Complutense University of Madrid

Final report modelling week

Existence of time compaction in the human brain: Theoretical and experimental study

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Abstract

José Antonio Villacorta Atienza and Carlos Calvo from the Institute of Interdisciplinary Mathematics are studying actually how the cognitive map of the brain works. They use robots and do experiments, with for example rats to study it. They've proposed as to investigate the **compaction of time** in our brain, an area that they are studying now.

Our objective is to see if our brain can handle dynamic situations as a single static situation assuming that time is "compact".

Having this on mind, we will proceed to do an experiment to the participants of the *Modelling week* and analyse data in order to endorse our theoretical hypothesis.

Chapter 1

Theoretical view

1.1 Introduction and procedure

In the last decades, we have studied how the brain processes static situation, the procedure is based on creating a cognitive map to understand it. Now we will try to understand how our brains works when trying to process dynamic situations. If we consider a dynamic situation as a set of consecutive static environments the amount of information to be processed could increase explosively. For this reason, the idea is to apply the concept of the time is compacted and extract the critical events of the dynamic situation and project this events in to the cognitive map.

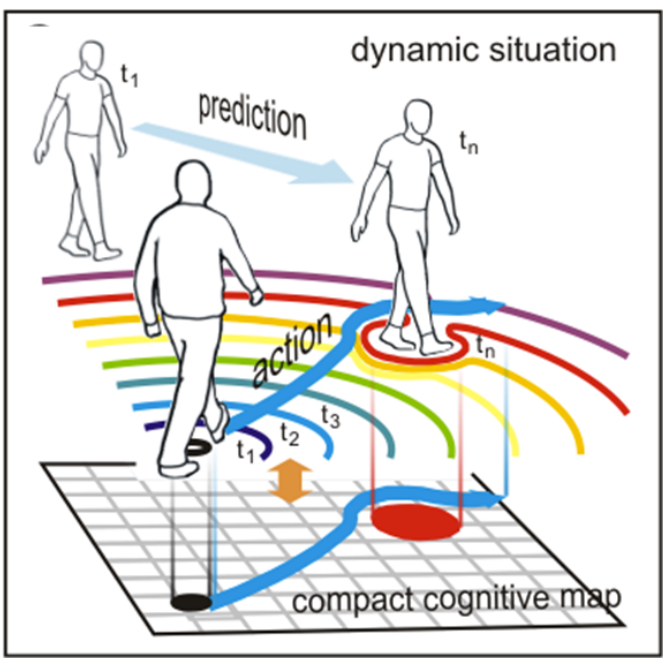


Figure 1.1: Compact cognitive map.

We want to see if our brain can handle dynamic situations as a single static situation assuming that time is "compacted". By the time compaction theory, in the dynamic situation in which we can see the collision case can be represented by a cognitive map. It is known as the static situation in which the circles are aligned.

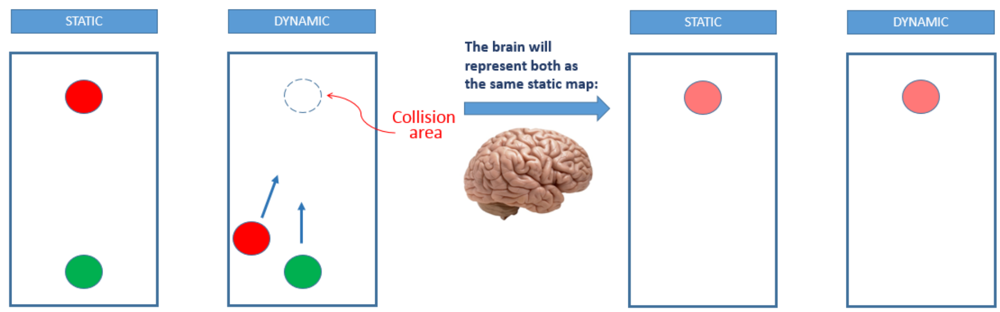


Figure 1.2: Hypothesis: time compaction in the brain.

We have conducted a series of experiments in which a static situation associated with a dynamic situation will be presented. The objective is to explore if the static situation helps to process the dynamic situation. It has been consider data of three different experiments:

- **Experiment I**: In this test the subjects do first the static stage and then the dynamic one. And the arrow that correspond with the aligned circles in the static is the same that when in the dynamic the circles are going to collision. This experiment make easier the learning of dynamic rule.

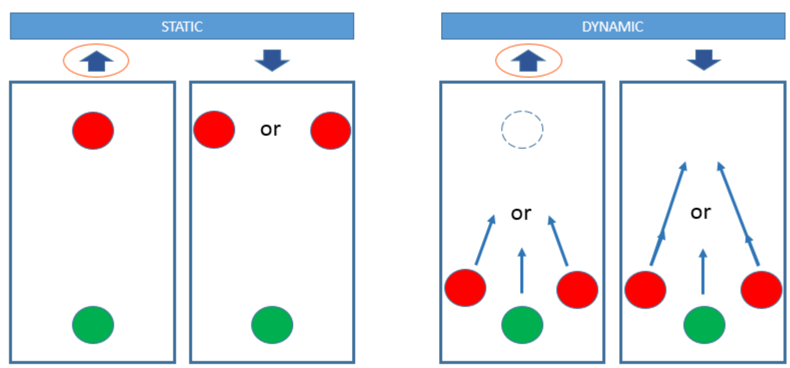


Figure 1.3: Experiment I.

