term store capacity determine second language vocabulary acquisition. *Applied Psycholinguistics*, 25 (2), 293-321.
- Tagarelli, K., Borges-Mota, M., & Rebuschat, P. (2011). The role of WM in implicit and explicit language learning. 2061-2066.
- Taraban, R. (2004). Drawing learners' attention to syntactic context aids gender-like category induction. *Journal of Memory and language*, 51 (2), 202-216.
- Tomasello, M. (2000). The item-based nature of children's early syntactic development. *Trends in Cognitive Sciences*, 4 (4), 156-163.
- Tomasello, M. (2003). *Constructing a language : a usage-based theory of language acquisition*. Cambridge: Harvard University Press.
- Tomasello, M. (2008). *Origins of human communication*. Cambridge: The MIT Press.
- Turner, M. L., & Engle, R. W. (1989). Is WM capacity task dependent? *Journal of Memory & Language*, 28, 127-154.
- Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, 37, 498-505.

Unsworth, N. & Engle, R.W. (2008). Speed and accuracy of accessing information in WM:

An individual differences investigation of focus switching. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34, 616-630.

Williams, J. (2005). Learning without awareness. *Studies in Second Language Acquisition*, 24, 269-304.

Williams, J., & Lovatt, P. (2003). Phonological memory and rule learning. *Language Learning*, 53 (1), 67-121.

Winitz, H., Sancier, R., Kort, J. (1981). Comprehension and production of the /z/ plural allomorph. *Journal of Psycholinguistics Research*, 10, 259-271.

Yang, J., & Li, P. (2012). Brain Networks of explicit and implicit learning. *PLOS ONE*, 7 (8), 1-9.

