## Abstract

Implicit statistical learning ability is the ability to recognize patterns and regularities in consecutive stimuli. This ability is essential for the acquisition of many day-to-day functions, and there is an extensive literature dealing with methods of promoting it. The present research examines the influence of two variables: repeated exposure to stimuli in training, and response attribution. The objective of the research is to examine the combined influence of these two variables on statistical learning processes and to evaluate their contribution to learning and achievements.

The first variable is **repeated exposure to stimuli**. This variable includes training subjects to repeated exposures to stimuli in order to improve their learning. There are two kinds of repeated exposure to stimuli: repeated exposure to constant (identical) stimuli and repeated exposure to varied (non-identical) stimuli. In repeated exposure to constant stimuli, identical stimuli are presented repeatedly, serving as constant representative examples of regularities to reinforce the learning of specific stimuli. In repeated exposure to varied stimuli, different stimuli are presented during each repetition. These stimuli provide varying representative examples of a system of regularities, to reinforce learning patterns and the organizing principles of the stimuli.

It is a reasonable assumption that repeated exposure to stimuli promotes statistical learning. In practice, however, there are inconsistent findings concerning its efficiency, and a different picture is presented for each kind of repeated exposure. Some research supports the efficiency of repeated exposure to constant stimuli and indicates that repeated exposure promotes achievements, while other research does not support it. As for repeated exposure to varied stimuli, there is evidence it promotes achievements. However, this evidence was presented in the context learning of mathematical digits with audio or visual stimuli, and thus has limited value for drawing conclusions concerning visual learning of letters. This limitation stems from the qualitative difference between processing audio and visual stimuli, and the difference in processing sequences of digits or letters. A further limitation stems from the fact that the findings related to the two types of exposure to stimuli were tested in separate studies under different learning conditions. It is therefore not possible to easily compare the two types of exposure in order to identify which is more efficient. Furthermore, the findings concerning repeated exposure to the two types of stimuli do not take into account the number of repetitions required in order to achieve an effect on learning, and it is

therefore impossible to establish the number of repetitions required for each kind of repeated exposure.

The question of the differences between exposure to constant stimuli and to varied stimuli in the context of artificial grammar learning has not yet been investigated. This lacuna in research is related to the planning of experiments and the interpretation of the findings, which ignore the influence of the type of stimuli and the number of repetitions in each type of training. The lacuna in research is also connected to the absence of guidelines for the design of learning environments based on statistical learning processes, including learning environments for reading and writing.

The **initial objective** of the current research was therefore to examine the difference in achievements in a visual artificial grammar task (a paradigm for evaluating statistical learning) between repeated exposure to constant stimuli and to varied stimuli. The research examined the number of repetitions required for each kind of stimuli (constant or varied) to achieve a significant effect on achievements. The investigation included a comparison between the influence of repeated exposure to constant stimuli and to varied stimuli, using three different numbers of repetitions.

The investigation of the difference between exposure to constant stimuli to repeated stimuli in the current research is a contribution to the identification of efficient methods of exposure for statistical learning. In consequence, it will be possible to examine existing studies that included repeated exposure to stimuli more extensively and to understand their findings with respect to the type of exposure and the number of repetitions in the training. In addition, the research will assist in delineating exposure guidelines for experimental paradigms and learning environments.

The second variable examined was **response attribution**. This variable relates to a subjective observation process during which subjects make connections between the judgment decisions they made during the task, the knowledge acquired, and the processes underlying their decisions. Although the artificial grammar learning task is considered an implicit task, in practice it combines implicit and explicit learning processes. Thus, awareness of the information acquired and the decision making process can develop throughout the learning. One of the tools for evaluating awareness of knowledge and the learning process in artificial grammar research is the “post decision attribution” multiple-choice questionnaire. In this questionnaire, subjects are

required to select which of five options best explains the process and knowledge underlying their judgment decisions. Collecting this information provides an evaluation of the subjects' awareness and perception concerning statistical learning. Evaluation of awareness is performed by examining the subjects' trends of attribution causing options in the questionnaire to be matched to responses with high frequency. The questionnaire permits the evaluation of the subjects' perception of the information acquired during the task, the processes involved in their decision making, or the extent of the subjects' awareness of these processes and information.

The combination of evaluation of awareness with evaluation of achievements is considered optimal by researchers, since it permits the understanding of learning from both objective and subjective perspectives, and also permits the establishment of connections between objective and subjective metrics. This is why the post decision attribution questionnaire is commonly used for evaluating subjects' awareness in many studies of statistical learning.

