



UNIVERSITAT DE BARCELONA

Final Degree Project **Biomedical Engineering Degree**

“Investigating sequential effects in humans performing a 2AFC psychophysical task”

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Author: Debora Lombardo

Director: Manuel Molano-Mazón

Co-director: Jaime De la Rocha

Tutor: Roser Sala Llonch

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Abstract

Perceptual decision making is the process by which our brain collects and accumulates sensory information and analyzes it to generate an action. However, not only perception is responsible for our decisions but it has been shown that they are also influenced by past choices. Indeed, in a variety of behavioral tasks, the subjects presented sequential effects, i.e. dependencies deriving from previous experiences in the decision-making process.

Based on previous studies conducted on rats, we aimed to investigate this matter on human subjects, to analyze similarities and differences between the two species and to verify the extent to which this behavior occurs. To do this, we developed a psychophysical experiment that consists of an auditory task in which the participants have to choose between two alternatives. The experiment was carried out using a software created by the laboratory and run on an iPad, a revolutionary methodology in the field of psychophysics.

Analyzing the data obtained we showed that most of the subjects presented sequential effects in the choice between the two alternatives, in particular when the decisions were taken in conditions of perceptual uncertainty.

Keywords

Perceptual decision making, sequential effects, psychophysical experiments, 2AFC task, humans, rats, data analysis

Contents

1. Introduction.	6
1.1. Main objectives	7
1.2. Methodology	7
1.3. Location of the project.	8
2. Background	9
2.1. State-of-the-art.	9
2.1.1. Perceptual Decision Making.	9
2.1.2. Sequential effects.	9
2.2. Previous work.	12
2.2.1. Rats performing a 2AFC auditory task.	12
2.2.2. Pretraining RNNs explains sub-optimal behavioral reset.	14
2.2.3. Proactive and reactive accumulation-to-bound processes in a 2AFC task.	14
3. Market Analysis.	16
3.1. Sectors involved.	16
3.2. Historical evolution of the techniques on the market.	16
3.3. Present and future perspectives.	17
4. Conception engineering.	19
4.1. Project basis.	19
4.2. Psychophysical experiments.	19
4.2.1. Different methods to conduct a psychophysical experiment.	19
4.2.2. Psychophysical Procedures for Discrimination Experiments.	21
4.2.3. Software.	22
4.3. Solution: auditory two-alternative forced choice task (2AFC) on StimuliApp	24
5. Detailed engineering.	25
5.1. Task design.	25
5.2. Task settings.	27
5.2.1. Structure.	27
5.2.2. Different versions.	28
5.2.3. Stimulus strength.	28
5.2.4. Patterns.	28
5.2.5. Performance.	29
5.2.6. Reward.	29
5.2.7. Interface.	29
5.3. Task implementation.	29

5.4. Data analysis.	32
5.4.1. Learning.	32
5.4.2. Psychometric curve.	32
5.4.3. Same choice repetition after correct or erroneous answers.	33
5.4.4. Influence of stimulus strength on Reaction time and Motor time.	33
5.4.5. Tachometric curve: reaction time vs accuracy.	33
6. Results and Discussion.	34
6.1. Analysis of human behavior.	34
6.1.1. Valid trials and learning.	34
6.1.2. Variability among stimulus perception: psychometric curve.	37
6.1.3. Same choice repetition after correct answers.	39
6.1.4. Same choice repetition after erroneous answers.	40
6.1.5. Influence of stimulus strength on Reaction time and Motor time.	42
6.1.6. Reaction time vs accuracy conditioned to stimulus strength.	43
6.1.7. Correlation between patterns and missed trials	44
7. Execution Chronogram.	46
8. Technical feasibility.	47
8.1. Technical Aspects.	47
8.2. SWOT.	48
9. Economic Feasibility.	50
9.1. Costs.	50
9.2. Funding.	51
10. Regulations and Legal Aspects.	52
11. Conclusions	53
11.1. Future directions.	53
References.	55

1. Introduction

We all are constantly surrounded by sensory stimuli: sounds, noises, smells, visual and tactile stimuli etc... It is thanks to these that we are able to orient ourselves in the world around us and to understand what are the actions that can benefit us and those to avoid as dangerous. Our senses, therefore, help us to distinguish what is the best decision to take in everyday life. Thus, we define as **perceptual decision making** the process by which sensory information is used to guide our behavior toward the external world. The information is gathered through the senses and it is evaluated according to the goals of the subject, in order to produce appropriate motor responses.

However, are only our perceptual senses responsible for decision making? Are there any other important factors that influence it? Studies show that perceptual decisions can also be influenced by expectations built from previous exposures. Anyhow, these **sequential effects** are not just a laboratory curiosity but they can have a relevant impact on decision making in real world.

Imagine, for example, that you are walking through a park and you see the shadow of a feline behind the trees. You cannot see it very well and you are not sure if it is an ordinary cat or a tiger. The decision to approach it or to run is fundamental for your survival; for this reason, you try to gather as much information as possible about the situation in order to understand which is the best action to take. To do so, you take into account the visual image you got and you combine it with your previous knowledge. For example, if you read about a tiger escaped from a zoo in your city you are more likely to run away; instead, if you are used to see your neighbors' cat walking around, you probably go on with your walk.

This example shows that different types of information can influence the decisions we take, making our choices dependent both on the sensory stimulus and on our previous experiences. For this reason, perceptual decision making and the influence of prior exposures have been the focus of many studies by researchers from all over the world.

One of the first example of a sequential effect is the Gambler's fallacy, identified by Robert Jarvik in 1946. It is defined as the individual erroneous belief that a certain random event is less likely or more likely to happen based on the outcome of a previous event or series of events [1]. It has been firstly identified in a huge win at a casino in Monte Carlo in 1913, when the roulette wheel's ball had fallen on black several times in a row. People, thinking it would have been impossible that the streak could continue, bet on the red square for the following turns; however, the ball only fell on the red square after 27 turns and millions of dollars had been lost by the players. Indeed, after a long sequence of repeated events, individuals present a bias, expecting a reversal of the sequence even if the events are independent and equally probable.

Sequential effects have been also identified in many everyday situations, such as automobile driving, clinical assessments, financial decisions, tennis or basketball shots etc... For example, in automobile driving, it has been found that pedal-press response times depend on the history of recent stimuli and responses, and they influence both response latencies and error rates, potentially making the difference between a collision and a near miss. [2] In tennis or basketball, instead, the choice of shot location has been shown to directly depend on recent attempts and successes [3][4].

However, a lot still remains unknown, and a lot of questions are still unanswered. Indeed, further research is required to have an additional and complete understanding of the matter and identify how history signals lead to decision formation. Therefore, through this work, we aim to give a general overview of the matter and to present the results obtained from our experiment, investigating the contributions that stimulus-based mechanisms have on choice history dependencies and how they influence the behavioral strategy adopted by humans.

1.1. Main objectives

This work aims to study perceptual decision making and sequential effects in humans. The leading objective is to test how humans react when exposed to a perceptual stimulus, investigating the extent to which perceptual decisions are influenced by expectations built from recent experiences.

To do so, we will create a psychophysical experiment consisting of an auditory task in which trials are correlated. Our scope is to formulate the most appropriate settings to carry out the experiment and to collect and analyze the data. Furthermore, we will discuss the results, the limitations detected and the future work.

Therefore, the specific objectives of this project include:

- Understanding the methodology used to develop psychophysical experiments
- Implementing appropriate settings to run the experiment
- Running the experiment on human subjects
- Analyzing and studying the results obtained and comparing them to previous studies
- Understanding the mechanisms that generate sequential effects

1.2. Methodology

The project has been carried out under the supervision of Manuel Molano-Mazón, investigator at Brain Circuits and Behavior Lab (IDIBAPS), and the direction of Jaime de la Rocha, principal investigator.

