



UNIVERSIDADE DO ALGARVE

**ARTIFICIAL GRAMMAR LEARNING:
PREFERENCE FOR ACOUSTIC OR VISUAL MODALITY?**

Ana Isabel Santos Bernardo

**Projeto de dissertação para a obtenção do grau de Mestre
Mestrado em Neurociências Cognitivas e Neuropsicologia**

Trabalho efetuado sob a orientação de:

Prof. Doutor Karl Magnus Petersson

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To all of the participants.

RESUMO

A presente tese reporta o paradigma da aprendizagem artificial da gramática (AGL) na investigação da aprendizagem implícita, como modelo de aquisição e processamento da linguagem. Ao longo dos tempos observou-se a um aumento do número de estudos sobre a linguagem e a sua aquisição, nomeadamente na capacidade da aprendizagem implícita e especificamente em estudos que reportam a aprendizagem artificial da gramática.

A linguagem desempenha um papel social universal e de importância grande, particular ao ser humano, que requer que cada individuo detenha uma capacidade cognitiva de compreender e produzir sinais que facilitam e caracterizam a comunicação verbal (Jackendoff, 2002). Não existe por si só uma definição global de linguagem, mas o que diferencia a linguagem humana da linguagem entre animais, que igualmente produzem sons de comunicação, relaciona-se com a capacidade do ser humano não comunicar somente através da utilização de sinais verbais. Considerando a linguagem verbal podemos decompô-la em unidades de análise mais pequenas: os fonemas e os morfemas. O léxico é o conjunto de palavras numa determinada língua e, sendo objeto do presente estudo, a sintaxe alude às combinações de palavras admissíveis numa frase, isto é, a gramática da frase.

Diversos estudos têm comprovado a presença destes componentes da linguagem (baseada no som) nas crianças, reforçando o exposto por Chomsky, ao referir que todos os humanos possuem um mecanismo inato para desenvolvimento da linguagem (Kolb & Wishaw). Como Jackendoff (2002) postula, a criança inicia o seu discurso não com palavras *per se*, mas sim por uma espécie de crioulo, em nada

diferente de um adulto aquando a aquisição de uma nova linguagem. Acresce ainda o facto de que para a compreensão da linguagem, tanto enviada de um emissor auditivo ou visual, é necessária a integração das propriedades de semântica (significado correspondente de cada léxico ou palavra) e de sintaxe.

A compreensão e percepção da linguagem têm sofrido diversas modificações, desde a teoria de Tulving em 1970, Collins e Loftus em 1975 e Damásio em 1996 até ao dia de hoje, mas no entanto a definição de linguagem humana passou a contemplar o sistema de memória (Gazzaniga et al., 2009). O ser humano aprende, retém e relembra milhões de informações. A memória é utilizada para inúmeros propósitos, desde tarefas do quotidiano a tarefas como recordar eventos históricos mundiais e advém da união entre subsistemas inter-relacionados. Ao longo da literatura foram identificados diferentes tipos de memória: a memória a curto termo, caracterizada por armazenamento limitado de informação no tempo (minutos) e a memória a longo termo, definida por um armazenamento de informação extenso, que se subdivide em diferentes tipos de memória e onde se encontra a memória não declarativa ou implícita. A memória implícita inclui diversos conhecimentos que são utilizados no quotidiano e que são, conseqüentemente adquiridos através da aprendizagem implícita (Sohlberg & Mateer, 2001). A aprendizagem implícita, em contraste à memória explícita, pode ser descrita como a aprendizagem de informação complexa sem a capacidade de nomear de forma consciente o que foi aprendido e de que forma foi realizada a aprendizagem (Eysenck & Keane, 2010). Considerando o anterior exposto a aprendizagem artificial da gramática apresenta ser o modelo mais apropriado de estudar a aquisição e

processamento da linguagem. Pretende-se no presente estudo descrever a variação da performance entre e intra indivíduos na mesma condição e entre condições, verificar eficácia no processamento de informação auditiva/fonológica e visual/ortográfica e, avaliar a natureza do efeito das diferentes modalidades.

Participaram no estudo de forma voluntária vinte e oito sujeitos, estudantes universitários, com idades compreendidas entre os 19 anos de idade e os 32 anos de idade. Kürten et al. (2010) demonstraram no seu estudo que a performance dos indivíduos mais velhos era mais elevada nos itens que requeriam aprendizagem baseada nas regras, pelo que foi tomado em consideração a idade dos participantes da presente experiência.

O modelo de tarefa utilizado na presente investigação foi baseada no estudo de Reber (1967). A presente experiência de aprendizagem artificial da gramática foi realizada em três sessões que decorreram em três dias ininterruptos. O presente estudo contempla duas modalidades de apresentação dos testes e, quatro condições: prova visual/consoantes, visual/símbolos, auditiva/sons, auditiva/sílabas. As provas, realizadas no computador, eram constituídas por sequências; no final de cada sequência os participantes respondiam carregando em teclas previamente adequadas e explicadas. No primeiro dia foi aplicado uma tarefa de preferência (de base para verificar como o participante classifica) e uma tarefa de memória. No segundo dia os participantes realizavam apenas uma tarefa de memória. No último dia os participantes foram expostos a uma tarefa de memória, seguida de uma tarefa de preferência, após as quais os participantes foram informados de que as sequências apresentadas nas tarefas anteriores obedeciam a um conjunto de regras

e na última tarefa, a tarefa de gramaticalidade, classificaram as sequências como gramaticais ou não gramaticais, tendo por critério de resposta o instinto imediato. No fim de cada tarefa, os participantes preencheram um questionário, que serviu igualmente para a discussão dos resultados.