However, in recent years the claim has been made that as well as recording awareness, the post decision attribution questionnaire can promote response attribution processes and influence achievements in artificial grammar learning. In other words, questioning the subjects on their learning in itself increases their awareness of their available knowledge and causes a corresponding adaptation of their behavior. Development of awareness permits more deliberate usage of strategies, regulation and self-control, which can lead eventually to improved results and achievements. In the domains of general learning, many studies exhibit this phenomenon, but in the domain of artificial grammar learning only one experiment is known that examined it. In this experiment, a comparison was conducted between the achievements of subjects who responded or did not respond to a post decision attribution questionnaire. The results of the study showed that subjects who responded to the questionnaire classified the stimuli in the test according to their similarity in appearance to the stimuli in the training. On the other hand, the subjects who did not respond to the questionnaire classified the stimuli in the test without connection to their degree of similarity to the stimuli in the training. The researchers explained that the response attribution processes involved in the questionnaire reinforced the learning processes relying on the appearance of the stimuli, and thus contributed to an increase in achievements. At the same time, they inhibited higher-level learning based on pattern recognition.

The present study maintains that this conclusion is over-generalized and does not relate to the type of stimuli in the study and their possible influence on response attribution processes. The training stage in the experiment included the repetition of constant stimuli, but the study's conclusion concerning response attribution did not distinguish between constant and varied stimuli. This is a crucial distinction, since constant stimuli include presentation of specific constant parts which are repeated and encourage learning their specific appearance, while inhibiting distinguishing patterns of organization, in contrast to varied stimuli, which include the presentation of varying parts exhibiting systematic patterns, encouraging learning the organizing principles of the stimuli. Studies of vocabulary learning, executive intelligence and memory tasks show that response attribution processes interact with the type of stimuli. For example, there are findings showing that stimuli that were prominent in learning which were especially familiar or were repeated, influenced the response attribution processes, and subjects tended to rely on them in learning. Therefore, the present research calls for reservations and attributing the contribution of response attribution to learning the appearance of stimuli to the combination of constant stimuli in the training and response attribution in the questionnaire. This prompts the question whether the combination of response attribution after training with varied stimuli contributes to learning and whether its contribution differs from the contribution of response attribution following constant stimuli.

The present study is the first to examine this question. The examination of this question extends the understanding of the contribution of response attribution to promoting statistical learning after each kind of exposure to repeated stimuli, and permits the identification of the most efficient combination of the two for learning. In addition, this examination permits a more comprehensive understanding of studies using a post decision attribution questionnaire, with respect to the influence of response attribution on learning processes. Accordingly, the **second objective** of the research is to examine (via a post decision attribution questionnaire) how the response attribution process influences artificial grammar learning after training with constant stimuli compared to varied stimuli. This comparison permit understanding the contribution of response attribution after each type of repeated exposure and identifying its contribution to statistical learning.

The **third objective** of the research is to examine, via a post decision attribution questionnaire, the **self-assessment of learning** developed after repeated exposure to constant stimuli compared to varied stimuli. The subjects' self-assessment of learning consists of two elements: self-awareness of how judgment decisions are made (judgmental knowledge) and self-awareness of the content of stimuli and their underlying principles (structural knowledge). Self-assessment of learning is evaluated via a post decision attribution questionnaire, since it refers to both elements of awareness. The five options in the questionnaire refer to different states of awareness of structural and judgmental knowledge. These options allow the subjects to attribute each judgment call to the self-assessment of awareness they consider most correct. By identifying common trends of attribution, it is possible to evaluate subjects' general self-assessment of learning. Two studies are known in the field of statistical learning that discussed the connection between self-assessment of learning and exposure to constant stimuli in training. The results of the experiments show that repeated exposure to constant stimuli increased the subjects' awareness of judgmental knowledge, but not of structural knowledge. That is to say, following repeated exposure to constant stimuli, subjects attributed more judgments to a specific process (judgmental knowledge), but did not succeed in attributing more judgements to specific content they learned (structural knowledge). In comparison, subjects trained with little repeated exposure to constant stimuli had difficulty in attributing their responses in terms of either judgmental or structural knowledge. Moreover, it emerged that training with constant stimuli reinforces the subjects' confidence in their responses. Subjects trained via repeated exposure to constant stimuli had more confidence in their answers than subjects not trained via repeated exposure to constant stimuli. These findings reveal that the self-assessment of learning was more positive following repeated exposure to constant stimuli. So far, there has been no testing of self-assessment of learning following exposure to varied stimuli, and there is no way of telling how they influence the subjects' self-assessment and awareness. Similarly, no comparisons have yet been made between trends of attribution after repeated exposure to constant stimuli or to varied stimuli, and there is no way of knowing whether the subjects' self-assessments differ according to the type of stimuli. The present study is the first to conduct such a comparison. Comparing the influence of repeated exposure to the two types of stimuli on self-assessment of learning will contribute to identifying which type of exposure makes a greater contribution to self-assessment and awareness of learning.

