The Dynamic Concept, Verbal-Nonverbal Taxonomy: A Study from Engram Theory and Conceptual Atomism

Miguel Ángel Muñoz-López (dclular@gmail.com)
Centro de actualización del magisterio, Durango https://orcid.org/0000-0002-8056-0061
María del Rocío Hernández-Pozo
Universidad Nacional Autónoma de México
Omar David Almaraz Rodríguez
Universidad pedagógica de Durango

Article

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Abstract

This article focuses on concept learning, exploring the variability of this process in relation to verbal and nonverbal taxonomy. The theories of concept and memory, particularly conceptual atomism and engram theory, are examined, which provide a solid foundation for understanding learning processes and concept formation. A novel definition of "dynamic concept" is elaborated based on these theories. Considering this, an experiment was designed to measure conceptual learning, revealing significant differences between verbal and nonverbal learning. In conclusion, the aim of this research is to contribute to the understanding of the nature of concepts and their relationship with engram formation in the brain. By addressing existing theories and conducting experiments, new perspectives and advancements are sought in the field of cognitive neuroscience.

Concept

Memory plays a crucial role in behavioral sciences and education. The study of memory has been of great relevance, and various theories have been developed to explain its functioning, such as cognitive schemas (Piaget & Warden, 1926) and their relationship with behavior (Beck, 1964, 1967). One notable advancement in this field is the discovery of memory engrams, which explain how information is processed and retrieved in the brain (Liu et al., 2015; Ramirez et al., 2013; Ryan et al., 2015).

However, in the study of engram theory, there is naturally a lack of research in the domain of semantic and declarative memory, as the optogenetics technique used for studying it is not suitable for application in humans. As a result, this aspect of memory has not been studied thus far, despite its importance in our current culture (Eichenbaum, 2016).

The concept represents the building blocks of thoughts, crucial for psychological processes like memory (Margolis, Eric & Laurence, Stephen, 2019). However, its nature has been the subject of intense debate (Margolis & Laurence, 1999; Margolis & Laurence, 2015). To explain the concept, numerous theories have been developed, with the most common one considering concepts as definitions that consist of two components: their reference and their meaning (Fodor & Pylyshyn, 2015), or as a "mental representation associated with a linguistic signifier" (Real Academia Española [RAE], 2022). This semantic variable inherently excludes nonverbal concepts or blocks of information that do not involve semantic or declarative information. This popular view serves as the basis for important situations such as education, where traditionally, only what can be declared is assessed. According to Fodor, cognitive science is mired in areas dependent on this topic (Fodor, as cited in Rodríguez, 2007).

Thus, Fodor proposes conceptual atomism, which suggests a concept without structure where most of them are atomic and determined by nomologically supported informational relationships between the individual and their context (Rodríguez, 2007). In conceptual atomism, the content of a concept depends on its relation to the world, resulting in its psychological variability as a consequence of causal relationships between the subject and the world. A concept is recalled when the individual experiences an appropriate causal relationship with the property of the world to which the concept refers (Margolis et al., 2019).

Fodor's definition of the concept has an analogical resemblance to the dynamics of memory formation (Figure 1) as discovered in neuroscience by Tonegawa in his reframe of the engram theory. This theory was based on Semon's work (1923) and reformulated as follows: When a subject experiences an event, selected stimuli from the experience activate sets of neurons that produce lasting physical and/or chemical changes (engrams) in those cells and their connections, facilitating memory storage. Later, when a part of the original stimulus returns, these cells connected by the created engram are reactivated to evoke the recall of a memory (Liu et al., 2015).

Based on this approach, the objective of this research was to propose a definition of a concept in accordance with the engram theory (Liu et al., 2015) and conceptual atomism (Fodor, 1975). Analyzing both theories (Table 1), the design of conceptual learning experiment was developed, making possible to analyze learning from this perspective and its relation to verbal and nonverbal taxonomy.

The dynamic concept

The concept is a basic element of thought, crucial to intellectual processes; it lacks structure, becoming dynamic and relative on the experience of each subject. It consists of the evocation of recollections from memory, because of the reactivation of neural engrams and in response to stimulation elicited by properties of previously paired objects or external or internal phenomena by the quantitative or qualitative exposure between them and the subject. This activation caused lasting physical and/or chemical changes between specific neurons, forming engrams (Muñoz-López, 2023).