- **Experiment III**: This case is like the first one, but we change the direction of the arrows in the dynamic stage. In this way we make learning of dynamic rule more difficult than in the first case.

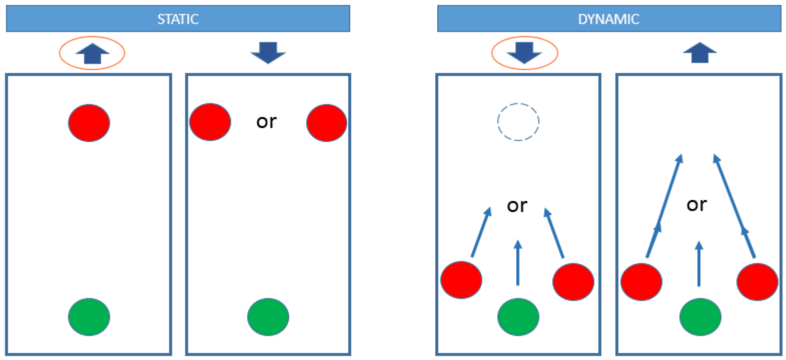


Figure 1.4: Experiment II.

- **Experiment II**: In this test the subjects do first the dynamic stage and then the static one. In this experiment base line for learning dynamic rule it's use.

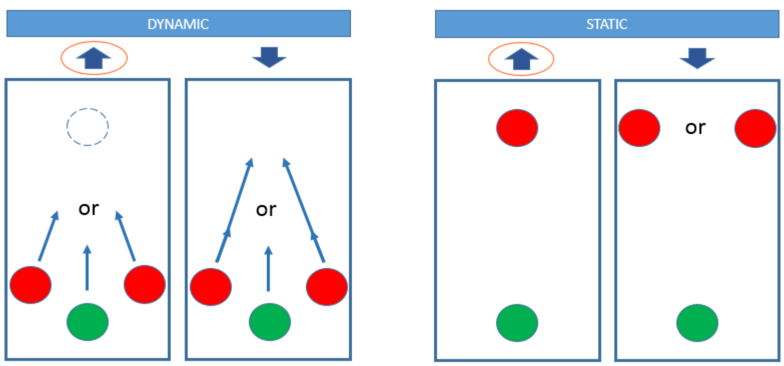


Figure 1.5: Experiment III.

To obtain the rule relating circles' behaviour with arrow keys both in static and dynamic stages: *"When circles are [...] I press up arrow; otherwise I press down arrow"*. The hypothesis of the experiment are:

- In Exp 1 the dynamic rule will be learnt faster than in Exp 2, since part of the rule was learnt previously during static stage.
- In Exp 3 the dynamic rule will be learnt slower than in Exp 2, since part of the rule was wrongly learnt previously during static stage.

We use our knowledge in statistics to analysis the collect data of the different experiments.

Chapter 2

Experimental study

2.1 Data Collection

During the *Modelling Week* we have performed the first experiment over the 43 participants. We go to the other groups and we have to explain that they have to done an static stage and then the dynamic stage. Also our instructors provide us with data of all the experiments that have been explained before.

2.2 Data preparation

All the experiments end when either 80 trials are reached or, in the last 20 trials, 18 correct answers are obtained.

To obtain a reference in the relationship of static and dynamic situations, we work with the following variables, which where stored in structures in MATLAB after each user performed his/her test:

- **Experiment**: Integer which represents the number of experiment we are performing: 1, 2, 3.
- **Success(Success_d)**: Vector of length 80 whose elements can be:
  - 1 If attempt is successful
  - 0 If attempt fails
  - NaN If the rule has been learned previously

  the "d" termination goes for the data associated to the dynamic experiment.
- **Num_Trials_Learn(Num_Trials_Learn_d)**: Integer with the number of attempts that have been made to learn the rule. In order to calculate this, we just look for the position of the first 'NaN' value in the Success/Success_d vector. If there is no 'NaN' element in the vector, the value will be 80 by default.
- **trgt_try(trgt_try_d)**: Binary value indicating whether the subject was able to learn the rule (1) or not (0). It is assigned as 1 if Num_Trials_Learn(Num_Trials_Learn_d) is smaller than 80.

- **AnswerTimes(AnswerTimes_d)**: Vector of length 80 whose elements mark the response time from the time the screen goes blank until the user dials the response. If the rule has been learned previously the result is NaN.
- **Gender**: Represents if the user is female (1) or male (0).