The comparison conducted in the current study enabled an examination of the development of awareness to structural knowledge and judgmental knowledge following each type of repeated exposure. This information represents the subjects' subjective self-assessment and complements the objective information collected from achievement metrics. The combination of subjective and objective metrics contributes to a comprehensive understanding of the unique advantages of each kind of exposure. These examinations increase existing knowledge of efficient strategies for promoting artificial grammar learning, taking into account the subjects' impressions and how they experience the influence of these strategies.

Two experiments were conducted to examine the research objectives. The aim of the **first experiment** was to examine the influence of repeated exposure to constant stimuli and to varied stimuli on artificial grammar learning processes. 146 subjects (65 men and 81 women) participated in the experiment, divided into two groups: the **first group** was trained by exposure to constant stimuli, and the **second group** by exposure to varied stimuli. Each of the two groups in the study was divided into three sub-groups, each of which was trained with a different number of repetition of the stimuli set: the **first sub-group** was trained with one exposure (15 stimuli comprising the basic set); the **second sub-group** was trained with two exposures (30 varied stimuli or 15 constant stimuli, from the basic set presented twice); the **third sub-group** was trained with three exposures (45 varied stimuli or 15 constant stimuli, from the basic set presented three times). The aim of the experiment was to examine the interaction between the type of exposure and the number of repetitions required to influence artificial grammar learning achievements. The experiment included testing statistical learning via a visual artificial grammar learning task including a training stage and a testing stage. In the training stage the subjects were exposed to the visual training stimuli, according to the experimental group they were assigned to, without being informed of the principles underlying the stimuli. After the training, the subjects were told that the stimuli they had observed were organized according to a certain principle, and were required to determine whether the new stimuli presented to them conformed to the underlying principle of the training stimuli. After each decision on a stimulus, the subjects were required to grade their degree of confidence in the answer on a scale of six levels ranging from "totally unconfident" to "highly confident".

The findings show that repeated exposure to constant stimuli did not contribute to achievements, with no effect from the number of repetitions of the set. However, it emerged that repeated exposure to varied stimuli contributed gradually to achievements. A significant contribution to achievements was found after training with 45 varied stimuli. These findings cast light on the efficiency of repeated exposure to varied stimuli compared to constant stimuli in artificial grammar learning. The results answer the existing lacunae in the literature and stress the importance of repeated exposure to **many varied** stimuli to receive the desired effect in learning.

The **second experiment** was intended to examine the influence of response attribution on artificial grammar learning processes, after training with repeated exposure to constant stimuli and varied stimuli. 90 subjects (43 men and 47 women) participated, divided into four groups: the **first group** was trained with three repetitions of a set of 15 constant stimuli; the **second group** was trained with three repetitions of 15 varied stimuli; the **third group** was trained with three repetitions of 15 varied stimuli; the **fourth group** was a control group, which was trained with three repetitions of 15 constant stimuli. In addition, the subjects assigned to the first and third groups responded to a post decision attribution questionnaire after each stimulus. The subjects were exposed to visual training stimuli according to the experimental group they were assigned to. Subsequently, in the testing stage, the subjects were informed of the principles and required to determine whether new stimuli presented to them were conforming or non-conforming, and to grade their level of confidence in their responses, using a similar process to the first experiment. The post decision attribution questionnaire answered by the first and third group provided five options to explain the response process: guessing, intuition, familiarity, application of principles, and remembering. Subjects were required to choose the most suitable option to describe their judgement decision.