Table 1 *Regularities between theories for the conformation of the concept*

Conceptual atomism	Engram Theory	Hebb Theory
Natural properties	External and internal stimuli	
Artificial properties	Internal stimuli	
Evocation	Reactivation	
Mental state	Engram	
Locking	Lasting chemical or physical changes between specific neurons	Plasticity by exposure and/or quality
Exposition	Stimulation	

Method

The subjects are high school students who can follow instructions and are likely to have a high capacity for brain plasticity, which is important for experiments based on learning activities. Individuals with psychological disorders, blindness or visual impairments, and those unable to use the experimental materials were excluded as criteria.

The participants come from different places in Mexico, especially Durango, Sinaloa, Mexico City, and the State of Mexico. The sample consisted of 268 individuals (M age = 17.33, SD = 1.059), 158 (59%) females, and 109 (40.7%) males (Figure 12). Participants were asked for their informed consent, which involved clarifying the privacy of their data, stating their participation was voluntary, and explaining the purpose of the research.

Based on the primary objective of the research, a hypothesis was formulated for resolution, which justifies the calculation of the sample size (Quispe, 2020):

H0 = There are no statistically significant differences between the mean of accuracy in verbal concept learning and the mean of accuracy in nonverbal concept learning in the experiment.

The sampling was probabilistic, to calculate the sample size, RStudio software and the 'pwr' package titled "Basic Functions for Power Analysis" (Champely et al., 2017) were used. This package contains functions for Cohen's statistical power analysis (1988).

The hypothesis involves two means from different populations with two tails, i.e., H0: $\mu 2 = \mu 1$ vs HA: $\mu 2 \neq \mu 1$.

To calculate the sample size, the effect size "d" or design effect needs to be obtained using the formula: (μ1 - μ2) / standard deviation. With μ1: 56, μ2: 53.43, and standard deviation: 7.024, the result is d = 0.36588838268792710706150341685649. The command for calculating the sample size for this type of hypothesis in RStudio is as follows:

Sample = pwr.t.test(d = 0.36588838268792710706150341685649, sig.level = 0.05, power = 0.50, type = 'two.sample', alternative = 'two.sided')

This resulted in a requirement of 58 subjects per group.

The subjects were matched based on their baseline anxiety, which represents the possibility of a person reacting with anxiety to life situations. Baseline anxiety is a variable that can affect learning (Blumer & Benson, 1975). To reduce confounding factors, the decision was made to match subjects based on this criterion. As a result of the matching process, three groups were obtained: high anxiety, medium anxiety, and low anxiety.

Each group obtained was randomly divided by the software into an experimental group and a control group (Figure 2), where the independent variable is verbal or nonverbal information.

At the end of the first experiment, the two low-anxiety groups terminated their participation in the trial since in the next experiment where anxiety is induced with a stressor, it is likely that the difference will be null. Therefore, these two groups were considered closed. The evaluation is performed automatically by the software at the moment that the subject interacts with it.

Data collection was conducted by the software application used in the experiment. For the assessment of subjects regarding the anxiety variable, the ASI-3 questionnaire was used: New Scale for the Assessment of Anxiety Sensitivity (Hernández-Pozo, Alvarado-Bravo, Espinosa-Luna, et al., 2022). The questionnaire was validated in the Mexican population with a total scale reliability of Cronbach's alpha equal to 0.919.

The data collected by the software were automatically sent to a spreadsheet on the network that captured data from all applications. This approach eliminated errors caused by the researcher's expectations during the experiment evaluation or personal observation.

Regarding the reliability of the experiment, with 268 valid cases and zero exclusions, 40 items were analyzed, resulting in a reliability coefficient of 0.885.

Experiment

An experiment was designed that consisted of two stages. In the first stage, the subjects were repeatedly exposed to a set of related stimuli to create a concept, as proposed by the engram and informational atomism theories when referring to the phenomenon known as "locking". The nature of the stimuli changed according to a verbal and nonverbal taxonomy, which defined the control and experimental groups.

In the second stage, concept learning was tested. During this part, a stimulus was presented to the subjects, and they were asked to relate it to the properties they had associated with it. This process aimed to recreate the theories that frame this research.

Since the design was double-blind, the response to the hypothesis could be determined at the end of the experiment because the subjects were randomly assigned to either the control or experimental group, without their knowledge of the subjects or the researcher, of which group they belonged to.