It consisted of the following stages:

Stage 1: Bibliographic research

In this stage I have focused on reading different studies regarding psychophysical experiments, especially centered on perceptual decision making. I concentrated on fully understanding the methodology used to carry out this type of experiments, also by examining similar studies conducted on rats. In addition, throughout all my stay at the Brain Circuits and Behavior Lab, I have attended several meetings organized by the laboratory in order to create a solid knowledge about this topic and to build a neuroscience background.

Stage 2: Setting implementation and Python courses

In the second stage I have started implementing the settings on the StimuliApp application. I focused on deciding the appropriate coherence levels, fixation time, sound duration and number of trials per session and in total. I adjusted these settings step by step by performing several times the experiment

by myself and by analyzing the subjects' results. In order to be able to correctly analyze the data I have attended some Basic and Data Analysis Python courses on Internet: in particular, they were offered by FreeCodeCamp, Udacity and EdX. It has also been fundamental the help and support of Manuel Molano for the code implementation.

Stage 3: Experiment running and subjects' recruitment

In this stage I have started recruiting subjects for the experiments and organizing appointments. 18 subjects took part, aged between 20 and 60 (mean 25, median 22), 50% women roughly. Some participants decided to perform the task in one session of two hours, other preferred to carry it out in two different sessions of one hour with 1000 trials each.

Stage 4: Results analysis

I have collected and saved the data from the experiments; then I have analyzed them using the Python code previously implemented. I have extracted information from the generated graphs in order to analyze similarities in the behavior and produce common results.

Stage 5: Editing

In this stage I focused on writing this report, explaining step by step all the work done during the experiment development. In addition, I analyzed the market concerning perceptual decision-making applications. Finally, I wrote the conclusion of the whole project and I prepared the oral presentation.

1.3. Location of the project

This project has been developed at the Institut d'Investigacions Biomèdiques August Pi i Sunyer (IDIBAPS), in collaboration with the Brain circuits and behavior lab research group. I received constant support and teaching from Manuel Molano, investigator at the laboratory and the supervision and direction of Jaime de la Rocha, the lab group's principal investigator.

In addition, Ms. Roser Sala Llonch, Assistant Professor at the University of Barcelona's Department of Biomedicine, tutored and supervised this project.

2. Background

To have a better understanding of the topic, general knowledge and previous studies will be analyzed in more detail in this section.

2.1. State-of-the-art

2.1.1. Perceptual decision making

Our behavior towards the surrounding environment is guided by the sensory information we gain from the situation. This process is defined as perceptual decision making and it involves the gathering of information through the senses in order to produce a proper motor response toward the stimuli we face [5]. Perception, indeed, is a complex cognitive process, in which our brain extracts signals from the environment and interprets them. This process has been largely studied in neuroscience with the goal of identifying the mechanisms behind it and the influence that other factors may have on it.

It has been found that perceptual decisions in natural environments not only result from the processing of sensory information but are also influenced by recent experience [6]. For instance, agents tend to repeat their decisions in a way that is not attributable to mere chance and they seem to be influenced by the choices they previously made. [7]. In psychophysical studies, this is called a *sequential effect*.

2.1.2. Sequential effects

A **sequential effect** is the influence that a preceding experience has on the performance of the current and subsequent decisions.

They have been observed in a wide range of experimental tasks conducted both in non-humans animals [8] and in humans [9]: they all rely on expectations, derived from experience, to make quick decisions.

The scientific branch that deals with the study of these phenomena is **psychophysics**: it focuses on the relationships between physical stimuli and the perceptions generated. Most psychophysical experiments are designed so that subjects would make choices based only on sensory evidence. However, it has been shown that subjects exhibit biases not directly related to the sensory stimulus but rather on the history of their choices.

The main tasks conducted in psychophysical experiments are focused on perception, memory and language. Most of them are based on simple choice tasks, where subjects need to choose between two possibilities (2AFC tasks) [10][11]. However, a small number of studies focus on 3AFC or NAFC tasks as well, which means the possibility to choose between three or more alternatives [12][13].

The stimuli presented are varied between the different studies. An example is the classical measurements of contrast sensitivity, where subjects are asked to report the position of a shown object which have different contrast from trial to trial [7][14]. Another example is the discrimination of different objects, where subjects are asked to recognize a specified target [11].

Other studies focus on auditory stimuli, where individuals are requested to distinguish the sound that has the highest intensity [15]. However, they can also include probability matching [16], magnitude estimation [17], visual search [18] and language production [19].

Sequential effects increase when individuals perform a task repeatedly or perform a series of tasks [11]. Especially, responses are facilitated when a stimulus seems to follow a pattern and there is a long repetition of it. In fact, it has been shown that there is a variation in response latencies based on the immediately preceding trial sequences: subjects, indeed, present faster responses with a higher accuracy if they detect a pattern [6][20]. As a demonstration of this, reaction times (RTs) and error rates (ERs) have been analyzed, showing that RTs tend to be shorter and ERs tend to be lower if the current stimulus confirms a subject's expectation [21][22].

When following an error, subjects manifest a more cautious behavior, that is demonstrated by an increase of RT and a decrease in accuracy [11]. In addition, subjects present a so-called win-stay-lose-switch bias [15]. It means that they are more likely to opt-in for the same choice if it previously led to a reward and, vice versa, to opt-away from the unrewarded one. It is a really common behavior that has been identified even in people playing the game of "rock-scissors-paper" [23]. These switching-staying biases have been mainly noted when stimulus intensities are harder to perceive.

Therefore, it emerges that subjects are more likely to be influenced by their previous choices if the situation confirms a bias and they apply this approach in order to improve their performance in situations characterized by autocorrelation from one trial to the next. [24] However, they keep following the patterns even if the bias leads to a lower performance [7] and there is evidence that doing it does not lead to any advantage. In fact, agents seem to apply this approach even in situations where there is no correlation between the events [25]. It has been demonstrated that, on totally randomized trials, subjects still exhibit a bias toward one particular choice depending on the recent history of trials [11] it happens even when subjects are explicitly informed that the stimuli are completely random. In this sense, it has been stated that they resemble *heuristics*, an approach that employs a practical method to rapidly reach a goal under condition of uncertainty, even if the result is not guaranteed to be optimal. [26]

As previously stated, this choice repetition bias is higher after previous decisions where subjects are more confident about the choice thanks to the detection of a pattern [27]; however, it emerges also when previous decisions are based on weak sensory evidence [28]. Indeed, choice biases increase when individuals are under conditions of perceptual uncertainty, that means when they face an ambiguous stimulus; vice versa, subjects are more likely to completely rely on the stimulus when this is really clear [7].

In addition, sequential effects have both automatic and strategic components [21][29]. It can be defined as an automatic process since it has been shown that sequential effects often occur without the subject's awareness and cannot be overridden by instructions. Indeed, studies have shown that people present sequential effects even when they are aware that there is not a dependency on the trials in the task they are performing [21]. It is also a strategic process since animals always try to adapt their behavior to better face the situations in which they are [30].

This seems to indicate that sequential effects are part of an intrinsic behavior that can be hardly modulated, probably being the result of the brain's attempt to adapt to a dynamic and constantly changing environment. [6] They look like a consequence of a learning process in which subjects try to increase future rewards, minimizing the error possibilities. [24]

They have been found dysfunctions in this mechanism especially in Parkinson's, autism, dyslexia, compulsion disorders, or in schizophrenia [31], whose states are characterized by under or over-reliance on expectations in behavior. For example, perceptual decisions of individuals with dyslexia and individuals with autisms are less influenced by previous trials than neurotypical participants [32]. In addition, it has been shown that Parkinson's disease patients have difficulty combining previously learned information with current sensory information to guide their decisions [33].

2.2. Previous work

This project emerges from previous studies conducted in recent years at Brain Circuits and Behavior Lab (IDIBAPS). They are mainly focused on testing how rats' perceptual decisions are affected by expectations derived from the history of past stimuli, choices and outcomes.