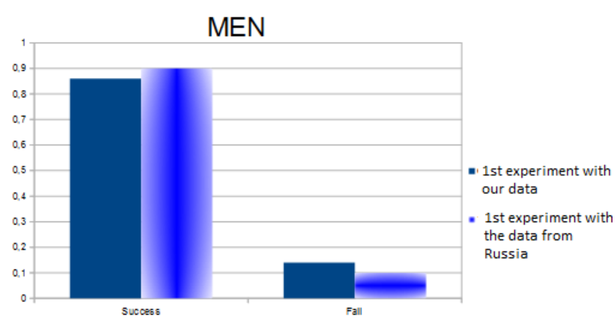
Other variables, as the age, whether the subjects practice sports, drive or play videogames, were also stored. However, those ones did not provide any visible conclussions.

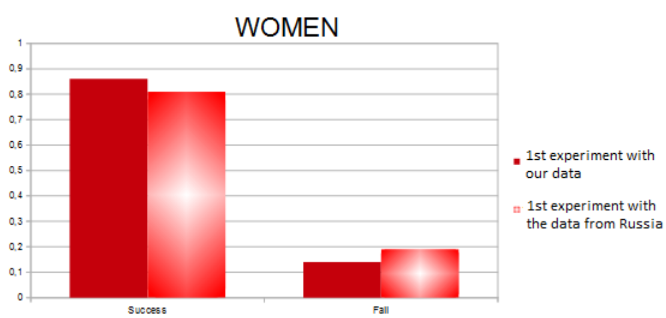
2.3 Comparison of the ratios of completed tests, for each type of experiment

For our project we collected data only for the 1^{st} type of experiment, due to time limitations. In the graphics below, we established a comparison between the % of persons who were able to finish the first type of **dynamic** tests, in our data and in the data provided by the coordinators of the project (corresponding to a group of biology students and teachers in Russia).

One test is considered correctly finished if the person performing it is able to get 20 right answers in a row, with less than 2 failures).

Reminder: We have 3 different types of experiments, perform one test of every experiment on each person, and one test consists on 80 (or less) trials.

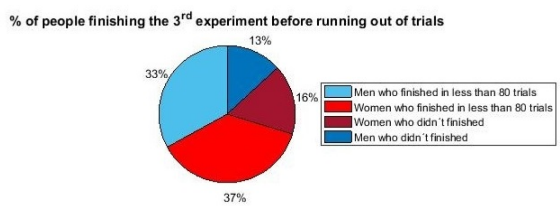


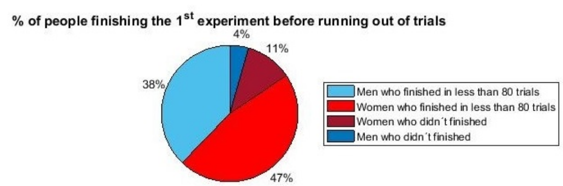


The graphics were quite similar, and from this we can infer that the different sources of data won't affect the results of the experiment (here we compared a group mainly conformed by European students of mathematics with another one with Russian students and teachers of biology).

From now on, we know that we can work also with the data collected in Russia, as if it was obtained from our subjects.

Subsequently, we contrasted the percentage of men and women who were able to finish the tests before reaching the 80^{th} trial, for the 1^{st} and 3^{rd} experiment.





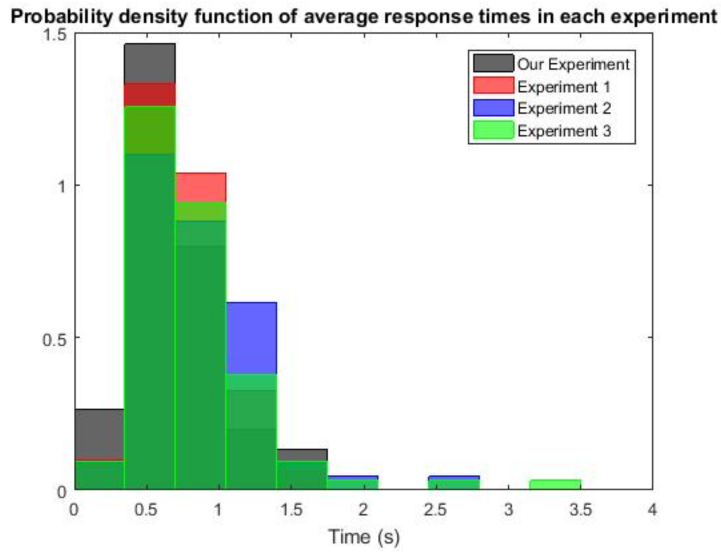
According to the graphics, women are less sensible to the different characteristics of the experiments; their ratio of success barely changes. However, men are more likely to obtain better results in the first experiment.

2.4 Study of the response times

This analysis is focused on how much time it takes the subject to answer each trial of the tests.

To begin with the study, we obviate the data corresponding to the first 5 trials in the tests (considering that, in these first steps, the individuals are still trying to figure out how the process works).

For every type of experiment, we calculate the probability density function (pdf) of the average response times in the trials.



Time is measured in seconds

From the graphic we see that the four pdf's are quite similar. There are no significance differences in the answering times among the experiments; the strategy our brain uses is the same but with different information.