Os resultados foram analisados no software SPSS utilizando a ANOVA de medidas repetidas e o programa Statistic para a análise post-hoc. Os resultados revelaram efeitos significativos na gramaticalidade e no ACS, observando-se uma interação entre gramaticalidade e o teste nas três sessões e interação entre gramaticalidade e ACS. Foi ainda calculado a acuidade e o d-prime que demonstrou efeitos significativos entre AGL2 e AGL3, traduzindo-se num efeito de aprendizagem significativa. Estes dados revelam que, apesar de existir efeito de aprendizagem significativo apenas do AGL2 para o AGL3, a mesma verifica-se ao longo de toda a prova, indicando que se o presente estudo fosse realizado num maior número de sessões/ dias, os efeitos de aprendizagem seriam mais elevados, sólidos e com um maior poder de significância. No que respeita às modalidades presentes no estudo observou-se que os resultados, particularmente da variável “consoantes” (modalidade visual), são os mais propícios a indicar efeito significativo nas três sessões com interação da gramaticalidade e do ACS. Nesta linha, os resultados referentes à variável “símbolos” (modalidade visual) são os mais favoráveis a indicar efeito significativo nas três sessões com interação da gramaticalidade e do ACS. Os dados levam a considerar que beneficiariam de um aumento do número de sessões de exposição, bem como da participação de um maior número de sujeitos voluntários.

Sumariamente, o presente estudo revela que existe capacidade aprendizagem implícita da gramática artificial, bem como a propensão de resultados mais elevados na modalidade visual, nomeadamente referente a estímulos dentro do domínio da linguagem.

Palavras-chave: aprendizagem implícita; aprendizagem artificial da gramática; modalidade auditiva; modalidade visual; sequências sílabas; sequências tons; sequências consoantes; sequências símbolos.

ABSTRACT

This thesis transmits the artificial grammar learning paradigm as an acquisition and processing model of language, within implicit learning investigation. The number of investigations about language and its acquisition has increased throughout the years, specifically in the implicit learning ability and artificial grammar learning as the most adequate model to verify it.

Language, and namely human language, is an important part in the social universe and requires that each single individual own a cognitive capacity to understand and produce the signs that characterizes and enable verbal communication between humans (Jackendoff, 2002). From Tulving's 1970 theory until the present, language comprehension and perception has change, but through out times language definition contemplated the memory systems (Gazzaniga et al., 2009). Several authors stated that implicit memory and implicit learning plays a vast role in language acquisition.

The present study explores artificial grammar learning paradigm as a model (based on Reber's study on 1967) to implicit learning and to observe modalities performances differences between and within subjects. Twenty-eight subjects participated voluntarily in the present experiment. The study was developed in three consecutive days and in the last task in the last day subjects were informed and expose to sequences with underling grammar. The results reveled significant effects in grammaticality and ACS, an interaction between test days*grammaticality*ACS, specifically significant effects in AGL2 and AGL3, and suggest implicit learning of artificial grammar. These results could be more consistent if the experiment were

extended to more days of exposure. The results point out to a tendency in visual modality to demonstrated significant effects, particularly consonants sequences, and imply the visual modality to be the modality with higher tendency to be efficient in artificial grammar learning, namely within the language domain.

Keywords: implicit learning; artificial grammar learning; auditory modality; visual modality; syllables sequences; tones sequences; consonants sequences; symbols sequences.

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LIST OF ABBREVIATIONS

AGL	Artificial Grammar Learning
ACS	Associative chunk set
AGL1	Baseline/day 1
AGL2	Preference/day 2
AGL3	Grammaticality/day 3
G	Grammatical
NG	Non-grammatical
H	High
L	Low

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CHAPTER I - INTRODUCTION

Language embodies an important universal social role. Human language is a vast and ongoing research topic. In particular, for the human species it is required that each individual acquires a cognitive ability of understanding and produce signals that characterize verbal communication (Eysenck & Keane, 2010).

When we analyze a particular language we are confronted with meaningful units: first a word is composed by sounds called phonemes; phonemes when combined together form morphemes: some morphemes are complete words and others combine to form words. The long-term memory collection of words is called the mental lexicon while sentence structure (i.e., syntax) typically is represented by rules of grammar, which specify how words are laced together in patterns. Additional components of language are semantics, or the meanings of words (lexical semantics) and sentences (sentence-level semantics), while prosody, characterized by intonation that can modify the meaning of words and sentences; and lastly discourse (Kolb & Wishaw, 2003).

Jackendoff (2002), following Chomsky, proposed that children during native language acquisition, starts by speaking something comparable to a creole, as also occurs in an adult when acquiring a new second language.

Unlike language comprehension, writing and reading, which are examples of taught cognitive skills, a native natural language is spontaneously acquired at an early age and largely without explicit feedback, and this requires the integration of complex semantic properties and syntax (Jackendoff, 2002).

The research for a better understanding of languages and the human faculty of language (i.e., a brain system) is vast and some theories argue that the faculty of

language is unique to only by humans, since animal communication systems are not equivalent to human languages (Jackendoff, 2002).

According to Hockett's (1963; 1987) human languages are characterized by several prominent features: discreteness, arbitrariness, productivity and the duality of patterning, in other words, these properties show that language and communication are subserved by a large network of brain regions (Pettersson, Folia & Hagoort, 2010), and according to Jackendoff (2011), language research should address three issues: the knowledge of a language, that is a speakers' ability to create and understand an unlimited number of sentences; language acquisition (i.e., answer the question of how native languages are acquired); and finally the evolution of language (how the species came to develop the capacity for language). In summary, natural language acquisition, and its structural aspects, is a largely spontaneous non-supervised and self-organized process which is acquired at an early age and largely without feedback. Nevertheless this does not suggest that the language user has conscious access to sentence structure nor the representation. In contrast, these aspects of language processing are largely unconscious (Jackendoff, 2002).

Siegel (1993) showed that the development of reading skills are based on five important processes: phonological processing (the understanding of grapheme-phoneme conversion rules and the exceptions to these rules); syntactic awareness (the ability to understand the syntax of language); working memory (decode and/or recognize words while remembering what has been read and retrieving information such as grapheme-phoneme conversion rules); semantic processing (the understanding of meaning); and orthographic processing (the understanding of

writing conventions and correct spellings of words).

