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# The effect of stimulus complexity and verbalizability on associative learning and related memory processes

Summary of PhD Thesis

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# 1. Introduction

Acquired equivalence learning is a specific kind of associative learning, where two or more independent stimuli are linked together, and they are considered as equivalent with each other if they share the same outcome, and this equivalence can be transferred (transfer or generalization) to new instances.

To investigate this type of learning in humans Myers and her colleagues (2003) developed a computer based neurocognitive test, the Rutgers Acquired Equivalence Test (RAET). The task of the test is to learn visual stimulus pairs (antecedent-consequent pairs) through trial-and-error learning. The test consists two main phases: the acquisition and the test phase. In the acquisition phase the participant learns the associations gradually, based on the feedback given by the software about the correctness of the answers. The required equivalence will be established between stimuli, which share the same consequence. In the test phase, no further feedback is given, and the already learned associations have to be recalled (retrieval part of the test phase). Furthermore, previously not shown, but based on the equivalence, predictable associations will be tested, too (transfer or generalization part of the test phase).

The main advantage of the RAET is that distinct neural structures are taking part in the two phases of the test. Both the original and further neurocognitive and neuroimaging studies proved that the acquisition phase primarily relies on the integrity of the basal-ganglia-frontal cortex loops, while the test phase primarily relies on the integrity of the hippocampal region.

Therefore, it is possible to use it to investigate the acquired equivalence learning in neurological and psychiatric disorders with basal ganglia or hippocampi dysfunctions. In the original study by Myers and her colleagues (2003) patients with Parkinson's disease performed poorer in the acquisition phase, but not in the test phase. On the contrary, performance of patients with hippocampal atrophy was poorer in the test phase but not in the acquisition phase. Besides Parkinson's disease the acquisition was also impaired in borderline personality disorder and Tourette syndrome. The test phase was impaired in Alzheimer's disease, schizophrenia and migraine in adult patients. In contrast, no deficit was found in generalized tonic clonic epilepsy, children with obsessive–compulsive disorder and children with migraine.

This raises a question regarding whether there are no differences in the learning abilities between the healthy and patient populations, or the test is not sensitive enough to detect the differences on behavioral level. Having recognized this, we aimed to improve the sensibility for basal ganglia-frontal cortex functions and developed a new visually guided equivalence learning test (Polygon). We argue that the applied stimuli in the RAET (i.e. drawn faces and drawn fish with different color) are complex stimuli, which can have semantic and verbal information, and they could serve as an extra clue for cognitive associations, and this gives a possibility to compensatory mechanisms involving other cortical areas.

In the new test (Polygon), we have reduced the complexity of the visual stimuli, we applied two-dimensional geometric shapes (grayscale shaded circles as antecedents; a triangle, a square, a rhombus, and a concave deltoid as consequents) instead of colored drawn faces and fish. We argue that these geometric shapes are less complex, have less semantic meanings and are more difficult to verbalize them. We hypothesize that because of the application of the new simplified stimuli set, and the reduction of the supporting information (i.e. semantic meaning, feature verbalizability) the learning will be more implicit, therefore, the test will be more sensible to the function of the basal ganglia and the connected fronto-striatal circuits.

It is known from earlier studies that brain structures fundamentally involved in acquired equivalence learning (i.e. the basal ganglia and the hippocampus) are involved in multisensory information processing and multisensory integration, too. Therefore, to investigate the effect of multimodal information on the acquired equivalence learning, our research group has developed an audiovisual test (SoundFace) based on the original RAET. In this test, the antecedent stimuli are distinct sounds (sound of a cat, a guitar, a vehicle and a woman), and the consequents are drawn faces. If we compare the learning performances of healthy humans in the two tests (RAET and SoudFace) there is no difference in the effectiveness of the equivalence learning. A possible explanation is that this type of associative learning is a very old and conserved function, where the multisensory information is not superior compared to unimodal modalities, which contribute to the associative learning equally. On the other hand, the retrieval and generalization functions are enhanced in the audiovisual test, which can be clearly seen in the shorter reaction times in the audiovisual paradigm. However, the semantic meanings and the verbalizability of the stimuli could also influence the results. In the SoundFace test the applied visual stimuli are the same drawn faces from the RAET. Furthermore, the auditory stimuli are ordinary sounds from the daily life. As a consequent, these can facilitate the learning process and the memory performance, because it is easier to make connections between the complex stimuli, due to previously learned associations or the semantic congruency.

Therefore, we also constructed a new audiovisual test with reduced visual stimuli. We kept the auditory stimuli from the SoundFace test as antecedents, and we changed the colored drawn faces to the two-dimensional geometric shapes from the Polygon test as consequents. We ask the question how can affect the reduced stimulus complexity and verbalizability of the visual stimuli the participant's performances in the audiovisually guided test.

# 2. Aims of the study

The aim of our studies was to investigate the visual and audiovisual associative learning in healthy adult humans. We aimed to validate our newly developed associative learning tests with reduced visual stimulus complexity, verbalizability and semantic meaning, and to examine how can this influence the performance of healthy adult participants in equivalence learning and the connected memory processes. Therefore, we compare the performances in tests with more and less complex visual stimuli, both in a visually and an audiovisually guided acquired equivalence learning.