The experiments were double-balanced in terms of learning and probing. In the training or learning phase, the training was balanced based on concepts. For each concept, seven exposures were conducted, resulting in a total of four concepts.

Table 2 *Distribution example*

Trial	**Discriminative Stimuli**	
	Concepto 1	Concepto 2
1	2	1
2	0	4
3	1	2
4	4	0
5	3	3

For Experiment 1, there were 5 probing trials per concept. Each trial consisted of a sample stimulus, six comparison stimuli, and discriminative stimuli presented with a balanced distribution of correct responses ranging from 0 to 4 for each concept (Table 2).

Experiment 2 consisted of concept retrieval exercises or information blocks. It comprised 10 probing trials, in which there were 4 possible responses, with only one being correct.

Results

The main hypothesis of the research was tested using Experiment 1, using the data obtained from Experiment 1, a modified Welch's t-test was performed (Table 3), which yielded a p-value indicating statistically significant differences between the groups with verbal and nonverbal concept learning, with a higher number of nonverbal correct responses.

Table 3 *Test for verbal and nonverbal groups*

Group	N	Mean	SD	p
Non verbal	121	104.4298	14.49645	.003
Verbal	154	98.9870	15.72101	

The evaluation of the hypothesis was initially conducted solely based on the accuracy achieved in the experiment. However, data on errors made by the subjects during the experiment, were also collected. This is relevant because one of the characteristics of a concept is the ability to discriminate, which is reflected in the results through the quantity of "selection errors." These errors occur when properties of unrelated objects are selected. Additionally, there is another type of error known as "generalization error," which occurs when the subject fails to select a quality of the base object, indicating a failure to generalize the concept.

To assess conceptual learning according to these considerations, errors were subtracted from the correct responses to re-evaluate the previously stated hypotheses. The same sample size (n) and statistical tests mentioned in Table 4 were used for this analysis.

Table 4 *Overall test*

Group	N	Mean	SD	Two-tailed p
Non verbal	121	88.8595	28.992	.003
Verbal	154	78.0455	31.317	

The results once again showed a significant difference where nonverbal learning accuracy was higher, rejecting the null hypothesis. Finally, to determine the effect size of the difference between the two groups, Cohen's d-test was used, yielding a result of 1.1. This value is interpreted as a large effect, as it exceeds 0.8. To analyze the variables' behavior in more detail, a structural equation model (SEM) was conducted, considering gender, nonverbal taxonomy, baseline anxiety (Axb), and nonverbal concept learning represented by the number of correct responses (Figure 3). The bootstrap process with 1000 samples (nboot) and a significance level of 0.05 (Alpha) was employed for this analysis.

Figure 3 shows that the variable "Mujer"(female) seems to have a negative effect on concept learning, both verbal and nonverbal. However, this effect did not turn out to be statistically significant. On the other hand, a significant relationship was found between the variable female and baseline anxiety, indicating that female was more frequently associated with higher levels of baseline anxiety. Regarding the variable "non verbal taxonomy," a significant weight was found on the dependent variable of concept learning. This was evidenced by a T statistic of 2.8, surpassing the minimum threshold of 1.6, and the confidence interval (CI) values between the 2.5% CI and 97.5% CI not including zero (Figure 4).

In general, regarding verbal and nonverbal concept learning, women learned similarly in response to these variables. However, men had nonverbal and verbal concept learning scores of 107.2 and 98.8, respectively, with a higher number of correct responses for nonverbal concepts. After analyzing the means using the modified Welch's T-test, a p-value of 0.002 was obtained. When comparing the results between men and women in non-verbal learning, disparities were observed, as men achieved an average of 107.2 correct responses, while women had an average of 102.7 correct responses. However, when performing the statistical analysis using Welch's T-test, a p-value of 0.07 was obtained, indicating that there is no statistically significant difference between the sexes.

Discussion

Addressing the research hypothesis, statistically significant differences were found between the mean scores in the learning of verbal and non-verbal concepts. It was observed that non-verbal concepts were retrieved to a greater extent than verbal concepts, with a large effect size. This finding is consistent with previous research reported in recent years (Margolis & Laurence, 2015).

The higher retrieval of non-verbal concepts compared to verbal concepts could be explained by the wide diversity of object-related properties that can be associated with a single word. This phenomenon is context-based and requires a greater amount of mental processing compared to a visual stimulus, which directly relates to a set of properties without the need for prior processing (Malt et al., 1999), while a concept without the use of verbs would theoretically require fewer mental operations.