IMPLICIT LEARNING

Although it sounds improbable to learn something without being aware of it, humans are sensitive to structural patterns and acquire information unintentionally, adapting their behavior to the regularities present in the environment (Forkstam & Pertersson, 2005; Reber, 1967; Eysenck et. al, 2010). Such process is known as implicit learning and Reber (1989) defined it as a process considered independent of intention and the knowledge acquired is taken to be an abstract representation not accessible to verbal description. This knowledge is characterized for not being sensitive to interindividual differences, remains longer in memory and is more resilient to cognitive and neurological disorders (Bigand et al., 1998). In contrast to explicit memory, implicit memory does not involve conscious recollection that, in some cases, degrades performance and empowers the acquisition of highly complex information (Eysenck & Keane, 2010; Seger et. al, 2000).

Following Seger (1994) and Reber (1993), Forkstam & Pertersson (2005) implicit learning reviews, four characteristics are primary for implicit learning:

- 1) Limited explicit accessibility to the acquire knowledge (i.e. subjects normally cannot provide explicit report of what they have learned);
- 2) The nature of the knowledge acquire is more complex than simple associations or exemplar-specific frequency-counts;
- 3) Is an incidental and automatic consequence of the type and amount of processing preformed on the stimuli;

4) Does not rely on declarative memory mechanisms in medial temporal lobe, since lesions in these areas impair explicit but not implicit learning and memory.

Several studies indicate that implicit learning involves activity in multiple brain regions and suggest distinctive network involved, depending whether the subjects are aware or not of the material they learn (Cleeremans, Destrebecqz & Boyer, 1998). Throughout the literature, it appears that the brain regions most related to implicit learning are the basal ganglia, involved in aspects of response programming; the association cortex, involved in perceptual aspects of implicit learning; and frontal cortex, involved in the evaluation of implicit knowledge in fluency judgments (Forkstam & Petersson, 2005; Forkstam, Hagoort, Fernandez, Ingvar & Petersson, 2006).

ARTIFICIAL GRAMMAR LEARNING

Implicit learning can be studied with paradigms that vary the stimulus structure and the response modality, but the most investigated are the serial reaction time task (a visual motor procedure learning task) and the artificial grammar learning task (Petersson et. al, 2010).

The artificial grammar learning (AGL) paradigm has been proposed as a model for aspects of language acquisition and provides an approach to investigating aspects of structural (syntax) acquisition from exposure to grammatical examples alone, without explicit feedback (Forkstam & Pertersson, 2005; Petersson et al., 2004). According to Hanser et al. (2002), the AGL paradigm is also a model for exploring differences between human and animal learning relevant to the faculty of language.

The classical study on artificial grammar learning was conducted by Reber (1967), using a regular rule system. Participants were exposed to letters sequences, such as VXVPS, but they were unaware of the fact that crossing through a regular grammar such as Figure 1 generated the sequences. After this phase participants were subsequently informed that sequences they were exposed to complied with a complex set of rules, and received after a new set of sequences that were either grammatical (follow a set of complex rules) or not (does not follow the rules). In other words, the participants observe a set of novel sequences and were asked to make a grammaticality judgment based on their immediate “gut feeling”. The average of correct responses was above chance (69%) and Reber argued that participants implicitly learned the abstract rules during the initial study phase and that this knowledge is unavailable for conscious examination and therefore, the grammaticality judgment was based on structural aspects of grammar (Folia et al., 2008).

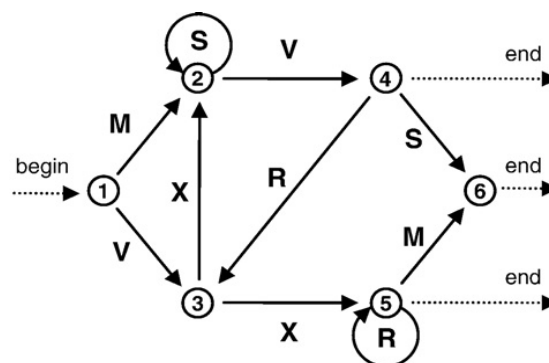


Figure 1 – The transition graph representation of the Reber machine used to generate the stimulus material. Grammatical sequences are generated by traversing the transition graph from state 1 through the internal states along the direction indicated by the arrows (grammatical transitions) until an end state is reached.

Anatomically, brain studies in artificial grammar learning show diverse results. Throughout amnesic research (see Seger et. al, 2000; Cleeremans et. al, 1998) it is possible to verify that amnesic patients exhibit normal performance on artificial grammar learning (AGL) and other implicit sequence learning tasks. Knowlton and Squire (1996) also investigated amnesic patients and normal controls on the standard artificial grammar learning task as well as a modify version of the task and showed the amnesic patients and their normal controls performed similarly on both versions of AGL, despite the fact that amnesic patients could not explicitly retrieve any sequence information. Lieberman et al., (2004) identified distinct neural systems, through the use of event-related fMRI, contributing to the classification task. Evidence from functional neuroimaging suggest that Brodmann's area (BA) 44/45 (Broca's region) is associated with natural language syntax and also is engaged in artificial syntactic processing, since this region is sensitive to the structural properties of the item sequences used in an AGL experiment (Petersson et al., 2004). Thus the artificial grammar learning task appears to be based on multiple cognitive processes with activation in the inferior frontal regions, the medial prefrontal cortex, and the basal ganglia, including the caudate nucleus (see Petersson et al., 2012;).

One of the main topics of discussion on implicit learning is how participants learn and how they acquire the relevant knowledge. Different studies highlight different aspects of implicit learning that could condition the outcome of the task. According to Tunney (2007), we can speculate that familiarity plays an important role in implicit learning, since it can be acquired incidentally. In their experiments,

Zizak & Reber (2004) used unfamiliar symbols to represent artificial grammar and on another experiment highly familiar symbols were used. In all cases artificial grammar learning was demonstrated and the authors observed participants classified stimuli according to principles of the grammar. Additionally it was possible to verify that symbols with higher familiarity produced a structured mere-exposure effect whereas unfamiliar symbols produced no such exposure effect.