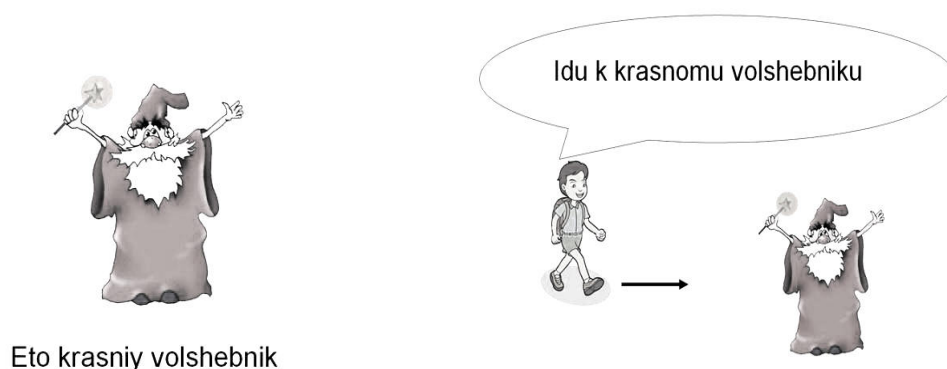




Figure 1. Example of the training slides

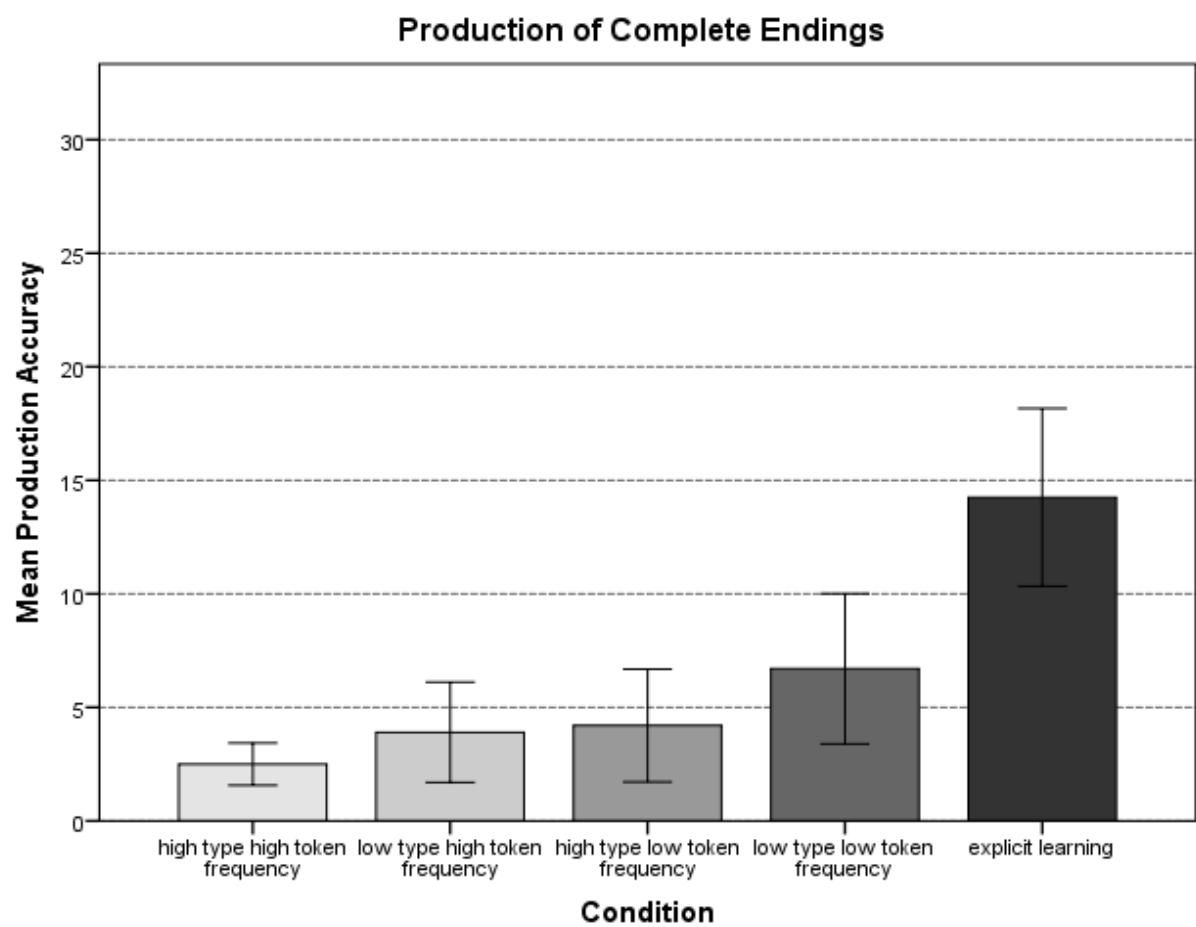


Figure 2. Production accuracy of complete endings in explicit and incidental learning conditions