2.5 Study of the probability distribution of number of trials

Here we study the probability distribution of the **number of trials** of our experiment. It can vary from **20 trials** to **80 trials**. The rule to finish the test at any trial is to have 18 success in the last 20 attempts.

First we study the accumulative histogram of our four experiments:

Table 2.1: Table of hypothesis test between experiments. **Dynamic stage**.

H_0= *Same distribution* H_1= *Different distribution*	**Experiment I Data Comparision**	**Experiment II Data Comparision**	**Experiment III Data Comparision**
Experimento MW	ACCEPT	REJECT	REJECT
p-value	0.7397	0.0000	0.0078

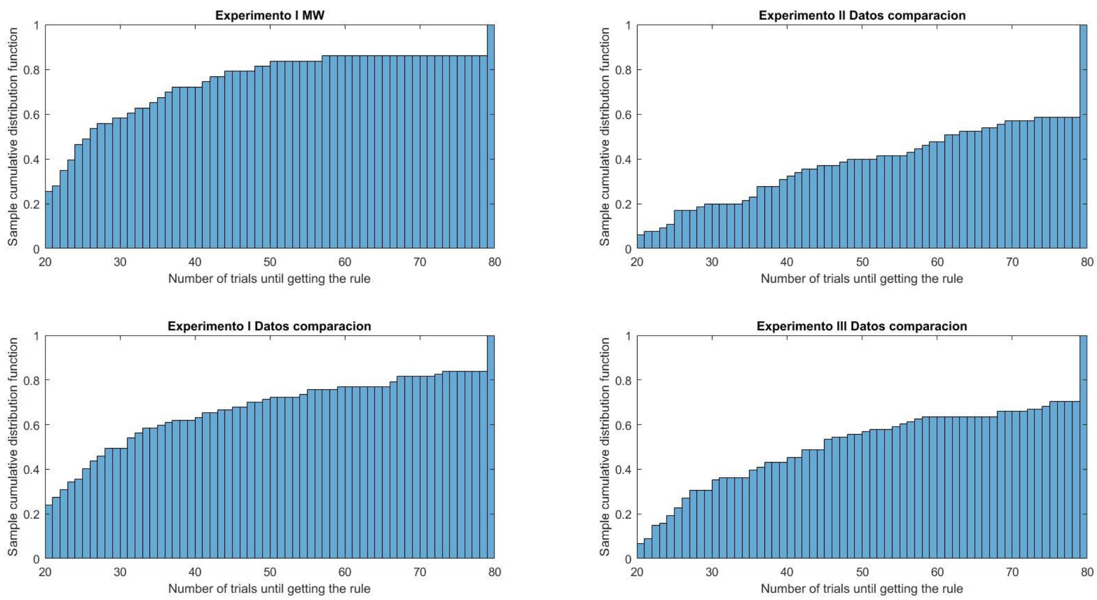


Figure 2.1: CDF.**Dynamic stage**.

As we see there is a big bar/stick at the trial 80, because all the people learn after 80 trial accumulate there. The MW experiment and the first experiment of the data comparison seems similar distribution, nevertheless the learning is lower in the second and third experiment, so the distribution is different. We can check this through a **hypothesis test**, in this case the Kolgomorov-Smirnov test. See table 2.1.

As we expected, the tests says that experiment I have same distribution and other experiments have different ones.

How we are going to see, we can divide the experiment by gender and see that **distributions between sex have different patterns**.

In the figure 2.2 we represent the distributions separated by gender

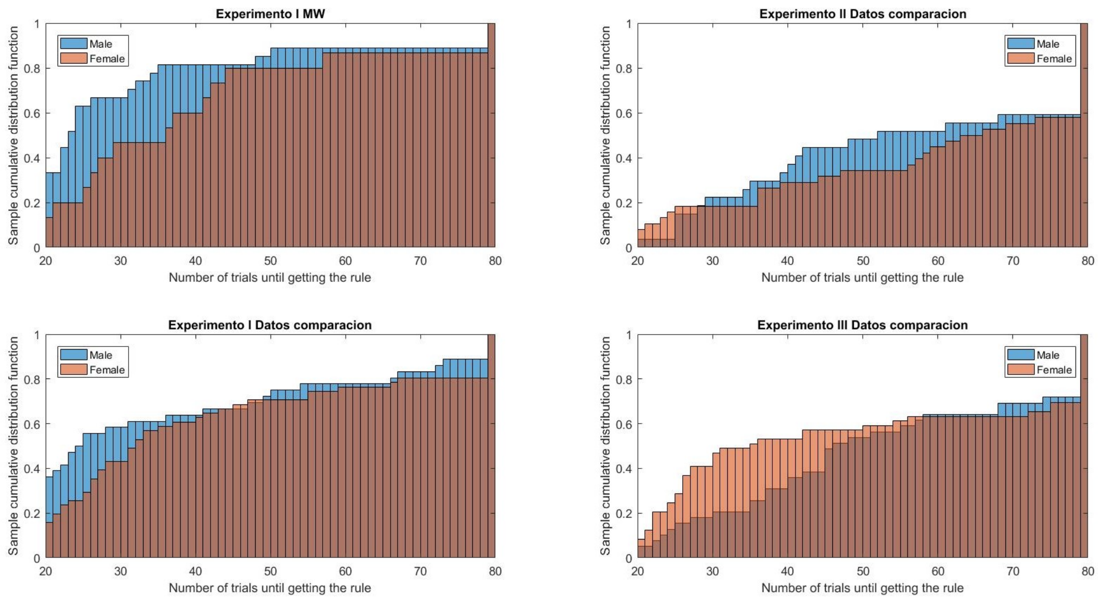


Figure 2.2: CDF by **gender**.**Dynamic stage**.