Wan et al. (2008) divided his first experiment in two parts: a study phase where subjects trained grammar "A" and grammar "B" and in test phase half of the subjects were told to check sequences from the first grammar and the other half from the second grammar. When asked subjects said they were using familiarity more than any other source, as intuition, and results showed subjects could intentionally control which grammar to apply while considering their responses to be based on familiarity. But if subjects are equally familiar with two grammars they should endorse sequences from either grammar. So this result shows that the control of artificial grammar knowledge is consistent with not being aware of structural knowledge.

As stated earlier, different types of exposure can alter the outcome of an AGL task, for example, when grammaticality judgment is based on superficial aspects of grammar. Previous research (see Lieberman et al., 2004; Seger, 2004; Knowlton and Squire, 1996) indicated that the similarity of the whole and partial items have an influence on grammaticality judgments. For instance, sequences composed by bigrams and trigrams that are repeated frequently during training are more likely to be recognized as grammatical compared to sequences that do not contain similarly

repeated chunks. Therefore, it is possible to avoid potential confounding between grammaticality status and chunk strength of items, when the superficial similarity between test items and training ones are used for classification, by using an experiment based on a balance chunk strength design. In order to address this issue in the experiment described in this thesis, and to control the task the associative chunk strength (ACS) measure was used. ACS is a statistical measure of local subsequences.

Knowlton and Squire (1996) argued that AGL depends on implicit acquisition of both abstract and exemplar-specific information, and provided evidence that the participants had acquired knowledge about distributional information of local sequential regularities (i.e., chunk regularities). In their study, they observed that individuals relied on chunk strength when it was available as a cue and thus endorsed non-grammatical items with high chunk strength to a greater extent than non-grammatical items with low chunk strength. These authors proposed that chunk strength and grammaticality status compete as cues controlling the classification decision (when both cues are presented), although grammaticality tends to prevail over chunk strength cues. In the experiment of Dienes et al. (1991), they found that the participants used a chunk strategy to classify experimental items and that this strategy was efficient in their experiment and a method of coding that can enable generalization.

Memory functions can be addressed in terms of the learner's intention to acquire information and subsequent access to this knowledge (Forkstam & Petersson, 2005). Thus additional feature interfering with AGL is subject age. While

explicit learning studies have strongly suggested that explicit memory decline with age, implicit learning studies indicate otherwise (Cleeremans et al., 1998). Other studies, as Kurten et al. (2010), demonstrated in their experiment that the majority of the elderly subjects exhibited difficulties with explicitly recalling sequences in the acquisition task. In the same experiment the authors verified that in the classification task the young participants classified correctly higher chunk strength items than elderly participants. Thus the results indicate an age differences in AGL performance, particularly on high chunk grammatical items (chunk-based learning) which involves at least some explicit learning aspects, whereas ruled-based learning was preserved.

ARTIFICIAL GRAMMAR LEARNING IN DIFFERENT MODALITIES

As stated before, meaningful learning of regularities generally occurs outside the laboratory in everyday situations without explicit training or practice (Ettlinger, 2011), for example in music and language.

Consequently, when subjects participate in a standard AGL task typically they are unable to provide a reason for their answers or they usually explain that they created their-own rules for classification, despite the instruction type (preference vs. grammaticality) (Bly, 2009).

These two examples of highly structured systems can equally well be evaluated in a laboratory context.

Implicit learning is usually studied with paradigms that vary the stimulus structure and the response modality. Since AGL is one of the most intensely investigated implicit learning paradigms, in the present study we intend to observe the AGL effect in linguistic and non- linguistic stimuli in different modalities, the visual and the auditory.

Effects of presentation modality are still largely unexplored in implicit learning and various modality constraints as been considered (cf., Cleeremans, Destrebecqz, & Boyer, 1998; Conway & Christiansen, 2006; Perruchet & Pacton, 2006; Reber, 1967; Saffran, Aslin, & Newport, 1996; Stadler & Frensch, 1998).

Bigand et al. (1998; Tillmann et al., 2000) studied 42 students (16 were advanced music students and 26 non-musicians) in order to observe if the subjects could indicate whether a certain timbre belonged to a sequence, or not. Results showed that subjects in this experiment performed poorly musical timbre sequences than visually presented letters. mere exposure to Western musical pieces suffices to develop implicit knowledge of Western harmony, and familiarity with the material (students) did not improve the performance.

In Saffran et al. (1999) conducted an experiment employing syllable sequences, and created sequences on piano notes, substituting each syllable for a note, generated in random order to be identical in structure. Their results indicated that participants rapidly group sequences of auditory sequences in the same manner for linguistic sequences or non-linguistic sequences. Overall, the previous suggest

that implicit learning of syllable and tone based on similar acquisition processes and offered evidence that subjects (native speakers and non-musicians listeners) are sensitive to underlying rules for both verbal language material and non-verbal sounds.

Conway & Christiansen (2005) found that both auditory learning performances were significantly higher than visual and tactile performance. These results were replicated in Conway & Christiansen (2009), suggesting that AGL might be constrained by modality, as the experimental group with auditory sequences presented a superior performance compared to visual-temporal sequences. Moreover, they observed that auditory learning was mediated by increased sensitivity to the sequence endings, whereas the participants were most sensitive to the beginnings of visual sequences.

In their study, Forkstam et al. (2009) generated sequences of letters for both auditory and visual presentation and the experiment was applied in five consecutive days/sessions. Results showed higher performance when the sequences were presented with the auditory compared to the visual modality. These results corroborate the previous studies.