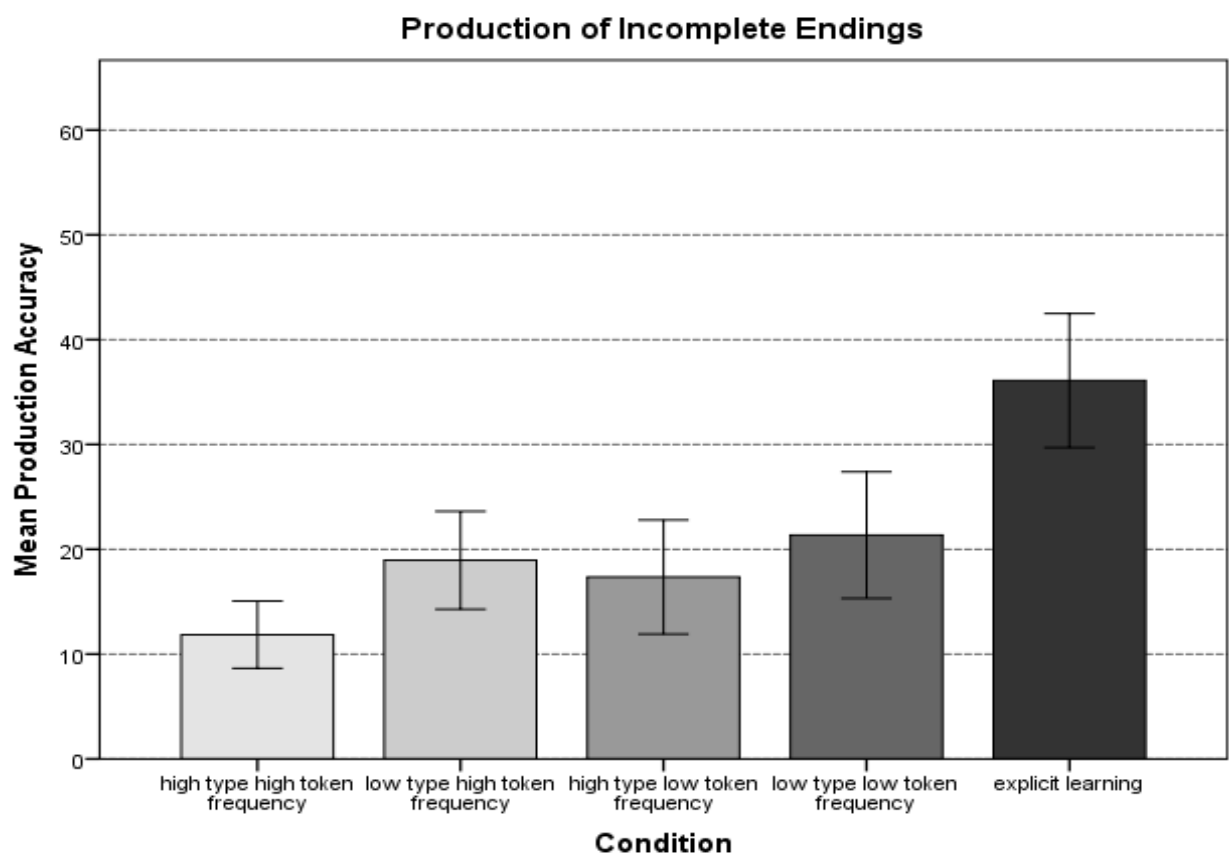


Figure 3. Production accuracy of incomplete endings in explicit and incidental learning conditions

Table 1. Case-marking paradigm for feminine and masculine genders in Russian

| masculine gender | | feminine gender | | |
|------------------|-----------|-----------------|-----------|------|
| case | adjective | noun | adjective | noun |
| Nominative | -iy | -∅ | -aya | -a |
| Dative | -omu | -u | -oy | -e |
| Instrumental | -im | -om | -oy | -oy |
| Genitive | -ogo | -a | -oy | -i |

Table 2. Examples of training sentences

| case | masculine | feminine |
|--------------|--|--|
| Nominative | <p>Eto krasniy volshebnik- This is a red magician</p> <p><i>Eto krasn-iy volshebnik-Ø</i></p> <p>This is red-MASC.NOM magician-MASC.NOM</p> | <p>Eto nizkaya vedma- This is a short witch</p> <p><i>Eto nizk-aya vedm-a</i></p> <p>This is short-FEM.NOM witch-FEM.NOM</p> |
| Dative | <p>Idu k krasnomu volshebniku- I am going towards the red magician</p> <p><i>Idu k krasn-omu volshebnik-u</i></p> <p>I am going towards red-MASC.DAT magician-MASC.DAT</p> | <p>Idu k nizkoy vedme- I am going towards the short witch</p> <p><i>Idu k nizk-oy vedm-e</i></p> <p>I am going towards short-FEM.DAT witch-FEM.DAT</p> |
| Instrumental | <p>Idu s krasnim volshebnikom- I am going with the red magician</p> <p><i>Idu s krasn-omu volshebnik-om</i></p> <p>I am going with red-MASC.INST magician-MASC.INST</p> | <p>Idu s nizkoy vedmoy- I am going with the short witch</p> <p><i>Idu s nizk-oy vedm-oy</i></p> <p>I am going with short-FEM.INST witch-FEM.INST</p> |
| Genitive | <p>Idu ot krasnogo volshebnika- I am going away from the red magician</p> <p><i>Idu ot krasn-ogo volshebnik-a</i></p> <p>I am going away from red-MASC.GEN magician-MASC.GEN</p> | <p>Idu ot nizkoy vedmi- I am going away from the short witch</p> <p><i>Idu ot nizk-oy vedm-i</i></p> <p>I am going away from short-FEM.GEN witch-FEM.GEN</p> |

Table 3. Distribution of types and tokens per condition

| condition | feminine gender | masculine gender | cases | repeated | number of slides |
|-----------------------------------|--------------------|---------------------|---------|----------|---------------------|
| high type high token frequency | 7 types | 7 types | 4 cases | 7 times | 392 slides |
| high type low token frequency | 7 types | 7 types | 4 cases | 3 times. | 168 slides |
| low type high token frequency | 3 types | 3 types | 4 cases | 7 times | 168 slides |
| low type low token | 3 types | 3 types | 4 cases | 3 times | 72 slides |

| | | | | | |
|-----------|--|--|--|--|--|
| frequency | | | | | |
|-----------|--|--|--|--|--|