2.2.1. Rats performing a 2AFC auditory task

A relevant study in this field has been conducted by Ainhoa Hermoso-Mendizabal et al. and it was published in 2020. [15]

The main goal of the project was to study how the recent history of stimuli, responses and outcomes influence perceptual choices in rats. They wanted to create a framework that could explain how rats form their expectations, investigating if and how the combination of these and sensory evidence can be dynamically modulated.

To do so, they trained rats in a two-alternative forced choice (2AFC) task, in which animals were exposed to auditory stimuli from both the left and right sides. The sounds had different strength. After a fixation period of 300 ms, the acoustic stimulus started, and the rats were asked to discriminate it by licking the port situated on the side where the sound was mainly coming from. If they responded correctly, water was provided as a reward. Instead, if they responded incorrectly, they were punished with a light and a 5-s timeout (Fig. 1).

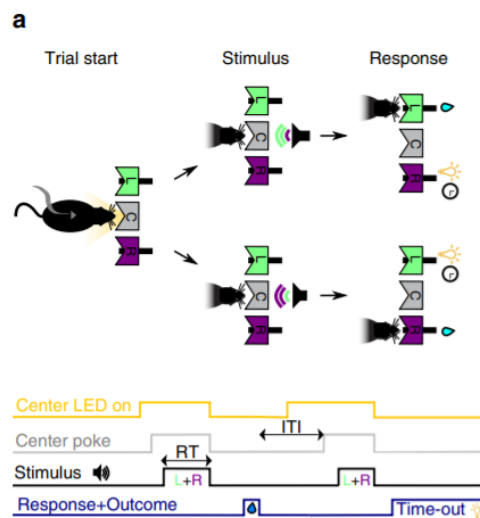


Fig 1: the figure shows the design of the experiment. Rats poke in the center port and then they choose one of the two sides, each of them is associated with reward or punishment. Correct responses are rewarded with water, and incorrect responses are punished with a light plus a 5-s timeout.

In this tasks, serial correlations were introduced in stimuli trial sequences: indeed, the probability to repeat the previous stimulus category was varied in trial-blocks. They used a two-state Markov chain in which $P_{rep}=0.7$ in Repeating blocks and $P_{rep}=0.2$ in Alternating blocks, where P_{rep} is the probability that it is presented a repetition of the same correct response.

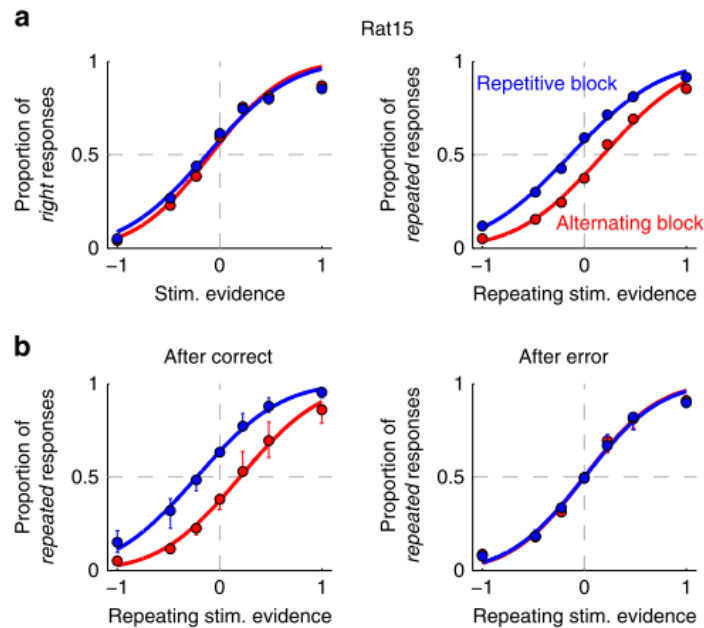


Fig 2: a. Psychometric curves showing the proportion of rightward responses vs. stimulus evidence (left), repeated responses vs. repeating stimulus evidence (right) computed in the repetitive (blue dots) or alternating blocks (red dots). b. Proportion of repeated responses in trials following a correct (left) or an incorrect response (right).

Indeed, they created and analyzed psychometric curves, showing the proportion of rightward responses as a function of the stimulus evidence, showing that rats did not present a history-independent bias towards one particular side.

Furthermore, they evaluated the proportion of trials where rats repeated the previous choice as a function of the repeating stimulus evidence (Fig. 2), finding that all animals developed a block-dependent repeating bias. They also found that expectations were mostly used by animals when stimuli were hard to categorize, confirming the findings of previous studies.

After having identified this behavior, they have also been detected the specific factors that generate this choice bias. In particular, these factors are:

- **lateral bias:** the subjects take into account the last choices made and they create an attraction to the most repeated response (e.g., if the last four response have been R+ R+ R+ L+, the subject will be more likely to repeat R, where “+” means correct answer)
- **transition bias:** the subjects detect a pattern in the trials such as repetition or alternation of the correct answer. (e.g., if the last four response have been L+ R+ R+ R+ R+ it means there have been Alt, Rep, Rep, Rep; subjects detect a repetition pattern)

In addition, they analyzed the responses to trials following an error (Fig. 2). They found that, in that case, rats did not use the history of their previous choices to guide their decision after error trials. Therefore, they presented a *reset* after every incorrect answer, ignoring the bias accumulated until that moment. The reset occurred independently of the stimulus strength, and it arised equally in both repeating and alternating blocks. They interpreted it as a switching from an exploitation mode to an expectation-free mode, where subjects completely relied on the stimulus. However, the choice bias

was not permanently cancelled and occurred again after the animal made a new correct response. This is called "reset-and-rebound" effect.

2.2.2 Pre-training RNNs on ecologically relevant tasks explains sub-optimal behavioral reset

It is important to mention the work of Molano-Mazon et al. [13] to deal comprehensively the sub-optimal **reset strategy** adopted in a 2AFC task with serial correlations, behavior originally identified by Hermoso-Mendizabal et al. [15]. The paper has been published in 2021.

As previously said, animals' decision-making processes are determined by the perceptual stimulus but also by individual experience and structural priors. However, after error trials, animals ignored the information acquired by the choice history and followed a strategy only based on the current stimulus. An optimal agent, instead, would have had a momentary reversal of the transition bias (**reverse strategy**).

The aim of this study was to quantify the extent to which rats followed the reset or the reverse strategies. To do so, they trained rats in different variants of a 2AFC task and modeled their choices using a Generalized Linear Model (GLM). One variant of the task included no stimuli or predictable repeating and alternating sequences in order to make the pattern of transitions more evident. Despite the task was really simple, rats still applied a reset strategy.

Then, they trained RNNs in these conditions. They found that RNNs did not manifest the reset strategy and they adopted, instead, a reverse strategy. For this reason, they hypothesize that a difference between the 2AFC task and naturalistic environments is the number of available alternatives. Subsequently, they pre-trained RNNs in an environment containing more than two alternatives, in order to mimic real world situations. These pre-trained networks exhibited the same reset strategy manifested by the rats.

They concluded that the reset strategy originates from evolution as adaptation to a dynamic environment. The reset strategy, indeed, is the result of a structural prior which adapted to an environment with multiple alternatives.

2.2.3 Proactive and reactive accumulation-to-bound processes in a 2AFC task

Another important study in this field has been conducted by Lluís Hernández-Navarro et al. and it was published in 2021. [34] The aim of this study was to provide an alternative model to the standard ones regarding the way perceptual decisions are taken. Standard models, demonstrate that responses are given when there is an adequate accumulated stimulus evidence, showing that subjects make a choice only when the evidence reaches a decision threshold. Hernández-Navarro et al, instead, suggest that choice selection and motor initiation, commonly viewed as serial processes, might in fact occur in parallel as decoupled processes.