The findings revealed that the contribution to achievements and development of self-assessment of learning depends on the interaction between the type of repeated exposure to stimuli and response attribution. With respect to contribution to achievements, it emerged that response attribution following training with constant stimuli contributed to achievements, but response attribution following training with varied stimuli did not. That is to say, the advantage of varied stimuli over constant stimuli that appeared in the first experiment was no longer perceptible in the second

experiment, after the use of the post decision attribution questionnaire. Subjects trained with constant stimuli who responded to the post decision attribution questionnaire had comparable achievements to subjects trained with varied stimuli. However, from a subjective perspective there was a perceptible advantage to varied stimuli over constant stimuli, in combination with response attribution. Following exposure to varied stimuli, there was a visible increase in the frequency of attributing answers to processes of recognizing principles and memory – states including awareness of judgmental knowledge and structural knowledge. However, following exposure to constant stimuli an increase was visible in attributing answers to processes of intuition and guessing – states including a lack of awareness of structural knowledge and partial awareness of judgmental knowledge. That is to say, subjects tested with varied stimuli were mostly successful in recognizing specific content that provided information on the stimuli, and also in recognizing the processes guiding their decision making. On the other hand, subjects trained with constant stimuli mostly had difficulty in recognizing specific content or processes guiding their decision making.

On the one hand, these findings cast light on the contribution of response attribution in combination with training with constant stimuli to increased achievements. On the other hand, from the prism of awareness and quality of learning processes, the findings cast light on the advantage of repeated exposure to varied stimuli over constant stimuli for more explicit self-assessment of learning with reference to principles. These results are consistent with the claim that exposure to varied stimuli encourages deeper learning processes, aimed at creating generalizations and recognizing principles, while exposure to constant stimuli encourages learning processes aimed at specific and local learning of the appearance of the stimuli.

In conclusion, this research contributes to the understanding of how repeated exposure to constant stimuli and varied stimuli together with response attribution can increase the quality and efficiency of statistical learning processes. The research was intended to provide answers concerning the influence of constant stimuli on learning compared to varied stimuli, and was focused in particular on examining the differences between the two. In addition, in contrast to previous research, the present research examined the influence of each kind of stimuli on learning – both from an objective point of view (in terms of achievements) and from a subjective point of view (in terms of the processes to which the subjects attributed their responses). The research findings

revealed that repeated exposure to varied stimuli contributes to achievements and to self-assessment of statistical learning. With respect to achievements, the influence of repeated exposure to varied stimuli is dependent on the number of repetitions of the stimuli. After three repetitions of a set of 15 varied stimuli, a clear increase in the level of achievements was detectable. With respect to self-assessment of learning, exposure to varied stimuli significantly increased the number of cases where the subjects reported relying on understanding principles and on memory – evidence of the development of awareness of the material learned and patterns of action.

In contrast, repeated exposure to constant stimuli makes an observable contribution to achievement only in combination with response attribution. No significant contribution to achievements was found following repeated exposure to constant stimuli without response attribution – with no effect from the number of repetitions of the stimuli. But after repeated exposure to constant stimuli combined with response attribution, a contribution to achievements was observed – to a level of achievement comparable to that reached after varied stimuli. With respect to self-assessment of achievement, it was found that repeated exposure to constant stimuli is connected to an increase in the frequency of attributing answers to the operation of intuition and guessing – processes classified as essentially implicit. These reports are evidence that exposure to constant stimuli does not reinforce the development of awareness of learning. In conclusion, the present research makes a unique contribution to understanding how to promote processes of statistical learning via repeated exposure to stimuli and response attribution in several respects. Firstly, the research included a specific examination of the influence of repeated exposure on the learning process and a direct comparison between the two kinds of repeated exposure (to constant stimuli and varied stimuli), which have not previously both been examined in a single experiment. This examination promotes the understanding of the role played by repeated exposure to constant stimuli and repeated stimuli in promoting statistical learning. Secondly, the research tested the influence of repeated exposure through objective and subjective metrics. This combination of metrics permitted the examination of the influence of repeated exposure on the development of the subjects' awareness and self-assessment, as well as the level of achievements in practice. Thirdly, the research includes a new interpretation of the contribution of response attribution to

statistical learning, with stress on the interdependence of response attribution and the type of stimuli in training and their influence on achievements.

The present research has implications both for the domain of research and for the domain of education. With respect to research, the findings increase the precision with which previous experiments may be interpreted and understood, and will assist in planning future experiments taking into consideration the influence of the types of stimuli in training, the number of repeated exposures, and response attribution processes. With respect to education, the findings will assist in identifying guidelines to promote learning and the design of pattern-based learning environments, such as reading and writing.