As we can see in the experiments, males learn in the static stage, and this help them to do better the dynamic one. On one hand, males, in the third experiment, get disturbed by the false rule learn in the static stage. On the other hand, the static stage doesn't influence women at the time to resolve the dynamic stage (see experiments I and III).

In the second experiment which is the **base line** we can see that all do worst. This is in part because the **surprise effect**.

Finally we want remark that if we start with the dynamic test, it has worst results. This also happens because **surprise effect**.

Complementary we observe the histogram separated by gender

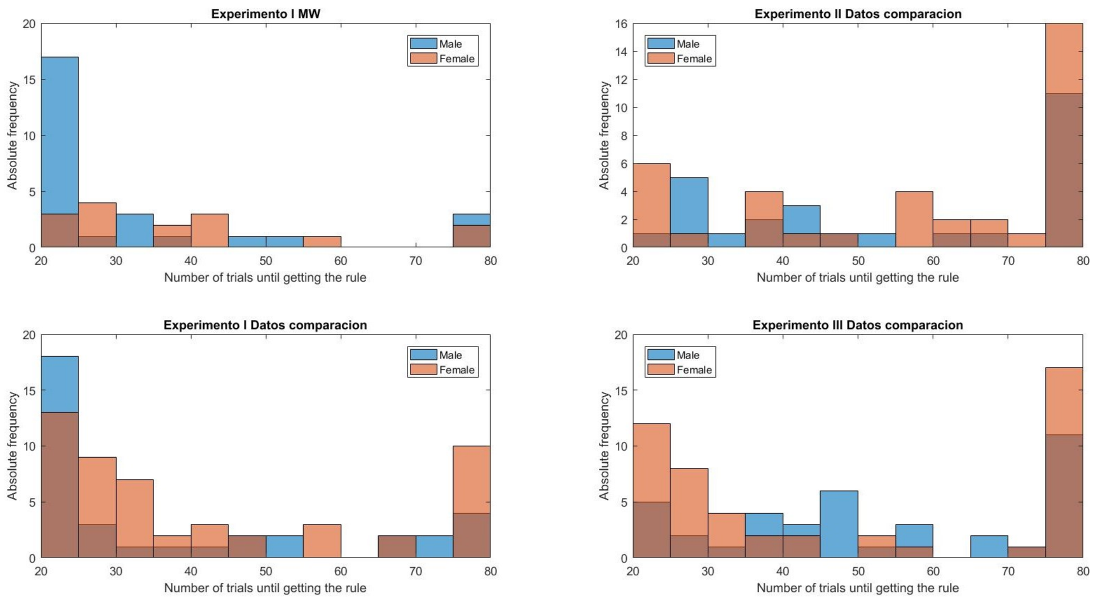
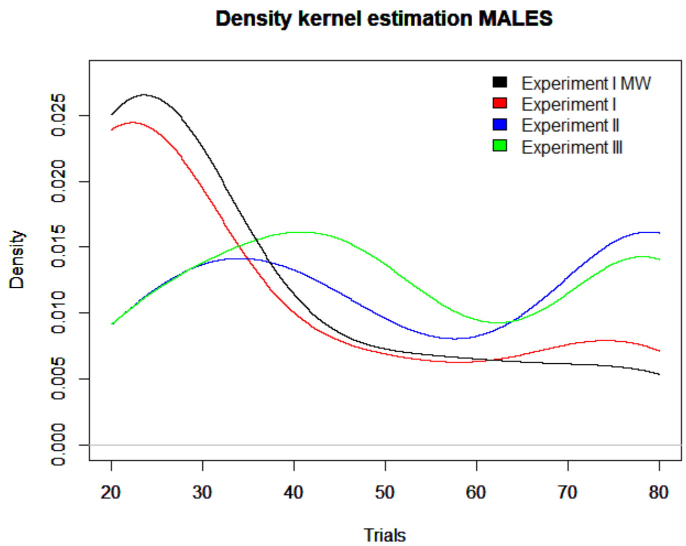


Figure 2.3: Histogram by **gender**.**Dynamic stage**.

We observe that:

- In the first experiment males learn mostly at beginning, nevertheless the women frequency are more homogeneous.
- In the second experiment there are more people that doesn't learn relative to other experiments, and less people that learn early.
- In the third experiment, because the fact of the disturbed effect, the mode of males are displaced at the middle of the domain, nevertheless women get similar results as one.