Regarding demographics, women learned verbal and non-verbal concepts in the same way, while men showed greater learning in non-verbal concepts.

In terms of non-verbal learning, which encompasses storage and reactivation/recall, the first experiment found that subjects were able to construct concepts by combining properties without the need for verbs. They were also able to solve problems that required knowledge of these non-verbal concepts. In other words, the subjects recalled non-verbal information to solve each trial. From this, we can deduce that human beings are capable of acquiring knowledge and acting accordingly without the need to verbalize it.

Another consideration, as stated by Margolis and Laurence (2015), is that learning is not necessarily tied to words. However, a problem arises when trying to express what has been learned in a non-verbal manner. This occurs in various environments, such as the academic setting, where students who do not speak the native language declare their main problem as not being able to find or remember the appropriate vocabulary to communicate, even though they know the answer (Sifrar, 2006).

The experiment conducted in this research was based on the conceptual atomism proposed by Fodor (1998), as well as Tonegawa's engram theory (Tonegawa, 2015) for the creation and retrieval of concepts. Additionally, Hebb's theory (Hebb, 1932) was used to explain offline association or locking between properties. Taking this set of theories as a starting point, a specific definition of dynamic concepts was elaborated to be applied in this research.

The main objective was to contribute to the debate on the nature of concepts, drawing upon Fodor's ideas on concepts and considering the scientific advancements made at MIT with engram theory. All of this was conducted from the perspective of cognitive neuroscience, which is dedicated to the study of how the brain facilitates cognitive functions and how the functions of the physical brain can generate seemingly intangible thoughts, ideas, and beliefs (Gazzaniga, Ivry, & Mangun, 2019).

This description of the concept allows us to approach the study of cognitive learning to the real characteristics of the development of human knowledge, taking into account its individuality. This has been considered from various perspectives, starting with Ausubel (2002) and his concept of meaningful learning, which emphasizes the importance of each student's prior knowledge for the achievement of new cognitive structures. It also extends to neuroscientific studies indicating that individuals' experiences over the years lead to completely individual brain anatomy (Valizadeh, Liem, Mérillat, Hänggi, & Jäcke, 2018).

This implies that each concept is unique in each person and develops based on their experiences when interacting with the environment. In this new description, the concept is recognized as structureless and dynamic, which is closer to real learning, where knowledge constantly changes through feedback. The semantic aspect becomes just one property among others, and for social agreements in communication, knowledge about an object is conveyed through common criteria assigned to a symbol (Ausubel, 1983).

Declarations

"The study from which the data for the article "The dynamic concept, verbal-nonverbal taxonomy: a study from the theory of engrams and conceptual atomism" is obtained, was approved by the ethics committee of the Universidad Pedagógica de Durango, as part of the process prior to the application of the doctoral thesis experiment, where this article is located."

Author contributions section:

Miguel Ángel Muñoz-López: Lead Researcher, writer, illustrator

María del Rocío Hernández Pozo: Thesis director, research, revision

Omar David Almaraz Rodríguez: Thesis director, methodology, revision

Corresponding author and lead contact:

Miguel Ángel Muñoz-López

Declaration of interests:

The authors declare no competing interests

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Figures

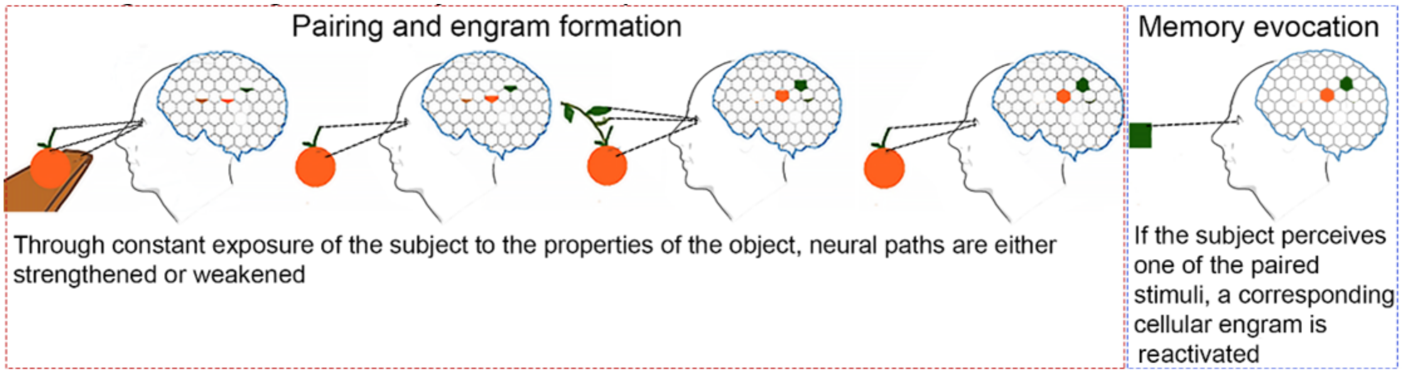

Figure 1

Learning from engram theory and conceptual atomism

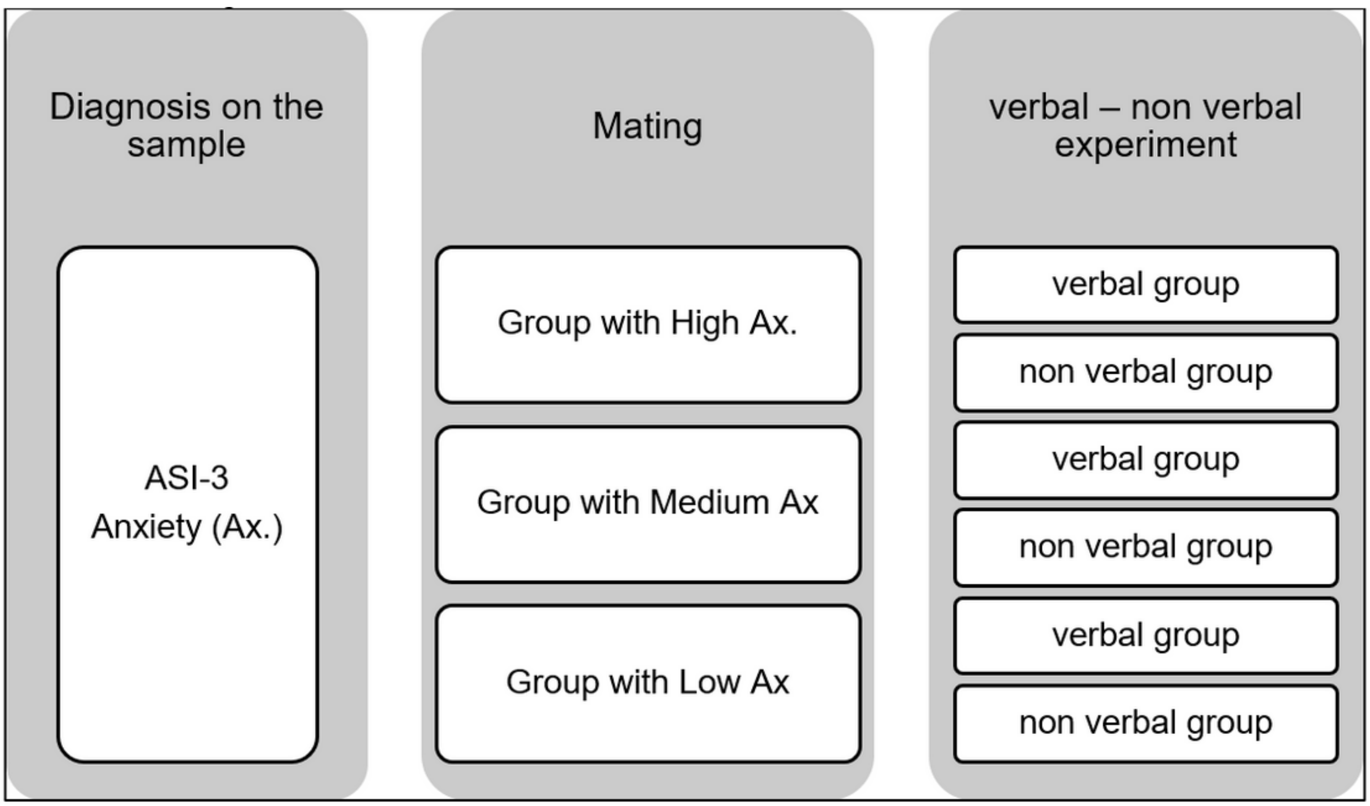

Figure 2

Research design

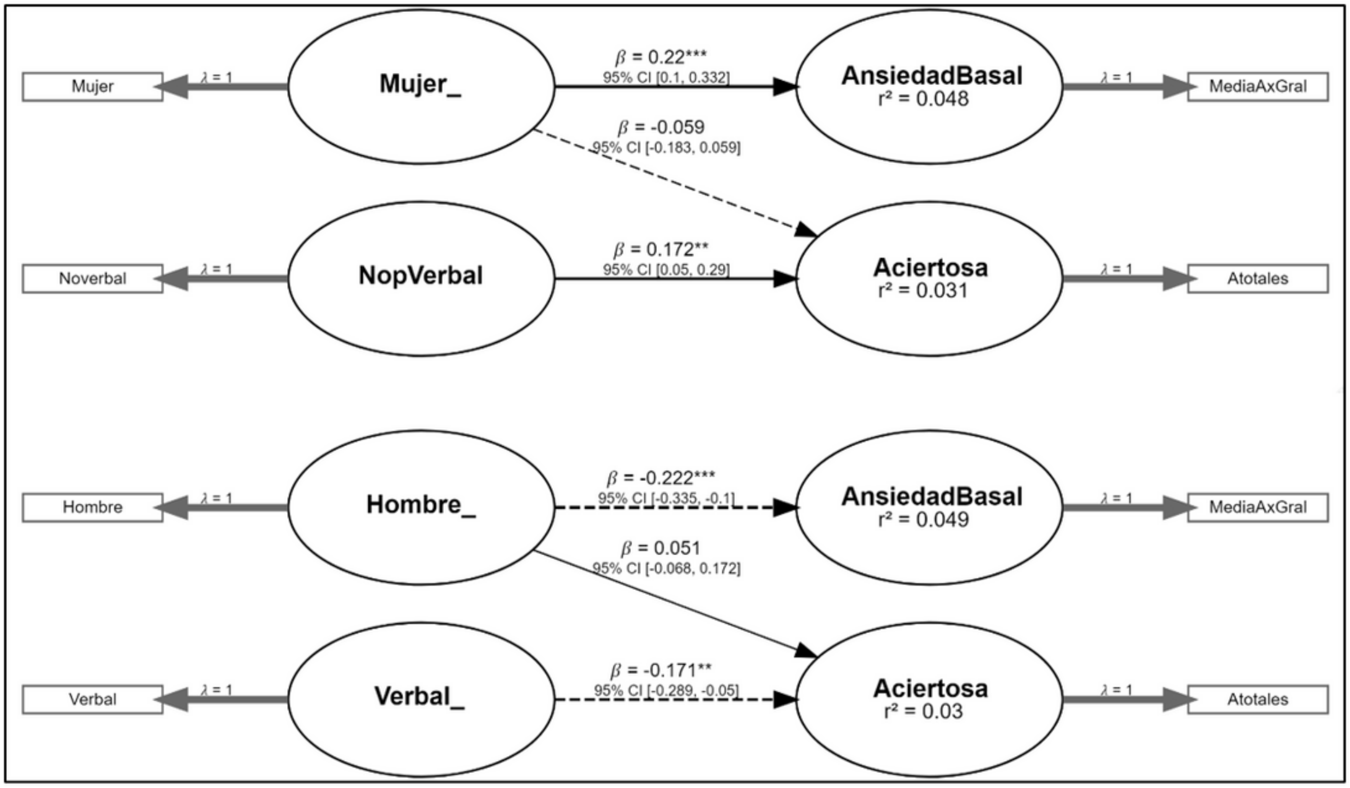

Figure 3

SEM Axb, Gender, nonverbal/verbal taxonomy, and nonverbal concept learning

```
> summM_boot <- summary(bootm_model, alpha = 0.05)
> summM_boot$bootstrapped_paths
                          Original Est. Bootstrap Mean Bootstrap SD T Stat. 2.5% CI 97.5% CI
NopVerbal  ->  Aciertosa          0.172          0.173        0.061   2.803   0.050    0.290
Mujer_  ->  Aciertosa            -0.059         -0.059        0.062  -0.952  -0.183    0.059
Mujer_  ->  AnsiedadBasal         0.220          0.219        0.057   3.867   0.100    0.332
```

Figure 4

SEM statistics