The standard AGL paradigm has more often been investigated with visual compared to auditory inputs to study implicit learning (Conway & Christiansen, 2005). In line with music, language sentences comprise perceptually arranged elements (syntax) that are combined into structured sequences according to complex regularities and the detection of violations occurs at an early age (Koelsh, 2009). Thus in the present study we intended to investigate if sequence processing is

more efficient in the auditory and phonological modality compared to the visual orthographic modality.

CHAPTER II - OBJECTIVES

In the present study we employed the implicit artificial grammar paradigm without feedback and observe differences between modalities: auditory vs. visual (and therefore reading vs. listening). We furthermore intended to examine if there is an additional efficacy when the sequences are presented in the language domain (e.g., working on sequences of letters (visual) or sequences of syllable sounds (auditory)) compared to when it is not (e.g., sequences of symbols (visual) or non-language related sound patterns such as human voice humming (auditory)).

CHAPTER III – METHODS AND MATERIALS

PARTICIPANTS

Twenty-eight university students (18 female and 10 male, mean age \pm SD = 24.8 \pm 4) voluntarily participate in the study. Fourteen of the participants were included in the auditory group (eight participants listened to syllables and eight participants listened to sounds) as the other 14 participants were included in the visual group (eight participants viewed consonants and other eight participants viewed symbols). All twenty-eight students signed an informed consent before the first task began.

STIMULUS MATERIAL

Grammatical sequences with a sequence length of 4-12 were generated from the Reber grammar, as seen in Figure 1, for either consonants sequences (M; V; X; R; S), syllables (spoken human humming by a female speaker blind to the experimental manipulations and hypothesis and carefully controlled for speech intonation), symbols (\triangle \square \circ \diamond \hexagon) and tones (of five chords harmonically related to the key of C Major: C Major (C), D Minor (Dm), F Major (F), G7, A Minor (Am) and G7). Each element was presented for 300 ms with an 300 ms inter-element-interval in all modalities. The frequency distribution of bi- and trigrams (two and three element chunks) for both terminal and whole sequence positions were calculated for each sequence in the learning material in order to derive the associative chunk strength (ACS) for each item. An acquisition set was selected as well as grammatical (G) and non-grammatical (NG) classification test sequences (see Figure 1A). The classification set was further divided into high and low ACS items relative the acquisition set. Thus

all sequences were organized in a 2x2 factorial design with grammaticality (G/NG) and ACS (low (L)/ high (H)) as factors. Each category included 24 sequences: high ACS grammatical (HG), low ACS grammatical (LG), high non grammatical (HNG) and low non grammatical (LNG). In this way, each set incorporated 48 grammatical/non grammatical sequences presented randomly.

Grammatical Sequences	Non-grammatical Sequences
VXRRM	VRRRM
MTVRXRRR	MTVRXMRR
VXVT	VRVT
MTTTTV	MTTTR

Figure 1A. Sequences generated by finite state grammar as seen in figure 1. Grammatical sequences are generated by entering the grammar through the 'begin' node and by moving from node to node until the 'end node is reached. Non-grammatical sequences are produced by switching at least one letter to another one. The sequences can be presented as sequences of consonants, symbols, syllables and tones.

PROCEDURE

The experience was divided in three sessions conducted over three consecutive days. The tasks were presented visually on a computer screen and acoustically played through headphones using the Presentation software (nbs.neuro-bs.com) and all responses were given using a keyboard. All tasks had an extent of approximately 30 minutes. Thus the first day lasted 1 hour overall, the second day lasted 30 minutes overall and the third day lasted one hour and 30 minutes overall. Before

beginning every task, instructions were read to the participants. After each task subjects were interviewed and answered a questionnaire in order to measure any difficulties that occurred during each task.

On the first day (AGL1 – baseline classification) the session started with the preference set. Subjects were instructed to classify based on their immediate intuitive impression (gut feeling) if they liked the sequence or not and respond by pressing the correspondent key (“like”/“don’t like”). This was followed by an acquisition set, where subjects viewed/ listened to pairs of sequences and had to categorized if the sequences were the same or different (pressing the corresponding key to “equal”/“different”).

On the second day (AGL2) only the acquisition set was presented, under the same instructions, followed by the questionnaire.

On the third and last day (AGL3 – preference and grammaticality classification) the session started with the acquisition set, followed by the same questionnaire; afterwards subjects engaged in the preference task, followed by a questionnaire that interrogated the subject about the presence of structure or patterns in the presented sequences. Lastly, the subjects engaged in the grammaticality task. Before the task began participants were informed about the existence of a complex set of rules that underlie the acquisition sequence structure and they were instructed to base their responses in their immediate intuition – “gut feeling” – and to avoid any attempt to understand the rules or analyze furthermore the sequences. Each sequence was presented followed by a grammaticality judgment (forced yes/no choice) using the response key-board. The session finalized

with a questionnaire in order to understand and assess their explicit knowledge about any rules or patterns present in sequences.

CHAPTER IV – RESULTS

All presented analysis were performed using statistical software package SPSS and the Statistic program for post-hoc analysis and an overall significance level of $p < .05$ was used. Mixed-effect repeated measures ANOVAs were used for the analysis of the classification performance translated to d-prime over the factors grammaticality and ACS using standard signal detection theory in the statistics package R (www.r-project.org). For each analysis we modeled the main factors classification session [within modality/between modality] as within-subject fixed-effects, group [acoustic/visual] as between-subject fixed-effect, and subject as a random-effect. One subject was excluded from the analysis, because the subject did not presented any discrimination behavior.