For the last but not least, we tried to estimate a continuous density approximation of our all four experiments. Because there is not enough data this aren't very pinpoint, however we can see general patterns. In 2.8 we represent two graphics with all experiments, one for males another for females:



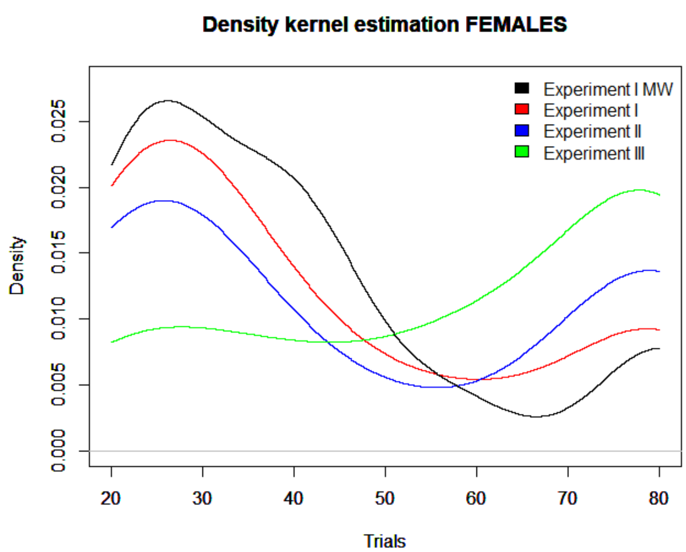


Figure 2.4: Estimated density by **gender**. **Dynamic stage**. Used a normal kernel.

Clearly we see that the maximum on woman is reach more off less at the same time, though, males have translated it in the experiment II and more even in the experiment III. This means that **static stage is used to learn**, and when we alter this, putting dynamic first or disturbing the rule, result are worst.

An observation. It looks like a bi-modal distribution but isn't. It just happens because we stop the test at trial 80, so people who didn't learnt accumulate there.

2.6 Study of the time average

As it has been stated before, experiment 1 is supposed to foster the subjects to learn faster the rule that governs the dynamic phase as their brain has been trained to make an association between the static and the dynamic phases of the experiment by means of the cognitive map generated by the subject's during the dynamic phase, which resembles the situation generated by the balls during the static phase. Therefore, we should expect a faster learning rate during the dynamical phase of the experiment for the subjects who have done the experiment 1. In order to measure the learning rate, we have proceed as follows:

- A subject is given, for every trial, a punctuation: 1 in case of success, 0 in case of failure. In case a subject has already learned the dynamic rule, we assign a 1 for every of his remaining trials.
- For all the subjects who have performed an experiment, we calculate the average of their punctuation in every trial.
- We represent this average as a function of the trial number and fit it with a function of the form x/(a+x), where a is a parameter to be adjusted. The results shown in Figure X conform very well with what it is expected. The fastest learning individuals are those of the Modelling Week population (which are subjects who have done the experiment 1), followed by the individuals who did the experiment 1 too in other time. Although it is supposed that subjects from experiments 2 should behave better than those from experiment 3, it appears that 3's are better than 2's. Anyway, the difference is not big enough to be significant, so this difference can appear due to the small amount of data used and other factors not considered.

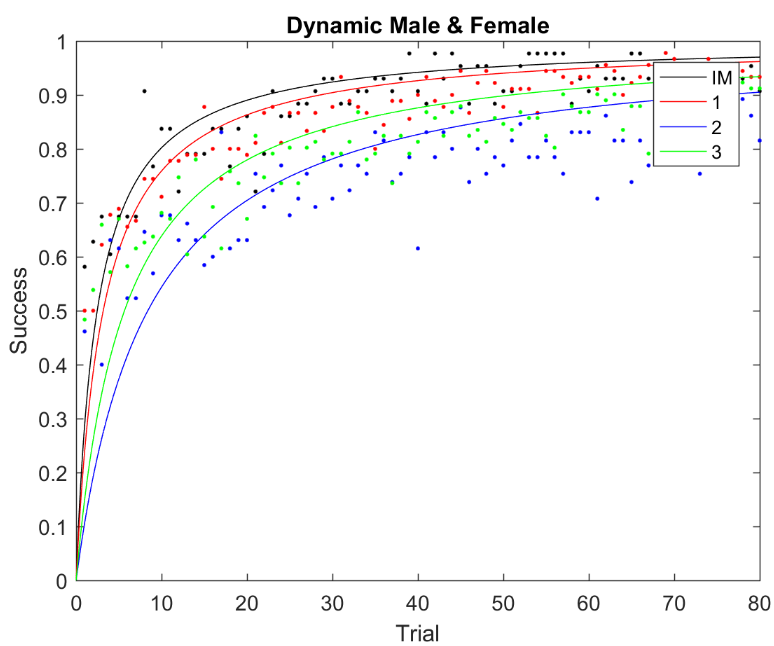


Figure 2.5: Estimated density by **gender**. **Dynamic stage**. Used a normal kernel.