Table 4. Analysis of production of complete endings

| | Estimate | Standard Error | wald z | <i>p</i> |
|------------------------------------|--------------|-------------------|--------------|------------------|
| (Intercept) | -3.30 | 0.40 | -8.27 | < .001 |
| Condition : | | | | |
| low type low token frequency | | | | |
| vs. low type high token frequency | -0.36 | 0.15 | -2.37 | 0.02 |
| low type low token frequency | | | | |
| vs. high type low token frequency | -0.29 | 0.15 | -1.88 | 0.06 |
| low type low token frequency | | | | |
| vs. high type high token frequency | -1.01 | 0.17 | -5.63 | < .001 |
| Operation Span Total score | 0.01 | 0.01 | 1.87 | 0.06 |
| Reading Span Total score | 0.02 | 0.01 | 3.49 | < .001 |

Table 5. Comparison between the incidental learning conditions

| condition | Std. Error | z wald | <i>p</i> value |
|---|------------|--------|----------------|
| high type high token frequency vs. low type high token frequency | 0.19 | 4.11 | < .001 |
| high type high token frequency vs. high type low token frequency | 0.11 | 2.90 | 0.004 |

| | | | |
|--|------|-------|------|
| low type high token frequency vs. high type low token frequency | 0.17 | -0.79 | 0.43 |
|--|------|-------|------|

Table 6. Analysis of production of incomplete endings

| | Estimate | Standard Error | wald z | <i>p</i> |
|------------------------------------|--------------|-------------------|--------------|------------------|
| (Intercept) | -2.24 | 0.27 | -8.56 | < .001 |
| Condition : | | | | |
| low type low token frequency | | | | |
| vs. low type high token frequency | 0.20 | 0.11 | 1.71 | 0.09 |
| low type low token frequency | | | | |
| vs. high type low token frequency | 0.21 | 0.12 | 1.78 | 0.08 |
| low type low token frequency | | | | |
| vs. high type high token frequency | -0.52 | 0.12 | -4.25 | < .001 |
| Operation Span Total score | 0.00 | 0.00 | 0.90 | 0.37 |
| Reading Span Total score | 0.04 | 0.00 | 7.34 | < .001 |

Table 7. Comparison between the incidental learning conditions

| condition | Std. Error | z wald | <i>p</i> value |
|---|------------|--------|----------------|
| high type high token frequency vs. low type high token frequency | 0.12 | 6.38 | < .001 |
| high type high token frequency vs. high type low token frequency | 0.14 | 3.11 | 0.002 |
| low type high token frequency vs. high type low token frequency | 0.13 | -2.890 | 0.004 |

Table 8. Old and new items production in each condition

| condition: | high type high token frequency | low type high token frequency | high type low token frequency | low type low token frequency | explicit learning |
|------------|--------------------------------------|-------------------------------------|-------------------------------------|------------------------------------|----------------------|
| | | | | | |

| | | | | | |
|-----------------------------------|--------|--------|-------|-------|------|
| <i>p</i> value: new vs. old items | < .001 | < .001 | 0.001 | 0.007 | 0.02 |
|-----------------------------------|--------|--------|-------|-------|------|

Table 9. Incomplete production of old and new items

| condition: | high type high token frequency | low type high token frequency | high type low token frequency | low type low token frequency | explicit learning |
|------------------------------|--------------------------------------|-------------------------------------|-------------------------------------|------------------------------------|----------------------|
| p value: new vs. old items | 0.08 | 0.74 | 0.33 | 0.94 | 0.66 |

Table 10. Complete production: Explicit learning and all other conditions

| condition | Std. Error | z wald | <i>p</i> value |
|--------------------------------|------------|--------|----------------|
| low token low type frequency | 0.49 | 6.54 | < .001 |
| high type low token frequency | 0.20 | 7.87 | < .001 |
| low type high token frequency | 0.07 | 7.52 | < .001 |
| high type high token frequency | 0.05 | 9.85 | < .001 |

Table 11. Incomplete production: Explicit learning condition and all other conditions

| condition | Std. Error | z wald | <i>p</i> value |
|-------------------------------|------------|--------|----------------|
| low token low type frequency | 0.46 | 6.04 | < .001 |
| high type low token frequency | 0.16 | 5.04 | < .001 |
| low type high token frequency | 0.05 | 6.98 | < .001 |

| | | | |
|-----------------------------------|------|-------|--------|
| high type high token frequency | 0.15 | 12.37 | < .001 |
|-----------------------------------|------|-------|--------|