They trained rats in two variants of a reaction-time auditory discrimination task. The difference between the two versions is the type of the stimulus: two noise bursts coming from the left and the right speaker or two pure tones with different frequency. However, on both variants, they set a fixation period of 300ms; afterwards an acoustic stimulus was played at the center port. The stimulus stopped once the animal moved from the center port and it poked at one of the two side ports to give a

response. In addition, stimulus sequences include serial correlations: this let researchers study choice biases.

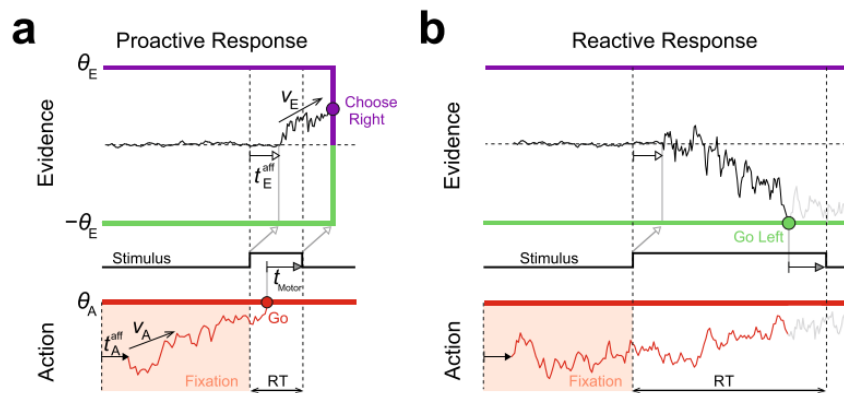


Fig 3: In (a) AI reaches the Go bound first, triggering a proactive response. In (b) EA process reaches a decision bound first, setting both RT and choice; the AI process plays no role.

They distinguished between reactive and proactive responses (Fig. 3a-b). Reactive responses are the ones triggered by **Evidence Accumulation**: subjects listen to the stimulus and initiate a motor response only after gathering enough evidence about the right choice. Proactive responses, instead, are initiated regardless of the integration of the stimulus and they are yielded by **Action Initiation** process. On a given trial subjects are more likely to perform a proactive response if they can anticipate the stimulus, for example driven by choice bias, or if they are under a strong time pressure.

Usually, the fastest proactive responses are classified as random anticipatory responses and are normally removed from the analysis. However, Hernández-Navarro et al. showed that these fast choices are not random, although their timing is independent of the stimulus.

Indeed, they defined these very fast responses as “express responses”, which are responses that occur between stimulus onset and RT modulation onset: here, timing is independent of evidence accumulation but the choice does depend on the stimulus. On the other hand, in slower responses, both timing and choice accuracy depend on the stimulus. Since the fixation period is constant, animals can predict the time when the stimulus starts, and they can prepare the motor action; in this way they respond rapidly after stimulus onset.

Hence, they developed PSIAM, a model proposing that both evidence accumulation and action initiation are responsible of the trigger of our actions. Action Initiation (AI) is a proactive timing process, that starts in anticipation of stimulus onset and goes on until it reaches a Go bound. Evidence Accumulation (EA) is a reactive process initiated by the stimulus itself, that integrates sensory evidence until reaching the decision bounds. The first process reaching bound initiates the response. The choice is always set by the category of the integrated evidence up to the response time.

3. Market Analysis

3.1. Sectors involved

Psychophysical experiments have been largely conducted for the study of perception and cognition in neuroscience. The study of how perceptual processes affect subject's behavior is a matter of interest mainly for neuroscientists and psychologists. However, it is a field where a lot is invested, and several other categories of researchers are hired to contribute to their realization. For example, informaticians focus on the creation of the software to run the task while neuroscientists on the design of the most appropriate experimental environment. Then, data analysts explore the data and finally psychologists and other categories of researchers interpret the results.

Through this kind of experiments, they are able to generate hypotheses about the brain functionalities, predicting human and animal behavior under specific conditions.

This can pave the way to further research that aim to identify the specific neural circuits and brain's areas responsible for such behaviors.

In addition, it constitutes a relevant basis for the investigation of particular neurological diseases: indeed, inquiring which behaviors are linked to a specific pathology allows to investigate which areas of the brain are not functioning correctly in those cases. These studies can help to find potential cures and to develop more effective devices that directly intervene on the dysfunctionality that the pathology causes.

Therefore, these studies can be addressed to *clinical and biomedical institutions and pharmaceutical or engineering companies* that specifically focus on neuroscience and the study of neurological diseases.

However, understanding the way humans take decisions and how they are influenced by previous exposures is also an important matter of interest in *marketing and education*. Indeed, it can be useful for the organization of study courses, where students rely on past studied topics to build new knowledge and they change their way of learning after receiving negative feedback. In addition, it is an interesting matter of study in neuromarketing areas [35], in order to develop targeted advertising. People, indeed, would be more likely to buy a product if they already heard about it, without even considering much the characteristics of the latter if they are under pressure or have short time available to take a decision.

3.2. Historical evolution of the techniques on the market

Many of the classical techniques to carry out psychophysical experiments were formulated in 1860 by Gustav Theodor Fechner [36]. His experiments generally focused on judgements related to small sets of quantitative data; however, this did not display the full picture of how the human brain interacts with physical stimuli.

Thanks to the invention of technology – such as computers and other devices - early psychophysical ideas have been modernized and improved. Indeed, thanks to the development of personal computers in 1970s, scientists had the opportunity to have more and precise control on the experiments. For

instance, thanks to this, it started to be possible to control, for example, the length of a stimulus with precision of milliseconds, the quantity of light emitted for a precise stimulus or to create specified range of colors and sounds.

3.3. Present and future perspectives

Nowadays, the three main platforms used to run psychophysical experiments are Microsoft, Macintosh, and Unix variants like Linux, Debian, Ubuntu etc. [37] Several programs have been developed to allow scientists to easily define the stimuli presented and to record and save the response of the subjects. In the 90s, it has been released VideoToolbox, one of the first software basis for visual psychophysics. Since earlier versions of Windows were not able to handle real-time applications, professional packages were first released only for Macintosh. Then other platforms have been developed for Microsoft users as well, such as Psychtoolbox [38] and Psychopy [39], that nowadays represent the most popular used programmes (fig 4). They are both characterized by a high timing performance [40] and the possibility to freely download them. Psychtoolbox is a toolbox written for Matlab, while Psychopy is a platform-independent program written in Python language. PsychoPy, moreover, offers the possibility of generating psychophysical tests using a GUI without the need for coding. The advantage of Psychopy over Psychtoolbox is that Python is freely available, whereas Matlab is a commercial and expensive package. In addition, Visionegg is another open-source software for generating stimuli, written in Python with some extensions in C. There are also other programs such as Presentation, e-Prime, and Psykinematix. The main difference with the one previously presented is that they are not free and their prices amount to more than 1000\$.

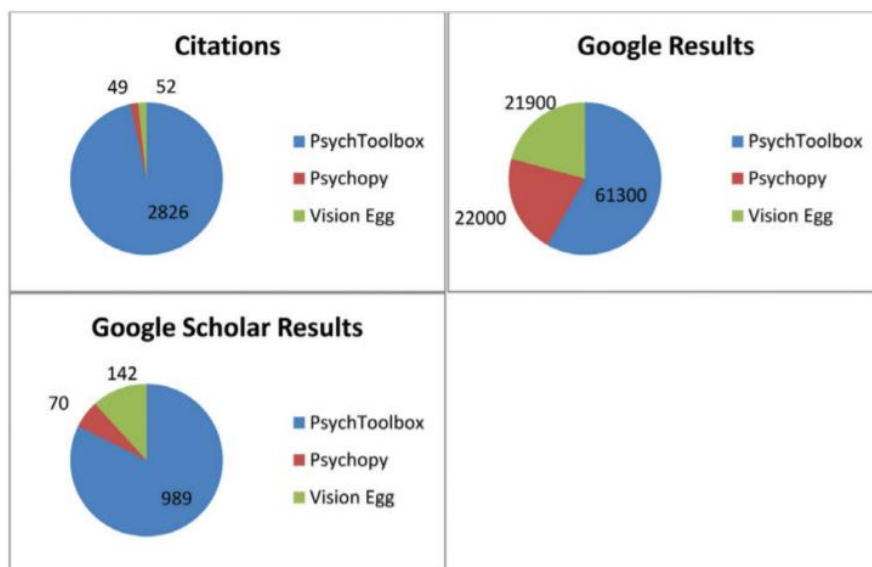


Fig 4: in the figure the number of citations of the different software presenting papers. It is shown that the most used is PsychToolbox.