CLASSIFICATION PERFORMANCE: ENDORSEMENT RATES

Performance on the classification test was analyzed in terms of endorsement rate (percentage of sequences perceived as grammatical; cf., Forkstam et al., 2006). To analyze the endorsement rates we performed a repeated measure ANOVA. The analysis of the endorsement rates demonstrated that the participants were sensitive to grammaticality ($F(1, 26) = 8.94$; $p = .006$) and ACS ($F(1, 26) = 24.3$; $p < .001$), (figures 2 and 3). Moreover, the analysis showed a significant interaction between grammatical sequences over the three sessions [$F(1, 52) = 4.27$; $p = .019$] and an interaction between grammaticality sequences and ACS [$F(1, 52) = 30.1$; $p < .001$]. In particular, we can verify that subjects increased their preference (AGL2) for G sequences [$F(1, 52) = 4.27$; $p = .014$] and non-preference for NG sequences [$F(1, 52) =$

4.27; $p < .001$]. Thus, the participants improved their classification performance in comparison to the baseline preference classification (AGL1): G sequences [$F(1, 52) = 4.27$; $p = .021$] and NG sequences [$F(1, 52) = 4.27$; $p = .021$], whereas AGL3 also show differences but did not show significant effect: G sequences [$F(1, 52) = 4.27$; $p = .099$] and NG sequences [$F(1, 52) = 4.27$; $p = .099$]. Post-hoc analysis of the interaction between grammaticality and ACS revealed significant effects in HG [$F(1, 52) = 4.27$; $p = .00017$], LG [$F(1, 52) = 4.27$; $p = .00017$] and HNG [$F(1, 52) = 4.27$; $p = .011$].

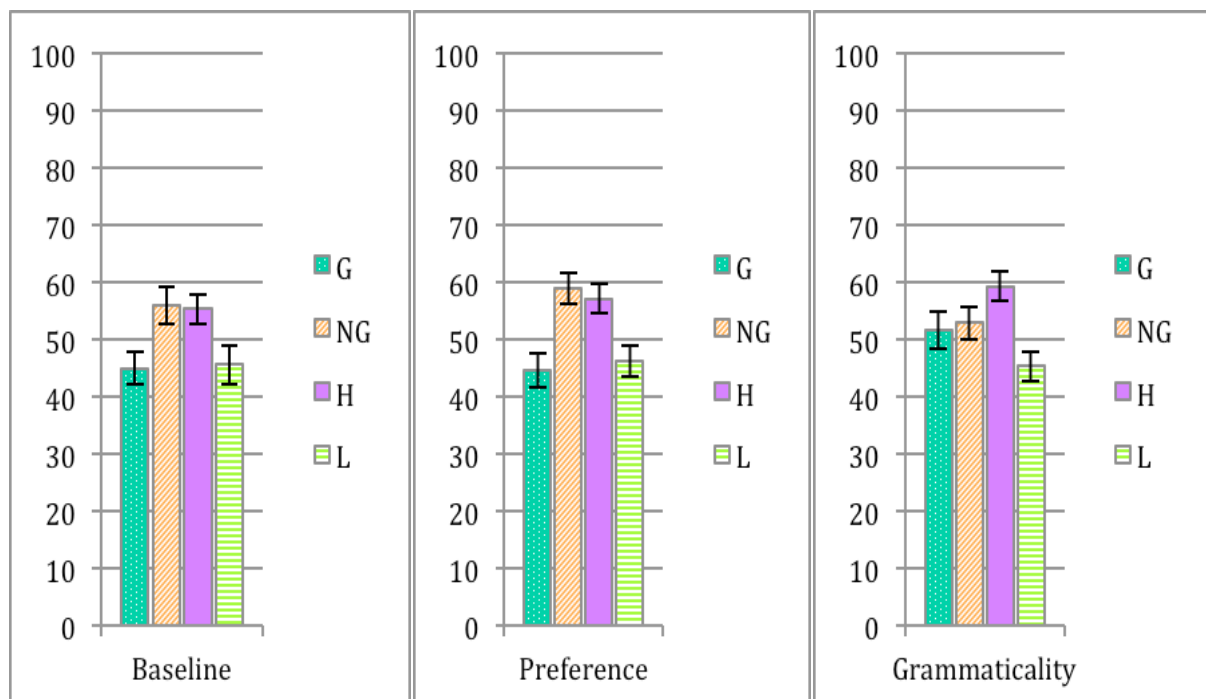


Figure 2 - Endorsement rates over grammaticality and ACS levels in Baseline, Preference and Grammaticality tests. The endorsement rates (i.e., item classified as grammatical independent of actual grammaticality status) as a function of grammaticality status as well as associative chunk strength (GH: grammatical high ACS strings, GL: grammatical low ACS strings, NGH: non-grammatical high ACS strings, NGL: non-grammatical low ACS strings). Error bars correspond to standard error of

We analyzed the endorsements specific to each modality using repeated measures ANOVA and results within subjects showed when the modality was

auditory: syllables ($n=7$) showed significant differences in ACS [$F(1, 12)= 8.41;p=.027$] and an interaction between grammaticality and ACS [$F(1, 12) = 12.0; p = .013$]; if we looked to tones ($n=7$) we observed significant differences in ACS [$F(1, 12)= 4.15; p = .088$] and an interaction between grammaticality and ACS [$F(1, 12) = 7.46; p= .034$]. If we analyzed visual modality it was found that: consonants ($n=8$) demonstrated significant differences in ACS [$F(1, 14) = 8.54; p = .022$], an interaction between grammaticality and ACS [$F(1, 14) = 7.72; p = .027$] and an interaction between grammaticality and ACS over the three sessions (interaction of third level) [$F(1, 14) = 3.65; p = .053$]; while the visual symbol analysis showed ($n=5$) differences over the three sessions [$F(1, 8) = 3.38; p = .086$] and significant differences in grammaticality [$F(1, 8) = 13.5; p = .021$].