Table 12. WM and production accuracy

| condition | OS total | | OS score | | RS total | | RS score | |
|--------------------------------|------------|------------|------------|------------|----------|----------|------------|------------|
| | <i>r</i> | <i>p</i> | <i>r</i> | <i>p</i> | <i>r</i> | <i>p</i> | <i>r</i> | <i>p</i> |
| explicit learning | .49 | .03 | .45 | .05 | .29 | .22 | .16 | .49 |
| high type low token frequency | .2 | .39 | .03 | .91 | .26 | .27 | .31 | .18 |
| low type high token frequency | .2 | .39 | .03 | .91 | .26 | .27 | .31 | .18- |
| high type high token frequency | .42 | .07 | .42 | .07 | .35 | .14 | .46 | .04 |
| low type low token frequency | .14 | .55 | .14 | .57 | -.10 | .68 | -.11 | .63 |

Table 13. WM and incomplete production

| condition | OS total | | OS score | | RS total | | RS score | |
|--------------------------------|-----------|------------|-----------|------------|----------|----------|------------|------------|
| | <i>r</i> | <i>p</i> | <i>r</i> | <i>p</i> | <i>r</i> | <i>p</i> | <i>r</i> | <i>p</i> |
| explicit learning | .5 | .05 | .5 | .03 | .22 | .35 | .12 | .62 |
| high type low token frequency | .33 | .16 | .13 | .59 | .38 | .10 | .45 | .04 |
| low type high token frequency | .33 | .16 | .13 | .59 | .38 | .10 | .46 | .04 |
| high type high token frequency | .23 | .34 | .18 | .46 | .39 | .09 | .39 | .09 |
| low type low token frequency | .25 | .28 | .31 | .19 | .12 | .61 | .1 | .68- |

Appendix

Stimuli

Vocabulary training and test

| noun | adjective | prepositions |
|--|--|--|
| vedma – witch karlik– dwarf babushka – grandmother tsarevna-princess volshebnik – magician pojarnik-firefighter | jeltiy-yellow krasniy - red lisiy - bold miliy - nice | Idu k...– I am going towards Idu s... – I am going with Idu ot... -I am going from |

Pre-training

Eto krasniy volshebnik (This is a red magician)

Idu k krasnomu volshebniku

Idu s krasnim volshebnikom

Idu ot krasnogo volshebника

Eto nizkaya vedma (This is a short witch)

Idu k nizkoy vedme

Idu s nizkoy vedmoy

Idu ot nizkoy vedmi

Training Sentences

Masculine:

Eto seriy pojarnik (This is a grey firefighter)

Idu k seromu pojarniku

Idu s serim pojarnikom

Idu ot serogo pojarnika

Eto miliy karlik (This is a nice dwarf)

Idu k milomu karliku

Idu s milim karlikom

Idu ot milogo karlika

Eto beliy vrach (This is a white doctor)

Idu k belomu vrachu

Idu s belim vrachom

Idu ot belogo vracha

Eto yuniy shkolnik (This is a young schoolboy)

Idu k yunomu shkolniku

Idu s yunim shkolnikom

Idu ot yunogo shkolnika

Eto lisiy letchik (This is a bold pilot)

Idu k lisomu letchiku

Idu s lisim letchikom

Idu ot lisogo letchika

Eto jeltiy povar (This is a yellow chef)

Idu k jeltomu povaru

Idu s jeltim povarom

Idu ot jeltogo povara

Eto temniy fokusnik (This is a brunette conjurer)

Idu k temnomu fokusniku

Idu s temnim fokusnikom

Idu ot temnogo fokusnika

Feminine:

Eto polnaya tsarevna (Thi is a plump princess)

Idu k polnoy tsarevne

Idu s polnoy tsarevnoy

Idu ot polnoy tsarevni

Eto svetlaya devochka (This is a blond girl)

Idu k svetloy devochke

Idu s svetloy devochkoy

Iduu ot svetloy devochki

Eto chernaya medsestra (This is a black nurse)

Idu k chernoy medsestre

Idu s chernoy medsestroy

Idu ot chernoy medsestri

Eto hudaya kuharka (This is a thin cook)

Idu k hudoy kuharke

Idu s hudoy kuharkoy

Idu ot hudoy kuharki

Eto tolstaya slujanka (This is a fat maid)

Idu k tolstoy slujanke

Idu s tolstoy slujankoy

Idu ot tolstoy slujanki

Eto grustnaya vdova (This is a sad widow)

Idu k grustnoy vdove

Idu s grustnoy vdovoy

Idu ot grustnoy vdovi

Eto staraya babushka (This is an old grandmother)

Idu k staroy babushke

Idu s staroy babushkoy

Idu ot staroy babushki