All the previously presented software are carried out on desktop or laptop computers. However lately, it started to increase the need to run the experiments outside the laboratory, for example in clinical environments [41]. Indeed, it looked indispensable the introduction and creation of

new software that could be run on small size and easily transportable device, such as smartphone or tablets.

The idea of the creation of the first software on for mobile devices came to IDIBAPS researchers, Rafael Marin-Campos and Daniel Linares. They created **StimuliApp**, an **open-source application** developed for iPadOS and iOS, in which the user can create psychophysical tests using different kind of stimuli [42].

StimuliApp represents a new and revolutionary way to create and run psychophysical tests. In fact, using an iPad or iPhone could be easier for people with little experience with traditional computers, thanks to their touchscreen interface. In addition, many people own one of them and they are generally less expensive than desktop or laptop devices.

In future, we expect that this direction will be followed: more and accurate applications and software for mobile devices will be released, becoming the first method used in psychophysical experiments. Surely, applications compatible with Android environments need to be developed, in order to make the software more universal and accessible. Other technologies can be used as well, such as a facial recognition system controlled by the main camera, that, for example, can track eye movements: this would be useful for a wide range of experiments, paving the way to further and more accurate studies.

4. Conception Engineering

4.1. Project basis

In certain situations of our life, we are led to take decisions in a really short time. We mainly rely on what information our senses give to us but, if the time is not much and we have a partial or ambiguous sensory information, the expectation provided by prior experience can have an important role. For example, in a tennis match, players have only some milliseconds to estimate where the ball is going and to return it. [3] Thus, they form an expectation based on the last serves and this allow them to gain some decisive tens of milliseconds in the return of it.

For instance, the idea of conducting this study comes from the aim of testing the contributions that choice history has on the following choices in human behavior, based on experiments previously conducted on rats.

First, we tried to implement a similar task to the one previously performed by rats at the IDIBAPS Brain circuits and behavior lab [13][15][34]. To do so, it has been designed a test on StimuliApp, an application developed by the laboratory and run on iPads. At the beginning we have implemented the same parameters as in the rats' experiment but then we adjusted them according to the human performance. Subsequently, the participants performed the task. We collected the data obtained and we analyzed them using a Python code previously implemented.

4.2. Psychophysical experiments

In order to analyze in deep this matter, we decided to run a psychophysical experiment.

Psychophysics is the branch of psychology that deals with the relationships between physical stimuli and the sensations and perceptions they affect. It is the analysis of perceptual processes conducted by studying the effect on a subject's experience or behavior, systematically varying the properties of a stimulus along one or more physical dimensions. [43]

The main aim of psychophysical experiments is the analysis of behavior and the interpretation of the brain activity in terms of perception.

Why conducting a psychophysical experiment and no other kind of neuroscience experiments?

Neuroscience methods, such as neurophysiology, neuroimaging or electrophysiology are extremely useful ways of studying the brain that aim to understand its behavior and its way of working. However, they cannot correctly investigate the field of sensations and perceptions, making it necessary the development of a different ways to conduct experiments. Thus, this is why psychophysics has started to assume a fundamental role in the study of perceptual decision making.

4.2.1 Different methods to conduct a psychophysical experiment

The starting point of a psychophysical experiment consists in identifying a *phenomenon*, that can be, for example, an observation of visual or auditory stimuli or the presentation of an illusionistic image.

In order to run psychophysics experiments, scientists employ stimuli that can be objectively measured, such as sounds with different intensities or lights with different contrasts.

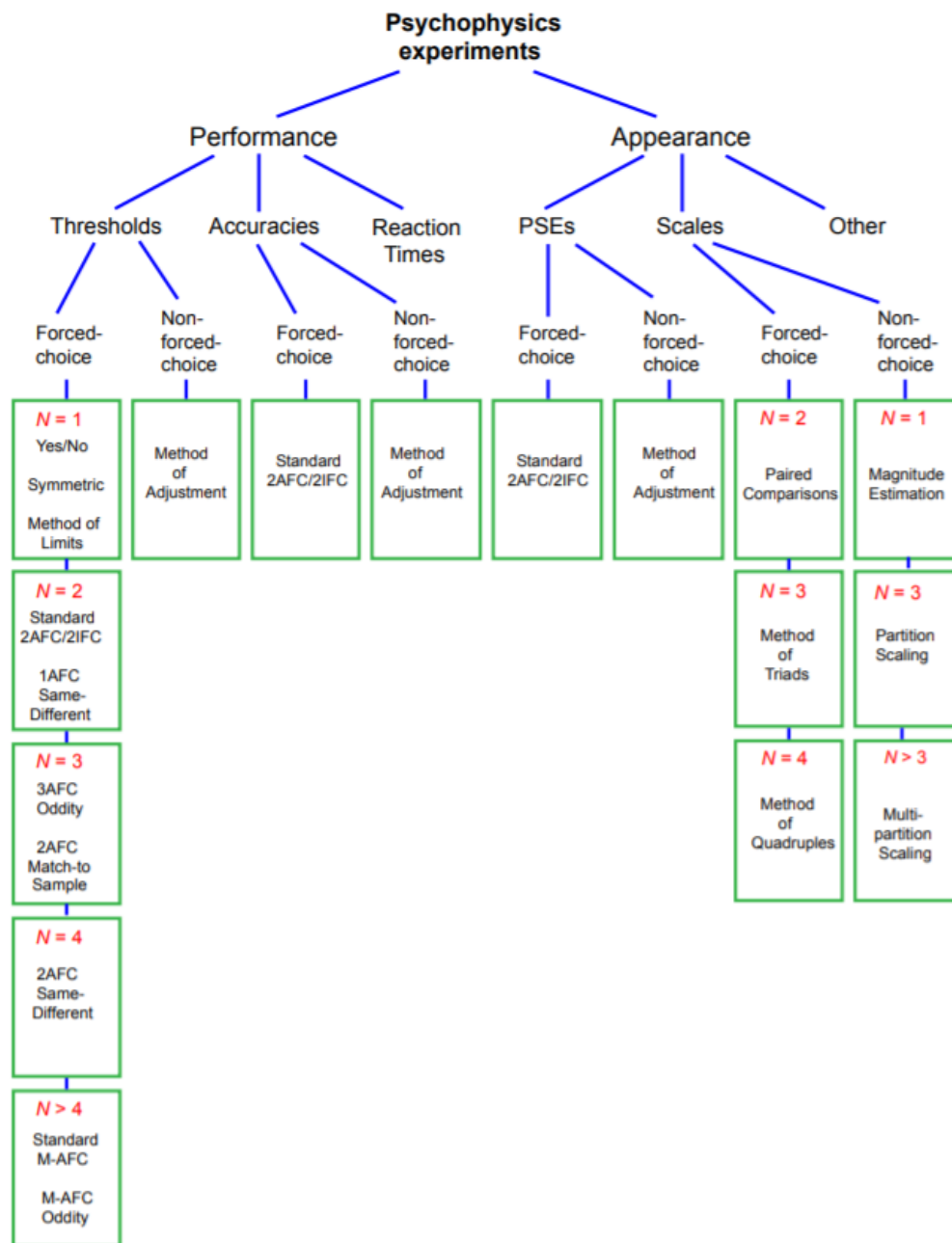


Fig 5: varieties of psychophysical procedures

As shown in fig. 5, the procedures to conduct psychophysical experiments are diverse [44]. In this memory, I will present only the main used methods, focusing on the modality we decided to adopt.