Besides, we have conducted some statistical tests in order to verify these conclusions. We have performed a two sample t test for equal means, checking whether the mean number of trials until the dynamic rule is learnt changes among the subjects of the different experiments. The p-value obtained for every of the cross checks done are represented in the following table:

	IM (1)	1	2	3
IM (1)		0.1906	0.0001	0.0053
1			0.0029	0.0742
2				0.1607
3				

Figure 2.6: Estimated density by **gender**. **Dynamic stage**. Used a normal kernel.

We have colored in green those tests which rejects the null hypothesis (which is that there is no difference in the mean number of trials until learning) at 90If we separate the results by gender, some interesting conclusions can be extracted. As predicted by the theory, men's brain are more sensitive to time compaction than women's, so it should be expected that male subjects learn better / suffer more when they face an favorable / adverse situation (such as the experiment 1 / 3, which are designed to help / confuse the brain). Therefore, men's results should be considerably worse in experiment 3 than in 1, as their ability to use time compaction misleads them. On the other hand, as women cannot take advantage of time compaction as men, their results from experiments 1 and 3 are very similar.

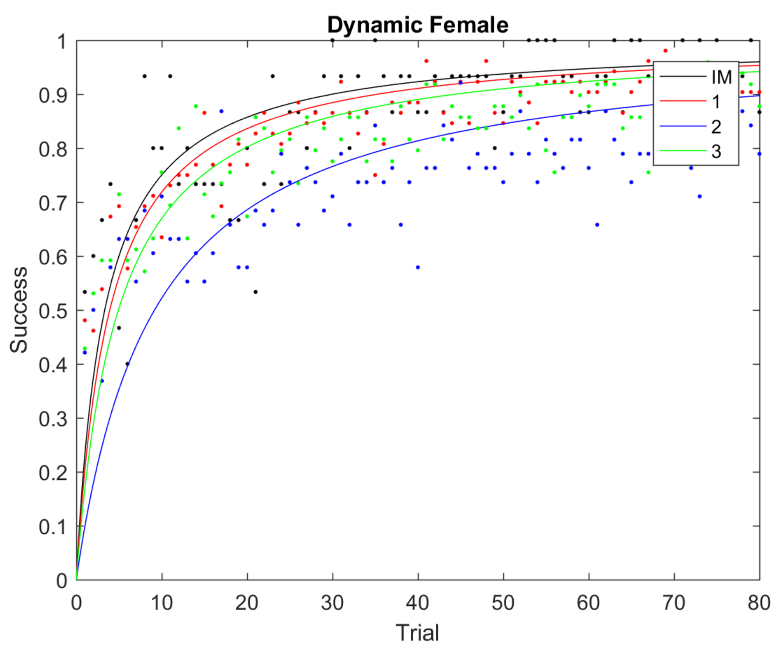


Figure 2.7: Estimated density by **gender**. **Dynamic stage**. Used a normal kernel.