# 3. Methods

## 3.1. Participants

Altogether 55 (but not the same) person participated in both study. The participants were recruited on a voluntary basis, no compensation was given, and they were free to quit any time without any consequence. All the participants were healthy adults without any neurological or psychiatric disorder. The study protocol followed the tenets of the Declaration of Helsinki in all respects, and it was approved by the Regional Research Ethics Committee for Medical Research at the University of Szeged, Hungary (27/2020-SZTE).

## 3.2. The applied visual tests

The tests were run on laptops. The testing sections took place in a silent room. They were tested one-by-one. No forced quick responses were expected from them. The participants executed the tests one after another in a pseudorandom order, to statistically minimalize the carry-over effect.

We used two visual tests, one with more complex stimuli (modified RAET), and one with a simplified stimuli (Polygon). In the RAET the antecedents were different drawn faces: a man, a woman, a boy and a girl. The consequents were different colored drawn fish, with the same shape: red, green, blue and yellow. The main goal of the tests is to learn associations between the antecedents and consequents. In the case of the Polygon test the antecedents were grayscale shaded circles: white, light gray, dark gray and black. The consequents were different two-dimensional blank, geometric shapes: a triangle, a square, a rhombus and a concave deltoid. Each antecedent is associated with two consequents, which makes eight possible pairings.

Both tests have the same structure, which is divided into two main phases: acquisition and test phase. In the acquisition phase the participants learn the associations between the antecedents and consequents through trial and error. The participant learns the associations (6 pairs from the possible 8), pair by pair, gradually, based on the feedback about the correctness of the responses given by the program. After each new introduced stimulus pair, the participant must give a certain number of subsequent correct answers (4, 6, 8, 10, 12 after each new association, respectively) to proceed further in the test, and finally accomplish the acquisition phase. As consequence, the number of trials in this phase was varied between the participants, depending on learning performance.

In the test phase, no further feedback was given about the correctness of the responses. In this phase, the participant had to recall the already learned associations (retrieval). Furthermore, the two remaining pairs were presented, and if the equivalence forming was successful, the participant could conclude the correct answers (generalization), even if he or she has not seen these pairs in the acquisition phase. Altogether, there are 48 trials in the test phase, of which 36 are in the retrieval part and 12 are in the generalization part of the test phase. The order of the two types of trials are randomly mixed in the test phase.

## 3.3. The applied audiovisual tests

The audiovisual tests have the same structure as the visual tests, but the antecedents were clearly distinguishable distant sounds: a cat, a guitar accord, a sound of a vehicle and a woman saying “Hello”. In the SoundFace test the consequents are the same drawn faces mentioned in the RAET. In the SoundPolygon they are identical to those geometric shapes, which we applied in the Polygon test.

## 3.4. Data analysis

The following cognitive learning parameters were calculated and analyzed in each test: the number of trials (NAT), the error ratios in the acquisition phase (ALER) and retrieval (RER) and generalization (GER) parts of the test phase. The error ratios were calculated by dividing the number of incorrect answers by the number of trials of the given section. The response times (RT) were also recorded in millisecond accuracy. The response times are the time duration between the appearance of the stimuli and the participant's response. Values greater than 3SD were excluded.

The Shapiro-Wilk normality test was applied to decide the data whether, or not has a normal distribution. Due to nonparametric distribution the Wilcoxon Matched-Pairs test was used to compare the cognitive learning performances in the different tests (RAET vs Polygon and SoundFace vs SoundPolygon).

# 4. Results

## 4.1. The comparison of performances in the visual tests

In the acquisition phase, significantly more trials (NAT) were necessary to learn the associations in the Polygon test, than in the RAET ($Z = 3.731$, $p = 0.0002$). Similarly, to the NAT, the learning error ratio (ALER) was also significantly higher ($Z = 3.939$, $p = 0.00008$).

Furthermore, the response times in the acquisition phase (RT) were significantly longer in the Polygon test ($Z = 2.983$, $p = 0.003$).

Contrary to the acquisition phase, there were no significant differences in the performance between the RAET and the Polygon tests, both in retrieval ($Z = 0.739$, $p = 0,460$) and generalization ($Z = 1.624$, $p = 0.104$) parts of the test phase.

The response times were also not significantly different both in retrieval (Z = 0.667, p = 0,505), and in generalization (Z = 0.595, p = 0,552) parts of the test phase between the two paradigms.

## 4.2. The comparison of performances in the audiovisual tests

In the acquisition phase, the participants needed significantly more trials (NAT) to learn the associations in the SoundPolygon test (Z = 2.417, p = 0.016). The learning error ratios were significantly higher as well (Z = 2.213, p = 0.027).

Furthermore, in the acquisition phase the response times (RT) were significantly longer in the SoundPolygon test (Z = 3.703, p = 0.0002).

Similarly to the acquisition phase, the error ratios were significantly higher both in retrieval (Z = 2.727, p = 0.0064) and generalization (Z = 3.085, p = 0.002) parts of the test phase.