A psychophysical experiment generally consists of these components: stimulus, task, method, measure and analysis.

The stimuli presented in a psychophysical experiment are generally *visual*, *auditory*, *haptic* or *tactile*. The tasks created are several: for example, it can be requested to recognize different contrast levels

or to indicate the position where a certain object is displayed, as well as to detect the auditory stimulus with the highest intensity.

There are three basic experimental methods that are used in perceptual psychology experiments: magnitude estimation, matching and discrimination.

Magnitude estimation

In this kind of experiments subject are requested to rate some particular aspects of a stimulus. For example, they are asked to state how bright a certain image appears or how loud is a sound, giving an evaluation on a scale.

Matching experiments

In a matching experiment, subjects are requested to pair stimuli that present similar characteristics, in terms of intensity, brightness etc... It can be also designed so that the subject's task is to adjust one of two stimuli so that they appear analogous. For example, it may be requested to adjust the brightness of two different images so that they look equally luminous.

Detection/discrimination experiments

In a detection experiment, the subject's task is to detect some differences in the stimuli presented. Participants may be asked to discriminate which stimulus is more intense or report the position where a light was displayed etc...

4.2.2 Psychophysical Procedures for Discrimination Experiments

The method of adjustment

Participants are asked to adjust the intensity of the light until they judge it to be just barely detectable. However, this is a mainly subjective task and it is not really effective.

Yes-No/method of constant stimuli

A series of tones of various intensities is presented. Each intensity is played several times and the observer is asked to report whether they heard it. Then it is calculated the probability of detection (or percentage of "yes" responses) for each tone intensity. However, to determine detectability, we need to know both the hit rate and the false alarm rate. This makes this kind of experiments not really effective.

Two-interval forced choice task

In this method, two stimuli are presented. They can be visual stimuli presented one close to the other, or they can be visual or auditory stimuli presented one after the other. One of the stimuli is a noise and the other is a signal with a noise stimulus. The task consists of indicating which of the two intervals the signal occurred.

Two-alternatives forced choice task

The stimuli are presented on each trial and subjects are requested to necessarily make a choice between two alternatives. On some experiments researchers introduce no signal on some of the trials (catch trial). With this method it is possible to count the number of hits and the number of false alarms to get an estimate of discriminability, independent on the criterion of each subject. In this kind of experiments, it is important to set an adequate stimulus presentation time: if it is too short the

subjects may become frustrated while attempting to scan the stimulus and if the time is very long participants are less likely to develop bias in the stimuli sequences.

4.2.3 Software

Since the introduction of laptops and computer, the field of psychophysical experiments has been revolutionized thanks to the development of software that can precisely define the main features, such as luminance, timing, position of the stimulus etc... In this section I will present the main software used in psychophysics and their characteristics [37]. In Table 1 it is shown a comparison between them.

1. *PsychToolbox*

Psychtoolbox is a toolbox written for Matlab and it is released under General Public License (GPL-2). It consists of plugins written in C and files written in Matlab and it is available for Macintosh, Microsoft Windows and Linux distributions.

It can create visual 2D stimuli using batch drawing, texture mapping and video playback; it can also set an accurate timing for the stimuli presentation using techniques such as double buffering. In addition, it supports OpenGL, a platform to create fast and high precision three-dimensional output. Besides visual stimuli, it can also generate low-latency and high precision sounds. Moreover, several other toolboxes for Matlab are based on Psychtoolbox. An example is Eyelink toolbox, which is used for eye-tracking or Masked Priming Toolbox to run masked and unmasked priming experiments. Psychtoolbox has the largest community size among all the psychophysics software.

2. *PsychoPy*

Psychopy is an open-source software package written in Python programming language. It is available for Macintosh, Microsoft Windows and Linux distributions and it is released under GPL. Thanks to the use of Python as the platform, time precision is more accurate than the other software. In addition, Python is freely available and downloadable, making it more accessible to several users compared to Matlab, which is a commercial and expensive package. Moreover, it can generate stimuli faster and it has an automated tool for calibration of displays.

3. *Vision Egg*

Vision Egg is a free, open-source library written in Python with some extensions in C. It focuses mainly on the use of OpenGL, an open-source cross-platform to generate 2D and 3D computer graphics; its use became popular in software such as CAD, Virtual Reality or flight simulation. It uses the Graphic processing Unit (GPU), which allows the stimuli to be generated much faster and independent of the workload of CPU. In addition, it is possible to remotely control the application via a TCP/IP standard protocol, which makes it suitable for remote collaborations.

	Psych Toolbox	Psychopy	Vision Egg
Free	✓ (Matlab is required)	✓✓	✓✓
Open Source	✓ (Matlab is required)	✓✓	✓✓
Platform Independence	✓	✓	✓
Usability	✓✓	✓✓	✓
Automated Calibration	✓	✓✓	✓
Real-time Stimuli	✓	✓	✓✓
Hardware Interfaces	✓	✓	✓✓
Community Size	✓	✓	✓✓

Table 1: features of the above mentioned open-source software programs.

4. *StimuliApp*

All the previously presented software are installable on desktop or laptop computers. StimuliApp, instead, is a free app that can be easily downloaded from the App Store and whose tests can be run directly on iPad or iPhone. It is developed in XCode, an integrated development environment (IDE) using the programming language Swift. The main characteristic of this application is that the visual or auditory stimulation are perfectly synchronized, and the interactive creation of stimuli use real-time preview. To be able to analyze the data obtained, the results are saved in .txt and .csv format and they can be easily sent by email and exported to other devices. In addition, it uses a Metal framework which provides direct access to the GPU of the device: this lets the frames not be dropped and ensures precise timing. To generate a psychophysical test, StimuliApp uses a graphical user interface (GUI) consisting of a system of menus. It offers a large number of templates for creating stimuli commonly used in the study of perception and cognition (Fig. 6): random-dots, texts, auditory noises, images, videos etc.

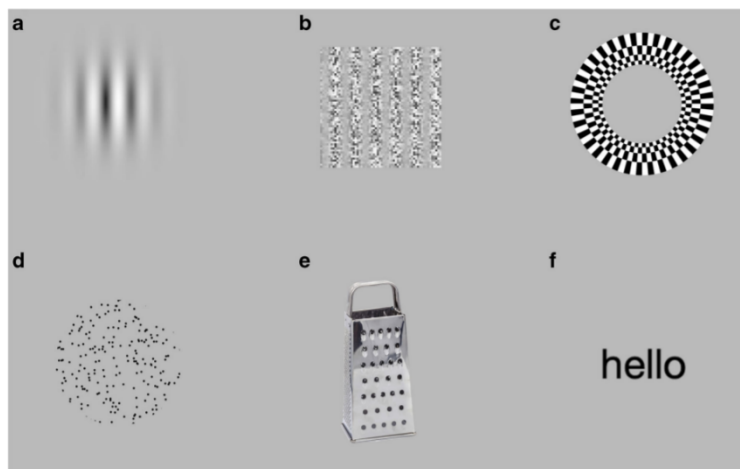


Fig. 6: type of visual stimuli that can be presented using StimuliApp. (A) Gabor. (B) Grating with modulated carrier contrast. (C) Radial checkerboard. (D) Random-dots. (E) Image. (F) Text.