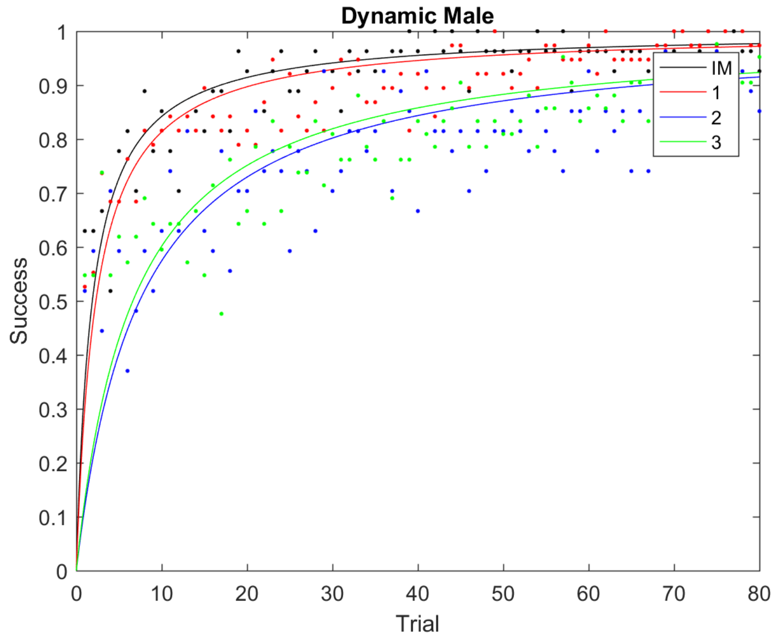


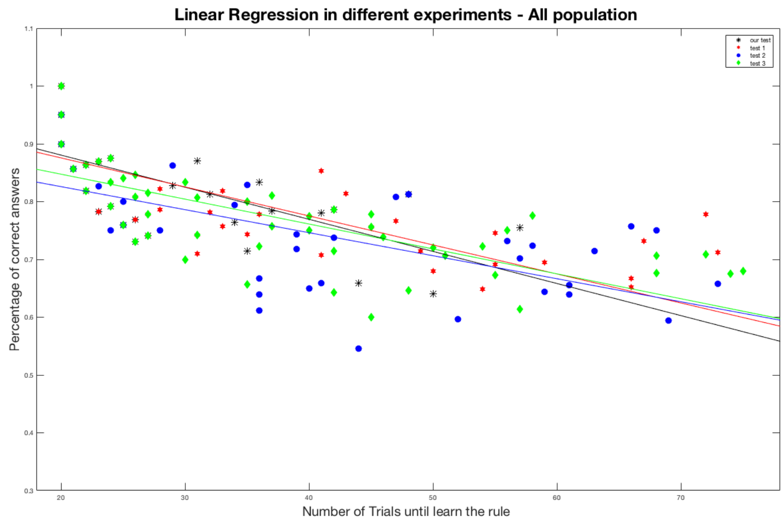
Figure 2.8: Estimated density by **gender**. **Dynamic stage**. Used a normal kernel.

2.7 Regression analysis

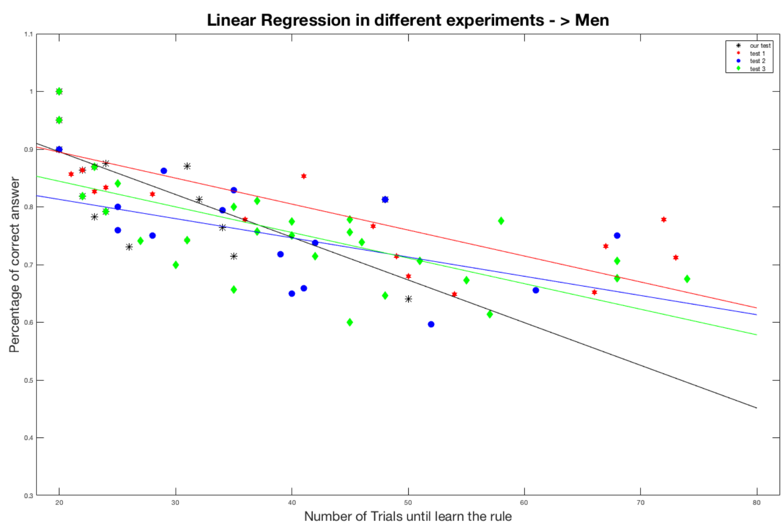
We are going to study that the percentage of successes in the classification varies with the number of trials that the subject need to reach the learning. We will compare these results in the different experiments in order to detect possible differences between them. To carry out this study, we decided to delete those individuals who didn't learn the rule after 80 trials. With this purpose we decide to apply a linear regression analysis for modelling the relationship between a scalar dependent variable Y and an explanatory variable (or independent variable) denoted X.

$$Y = \alpha_0 + \alpha_1 X$$

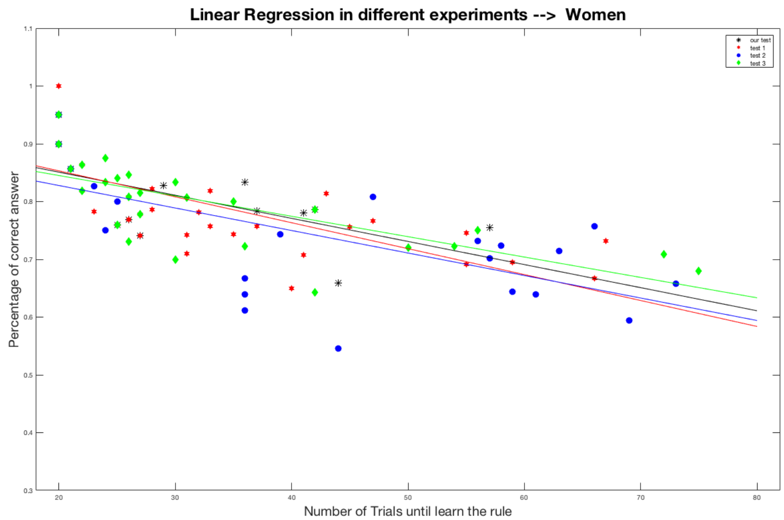
Firstly, we will study these results on the total population. In the next figure we can see that there are not many significative differences between the experiments.



We have decided to separate by gender in order to see more differences. People who need a greater number of trials to learn have a lower percentage of correct answers, as we can see in the slope of the regression lines.



Finally, it is appreciated that women learn in a similar way regardless of the experiment they perform. In comparision with the men graph, the behavior of women is more homogeneous in the different experiments as we can see in the next figure.



This conclusions emphasis the ideas that we have seen before. Despite off, these graphs don't provide so much additional information to our study.

Chapter 3

Conclusion

The main conclusions are this:

1. **Time compactions** exists in the human brain.
2. Males and females show **different strategies** to solve experiments. In fact, men are more likely to be influenced by the type of experiment (they are more sensitive to spacial information) and women tend to give more stable answers.
3. 1^{st} experiment helps the learning of dynamic rule and the 3^{rd} one makes it more difficult, specially for men.
4. No differences in **answering times** among experiments are observed. Our brain performs the same operations with the objetive of solving the problems, just with different data.