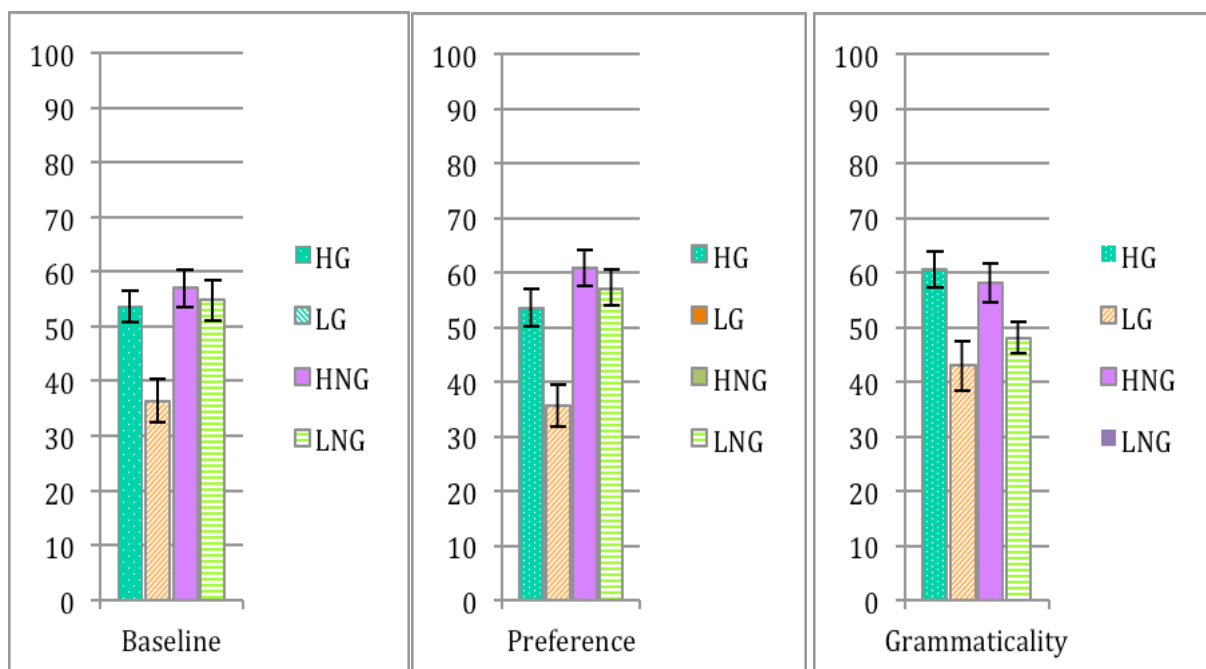


Figure 3 - Endorsement rates over grammaticality and ACS in AGL1, AGL2 and AGL3. The endorsement rates (i.e., item classified as grammatical independent of actual grammaticality status) as a function of grammaticality status (G = grammatical strings, NG = non-grammatical strings) as well as associative chunk strength (H = high ACS strings, L = low ACS strings). Error bars correspond to

CLASSIFICATION PERFORMANCE: ACCURACY

The analysis of accuracy (classification performance) showed that the subjects were sensitive to the grammaticality status of the items [$F(2, 46) = 3.75$; $p = .031$]. Particular in a post-hoc analysis subjects classified the grammatical sequences correctly more often in grammaticality classification > preference ($p = .025$).

ANALYSIS OF THE d-PRIME

The analysis of the d-prime (discrimination measure) demonstrated a negative d' (total mean): baseline = $-.30 \pm .45$, preference = $-.385 \pm .57$ and grammaticality = $-.0142 \pm .67$ (figure 4). Thus, subjects were more sensitive to non-grammatical sequences. The results also showed a significant d-prime effect over the three sessions [$F(2, 46) = 4.07$; $p = .024$] and no significant difference was found in the d-prime interacting with modality [$F(2, 46) = .36$; $p = .90$]. In a further post-hoc analysis it was possible to observed that the d-prime effect between baseline and preference were not significant [$F(2, 46) = 4.07$; $p = .80$], nor the difference between grammaticality and baseline [$F(2, 46) = 4.07$; $p = .089$], however a significant difference was found in grammaticality and preference classification with respect to d-prime, so grammaticality > preference [$F(2, 46) = 4.07$; $p = .020$].

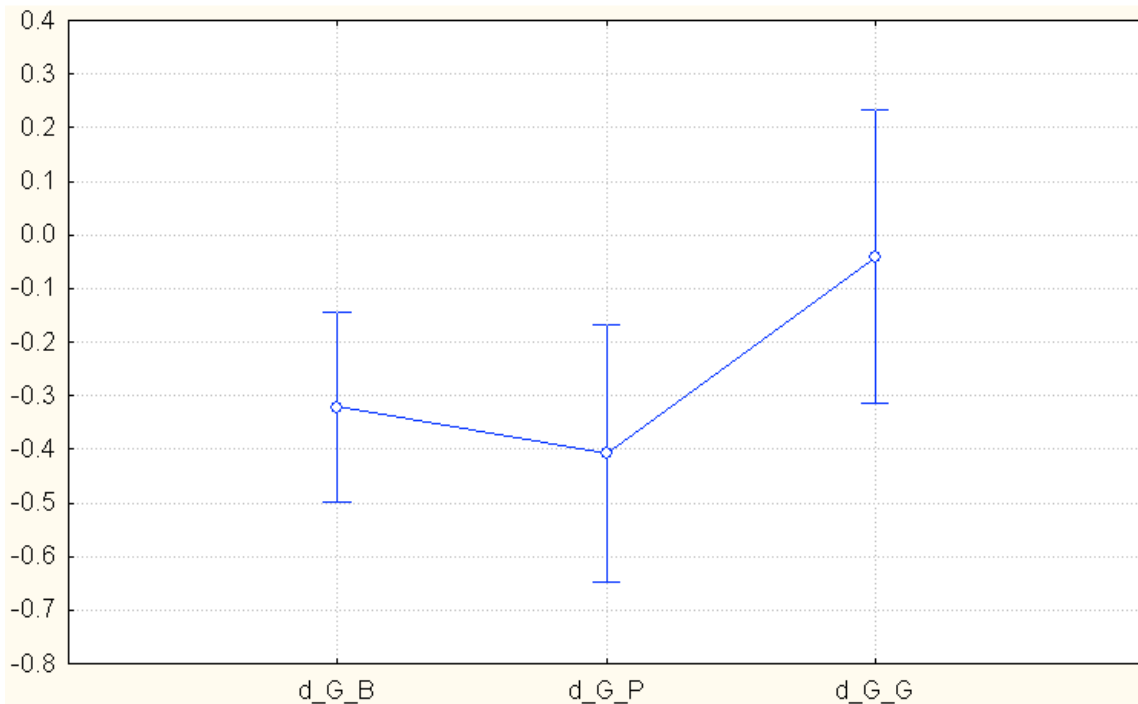


Figure 4 – d-prime means for AGL1, AGL2 and AGL3 with standard deviation [$F(2, 46) = 4.072$; $p = .024$].