4.3. Solution: auditory two-alternative forced choice task (2AFC) on StimuliApp

After having considered the previous procedures, methods and software, in order to conduct our experiment, we chose to carry out an auditory two-alternatives-forced-choice task (2AFC) using StimuliApp. In this kind of experiment, participants are presented on each trial with an auditory stimulus and they are required to necessarily choose between two responses. The decision to adopt this solution comes from the idea to mimic in all respects the experiments previously conducted on rats, in order to be able to compare the results obtained. It has been chosen an auditory stimulus instead of a visual one since rats have a limited sight and the results would have not been relevant for the aim of the study. In addition, 2AFC tasks have showed to be the most effective among a wide range of psychophysical studies. Indeed, they are categorical experiments where it is not given space to idiosyncratic bias toward the stimuli; in addition, by being a simplified environment with only two options, it is possible to correctly measure all the needed values such as hit rate, misses, time of reaction etc. and evaluate the influence that different factors may have.

Moreover, the interface design has been created in this way in order to simulate the trajectories in rats' studies.

We preferred to use StimuliApp over the other alternatives thanks to its ease of use. Differently to other software, StimuliApp can be run on iPad or iPhone: their small size and weight make it possible to run the experiments in non-laboratory settings. In addition, their touchscreen interface can be of more easy access by people with little experience with traditional computers. Moreover, a large number of people own them, and they are generally less expensive than desktop or laptop devices. This makes our experiment settings more easily reproducible by other scholars who want to conduct similar experiments.

5. Detailed Engineering

In this section it will be presented the process of task creation and implementation and the data acquisition and analysis.

In order to correctly investigate the matter, it is essential to generate an appropriate task for our test goal. For this purpose, we have implemented a 2AFC task in which participants need to choose between two alternatives after hearing a stimulus. As previously said, the task is based on previous studies conducted on rats: we extracted the parameters used in those experiments and we adapted them to human subjects. We tried to recreate a similar environment by using *StimuliApp*. As explained in section 2.2, in rats' experiments, they are asked to physically move to the port from which the sound is mainly coming. Human participants, instead, perform the whole task on iPad and they are asked to respond using the screen.

To conduct this experiment, we recruited 18 subjects. They are aged between 20 and 60 years, where the mean is 25 and the median 22. Roughly 50% of them were women. None of them presented auditory problems.

The code to analyze the obtained data has been implemented in Python programming language and it can be publicly consulted on GitHub repositories.

5.1. Task design

The task is divided into three sections: intro, training and trials.

Intro

In this section some questions are asked to the participants such as name, sex, age, writing hand and the presence of auditory problems. They can refuse to reply to any of them.

Training

Subjects are provided with 20 training trials to understand how the task needs to be performed. These data are not considered for our analysis.

Trials

This is the section in which the experiment takes place. In order to perform the task these tools are needed and provided by the experimenter: iPad, StimuliApp, headphones. (Fig. 7)

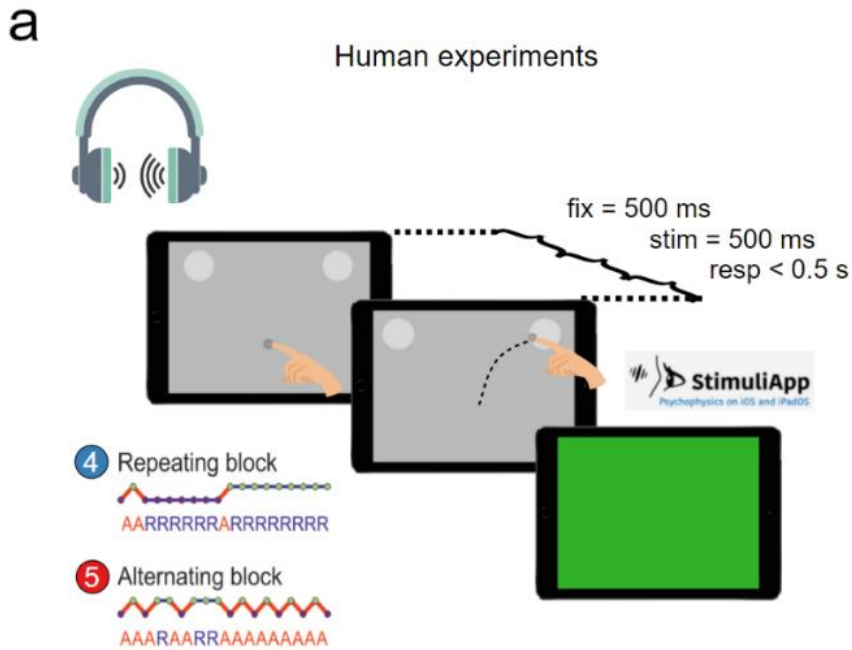


Fig 7: task design for the first Version (500ms)

At the beginning of the *Trials* section, participants are presented with a grey screen with two light grey circles in both sides of the top part and a dark grey circle in the middle of the bottom part (Fig. 8). The luminance of the screen is set at 0.7 (350.0 cd/m²) and the participants are asked to perform the task maintaining a constant distance from the screen of 50 cm; this value is used to calculate the pixels of the frames in order to give a clear image to the subjects.

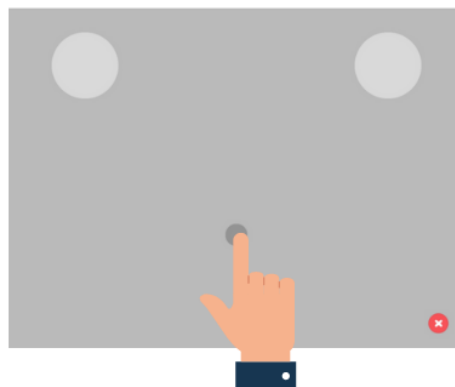


Fig. 8: The figure shows the main interface of the task. The two light grey circles represent left or right choice; the dark grey one is the circle participants have to move towards the light grey ones in order to indicate which side they heard the sound mainly coming from.

To start the trial, participants have to press on the dark grey circle and hold the finger for a period of 500ms. This is called *fixation time*. It is important that subjects use the index finger of their writing hand for all the experiment duration.

Subsequently, a **white noise** is played; it has a different intensity distribution on the left and on the right side. Participants are requested to decide the side from which the sound is mainly coming: to give a response they have to drag the dark circle towards the light circle of that side. The time it takes for the subject to give a response is called *motor time*.

We set some visual representations that let the participant have feedback about their response: the screen turns green, red or yellow depending on whether the response is correct, erroneous or it is done too early or too late (miss trial).

We divided the task into **trials** and **sections**. Each section consists of 100 trials: we found this amount to be the best match for the subjects not to be too tired in performing the task but still letting them develop an expectation from the previous trials. After every section the participants can take a break: it does not have a fixated length since every participant may need different time to recover and get ready for the following section.

The total number of trials is 2000 per participant. They can decide to perform the experiment in one session or two sessions of 1000 trials each.

5.2 Task settings

5.2.1. Structure

Each trial presents the same structure. (Fig. 7) These are the intervals in order of appearance:

- **Fixation time**: this is the period in which participants must hold their finger on the dark grey circle. In this time the sound is not playing. If subjects try to respond in this time the trial is considered invalid (missed). We set the duration at 500ms.

- **Stimulus period**: after the fixation time, the stimulus starts playing. Participants must move from the initial position before the end of the stimulus. At first, we set this period's duration at 500ms. We adjusted it to 300ms after testing half of the subjects.

In addition, there are other important time values to define. These are not fixated periods as the ones previously presented and they vary from trial to trial:

- **Reaction time**: this is the time participants take to move the dark grey circle from the initial position after the stimulus starts playing. They must move it before the stimulus ends (500/300ms).

- **Motor time**: it is the time subjects need to give a response. In this period, they drag the circle from the initial position to one of the big circles (left/right).

In addition, the task is designed so that the participants, as long as they move from the initial position, do not have a predetermined time to give a response. This feature has been set in order to mimic rats' experiments, where the physical movement from the central port to one of the others does not require to be done in a specific time. This setting was not previously communicated to the subjects: however, some of them noticed it and this let them have more time to think about the response to give.

Every trial ends when subjects give a response.