As for the response times (RT), similarly to the acquisition phase, they were significantly longer in the SoundPolygon test, both for the retrieval trials (Z = 4.994, p = 0.000001) and for the generalization trials (Z = 3.938, p = 0.00008).

# 5. Discussion

In the case of the unimodal visual acquired equivalence learning the participants' performances were significantly poorer in the acquisition phase of the Polygon test, compared to those of the RAET, as indicated by the significantly higher error ratios and the number of acquisition trials, even though the response times were significantly longer. Our results suggest that acquired equivalence learning, which is primary linked to intact function of the basal ganglia, is strongly influenced by the complexity and verbalizability of the applied visual stimuli.

As for the test phase, the error ratios in the retrieval and the generalization parts of the test phase did not differ between the RAET and Polygon tests, and neither did the response times. In other words, stimulus complexity and verbalizability had no effect on the retrieval of the previously learned associations and on the transfer of the acquired equivalence to previously unseen stimulus pairs.

We can conclude that due to the simplified stimuli set in the Polygon, participants tend to shift to a more implicit learning, with less cortical contribution by the declarative memory system. The results also suggest that the Polygon test is more sensitive regarding to basal ganglia-frontal loop functions, than the original RAET.

Comparing the two audiovisual tests, the results revealed that contrary to what was found when the two visual tests (RAET vs Polygon) were compared, in the case of the multimodal tests the reduced stimulus complexity and verbalizability influenced not only the performances in the acquisition phase, but in the entire test phase, including the retrieval and generalization. Based on these results, it seems that when the learning is unimodal (visual), the reduced stimulus complexity makes the learning difficult, but if it has been successful, retrieval and generalization are spared. Such a sparing does not seem to occur in the case of a multimodal (audiovisual) learning task.

A possible hypothesis can be for explaining why reduced stimulus complexity and verbalizability influences all the phases of the multimodal tests (but only the acquisition phase in the visual test), that hippocampal compensation is either specific to the visual modality or it works in unimodal learning. The other possible explanation is that in the case of the SoundFace, both the auditory stimuli (cat, human, vehicle, guitar) and visual stimuli (drawn faces) are rich in semantic meanings and can be easily described verbally; therefore, it is easier to make associative connections between them, and form a verbalized rule for the equivalence. Consequently, this can make the hippocampus more active (as the part of the declarative memory) and make the encoding more efficient (integrating the events more efficiently). On the other hand, it is much more difficult to make such a connection between the sounds and the geometric shapes, which can negatively influence not only the encoding but the recall and transfer functions, too.

# 6. Summary

The main aim of the present studies was to investigate the influential effect of visual stimulus complexity and verbalizability on the visual and audiovisual associative equivalence learning and the connected memory processes (retrieval and generalization).

In the case of the unimodal visual tests, we found that, it has a profound effect on the acquisition phase, but not on retrieval and generalization. We conclude that due to the reduced stimulus complexity and verbalizability the participants tend to shift to a more implicit strategy, with less cortical compensatory contribution. The results also indicate that contrary to the previously used Rutgers Acquired Equivalence Test (RAET), the Polygon test could be more sensitive to measure and analyze the basal ganglia-frontal lobe functions.

In the case of the audiovisual acquired equivalence learning, we found that, applying visual stimuli with reduced stimulus complexity and verbalizability, decrease the participants' performance in both phases of the learning paradigm. One explanation of it can be that the hippocampus is dominated by unimodal visual encoding and less sensitive to the audiovisual multisensory inputs. The second explanation could be that it is more difficult to make associative connections between the less verbalizable visual stimuli and the applied sounds through semantic congruency or previously learned associations.

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## List of publications providing the basis of the thesis

I. Eördegh, G., Tót, K., Kelemen, A., Kiss, Á., Bodosi, B., Hegedűs, A., Lazsádi, A., Hertelendy, Á., Kéri, S., & Nagy, A. (2022). The Influence of Stimulus Complexity on the Effectiveness of Visual Associative Learning. *Neuroscience*, *487*, 26–34. https://doi.org/10.1016/j.neuroscience.2022.01.022
SJR indicator: Q2
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II. Tót, K., Eördegh, G., Kiss, Á., Kelemen, A., Braunitzer, G., Kéri, S., Bodosi, B., & Nagy, A. (2022). Visual consequent stimulus complexity affects performance in audiovisual associative learning. *Scientific reports*, *12*(1), 17793. https://doi.org/10.1038/s41598-022-22880-z
SJR indicator: D1
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**Other publications:**

I. Eördegh, G., Tót, K., Kiss, Á., Kéri, S., Braunitzer, G., & Nagy, A. (2022). Multisensory stimuli enhance the effectiveness of equivalence learning in healthy children and adolescents. PloS one, 17(7), e0271513. https://doi.org/10.1371/journal.pone.0271513

II. Rosu, A., Tót, K., Godó, G., Kéri, S., Nagy, A., & Eördegh, G. (2022). Visually guided equivalence learning in borderline personality disorder. Heliyon, 8(10), e10823. https://doi.org/10.1016/j.heliyon.2022.e10823