PARTICIPANTS QUESTIONNAIRE

In order to assess if subjects were using or aware of any rule system underlying the sequences, they answered a questionnaire to rate their level of perceived difficulty, attention, distraction, engagement and boredom after each task. The majority of subjects realized that sequences always started “M” or “V” (or the corresponding item from each modality), which was true. Most participants rated grammaticality classification as more difficult or equal to preference classification and reported that the stimulus presented in the preference task was similar to what they had seen in prior tasks. Therefore, although subjects were aware of a few characteristics, they were not able to reproduce the more complex set of rules that generate the sequences, and in this sense their performance in the classification task was dependent on the previously acquired implicit knowledge, independently of any valid explicit knowledge of the rules.

CHAPTER V – DISCUSSION

In the present study we employed the implicit artificial grammar learning paradigm to investigate the difference in the enduring effects of artificial grammar learning in different presentation modalities, including as linguistic vs. non- linguistic acquisition. In the present study we intended to use the artificial grammar learning paradigm as a model of language acquisition and implicit learning based on Reber's (1967) and investigated whether auditory modality had an advantage in AGL over the visual modality. Additionally, the present study concerned whether the results showed an advantage for sequences within language domain compare to when it's not (e.g. symbols or voice humming).

The results of the present study showed that participants implicitly acquired knowledge about the underlying artificial grammar, since participants performed well on both preference and grammaticality classification in terms of accuracy.

Results also demonstrated that participants learned implicitly when we compared grammaticality classification to baseline, but the difference was not significant. Participants improved significantly their performance in grammaticality classification compared to preference classification, which can suggest an influence by the instruction type at the grammaticality test. Thus, these results show that grammaticality status is used for structural generalization in classifying novel sequences and provide support for the notion that grammatical structure instead of subsequence, or fragment features, determine classification. In line with this, grammaticality classification instruction is the main contributor to the increased performance namely in baseline and preference classification, but not significantly in

grammaticality classification, where participants could alternatively utilized statistical learning mechanisms instead of structured-based mechanisms (they were tested at a novel sequence).

Nevertheless if we examine the results carefully its possible to observe that visual modality presents results with a larger difference related to learning and therefore become significant. Within the visual modality we additionally investigated the results from consonants, which showed more significant results than visual symbols, and these results confirm that this modality is more suitable to demonstrate significant differences than all of the three modalities investigated in this study. These results deviate from results found in Conway & Christiansen (2005, 2009) and Forkstam et al (2009), since these experiments showed an auditory advantage for classifying novel sequences.

Additionally, the post-experimental interviews demonstrated that most participants did not have explicit knowledge about the underlying grammar, in other words, made their decisions based on “gut feeling”. Although we observe an implicit learning effect in the present study, the present results may be due to limited and a short acquisition periods in other words, if participants had had five days of AGL instead of only three, the results of the present study might have converged with previously reported results. Also for the results of the present study, we should consider the limited number of participants (small) as a possible constraint on results; hence a higher number of participants might strengthen the differences found.

Overall, the present results are constrained by modality, acquisition

opportunity and the number of subjects.

These results may be due to the limited number of participants in the present study. Likewise, if the present experiment were conducted over a long period of time, as five days (e.g., Forkstam et. al, 2005, 2006, 2009), the results could come out more consistent with previously reported results.

Our results suggests that visuals sequences are more easily to perceived and held in memory and subsequently easier to learn, Contrary to Forkstam et al. (2009), Conway & Christiansen (2005; 2009) or Saffran (2002), that used an AGL task to test participants' ability to learn predictive dependencies. She found that participants learned these predictive relationships best with an auditory–sequential or visual–simultaneous presentation and did poorly in a visual–sequential condition.

Visuals sequences, namely consonants sequences, would appear to be more neutral and inert, thus facilitating the encoding of artificial grammar regularities. Acoustic sequences, such musical sequences, are structurally extremely rich, which result strong and diverse interactions (Bigand, et. al, 1998).

In this view, present results emphasizes greater performance in language vs. non-language sequences, hence corroborate the natural ability that humans have to acquire language, and successively improving the learning of language sequences when presented (cf., Folia et al. 2010). Subjects practicing on acoustical syllables as well as subjects practicing on visual consonant letter sequences showed high performance levels after three days of implicit acquisition. This suggests that artificial language learning and processing is relevant to natural language learning

and processing.

Taken together, the present results, various aspects of cognitive functioning, including implicit learning, memory and language, appear to be constrained by factors having to do with the presentation modality of the input, which in turn may implicate the involvement of modality-specific, sensorimotor mechanisms and/or representations. Therefore, it seems important to understand the nature and extent of these potential constraints, so implicit learning and language can be elucidate in further studies and perhaps revise theoretical models.

More generally, constrained learning mechanisms require both experience and effort to learn and preexisting structures to capture and manipulate these experiments. Additional research must elucidate the nature of each modality-constrained learning system and how they support human cognition more broadly. We speculate that it is of particular relevance to consider the ecological validity of the input signal used in artificial grammar learning and in language learning paradigms in general.

We end with the final comment regarding a further major theme: infant learning. Experiments in this field are imperative to a true understanding of language acquisition, as complexity is introduced from many different sources (such physical and biological development and environment differences). These sources cannot be dismissed or devaluate since language acquisition can be more then the sum of its parts.

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