5.2.2. Different versions

We created two different versions of this experiment. In the first one, we set the duration of the stimulus at 500ms. After testing half of the subjects, we adjusted it to 300ms in order to force them to give a response in a shorter time and make the task more difficult. We wanted the participants to find themselves in a situation of uncertainty due to the short duration of the stimulus so that, consequently, they could rely more on the choice history than on the stimulus. From now on we will refer to the two different experiments as **Version 1**, for the 500ms experiment, and **Version 2**, for the 300ms one. All the variables presented subsequently are unchanged in the two experiments.

5.2.3. Stimulus strength

The white noise sound presented to the subjects has different distributions on the left or on the right side. We refer to this stimulus strength as *coherence*, *stimulus strength* or *evidence*. Left stimuli have a coherence of $0 \leq x < 0.5$. For the right ones, instead, it is $0.5 < x \leq 1$. The values we set are:

- 0.3, 0.4, 0.45, 0.499: left stimuli
- 0.7, 0.6, 0.55, 0.501: right stimuli

A coherence of 0 means the sound is played totally on the left side; vice versa, a coherence of 1 refers to a sound completely played on the right side. The intermediate values – close to 0.5 - indicate a sound that has almost the same intensity both on the right and the left side. This means that if the value is closer to 1 the subjects will hear a sound mostly coming from the right and vice versa; if it is closer to 0.5 the participants will have the impression the sound is equally distributed on both sides.

5.2.4. Patterns

Trials are organized into blocks: repeating and alternating (Fig. 9). In the repeating block, the probability that the correct choice at trial t is the same as in trial $t-1$ is $P_{rep}=0.8$. In the alternating blocks $P_{rep}=0.2$. It has been used a Markov chain parametrized.

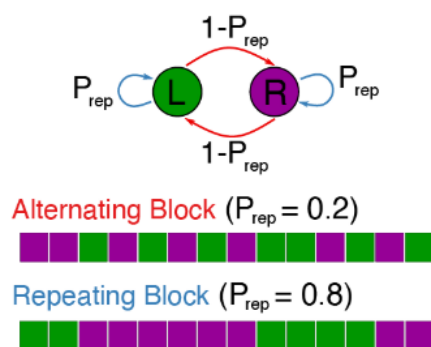


Fig 9: the figure shows the two types of blocks and a chronicle possible presentation of the correct choices

The introduction of these patterns derives from the need to create choice expectations in the participants in order to test perceptual bias. Obviously, participants are not informed about the presence of these schemes.

5.2.5. Performance

At the end of each trial, the response can be correct (1) or wrong (0); if subjects do not reply on time (too early or too late) the answer is considered wrong (0).

There are two types of performance measurements:

- P_{section} : the performance is evaluated every section of 100 trials and calculated as a percentage of correct answers on total trials. The accuracy is displayed after the end of every section and showed to the subjects.

- P_{tot} : the performance is calculated as total of correct answers on total trials. This is not showed to the subjects.

5.2.6. Reward

Each participant receives a reward of €0.01 for every correct answer. We introduced this variable in order to motivate the subjects to engage in the experiment and not to give random responses.

5.2.7. Interface

As showed in fig x we have decided to create this interface in order to study the trajectories. Thanks to the circle dragging it is easy to test, for example, changes of mind and check if participants altered directions from one side to the other.

5.3. Task implementation

In this section they will be presented the main steps needed to develop the experiment on StimuliApp.

In Fig. 10 it is showed the main interface of the application. At the bottom, they can be seen the different sections: Tests, Run Test, Results, App settings.

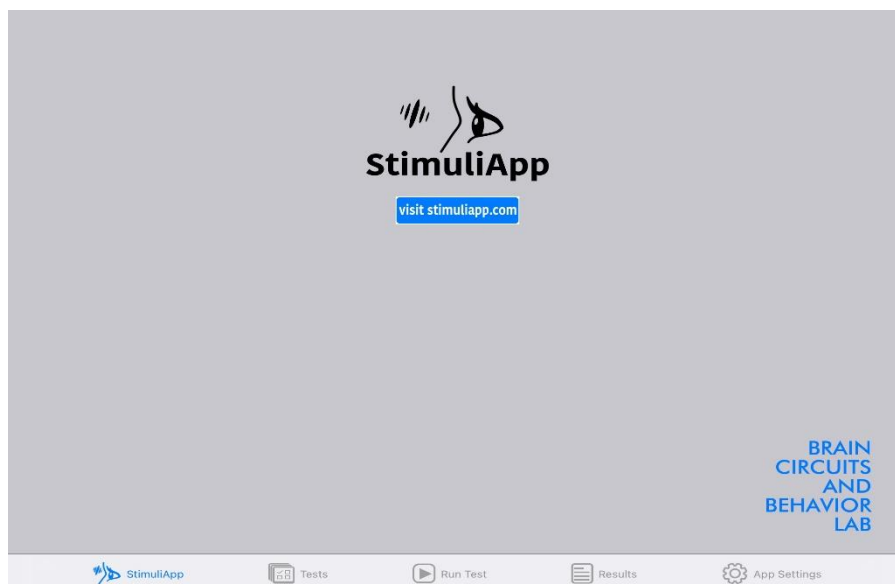


Fig 10: main App interface

As it is shown in Fig. 11, each section presents a different sub-section.

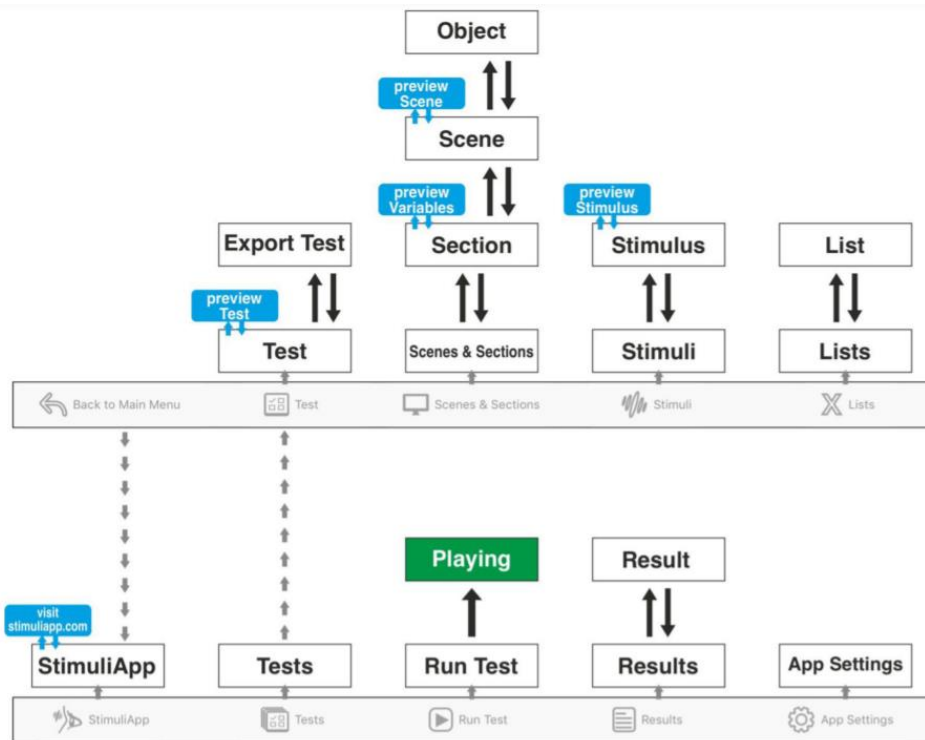


Fig 11: hierarchy of StimuliApp menu

To start to implement the present experiment we created a *New Test* from the *Tests menu* section. In order to add the auditory stimulus, we pressed *New Stimulus* on the *Stimuli menu*. We selected *pureTone* from the type experiment list, changed the *soundType* to *whiteNoise* and the *leftRightBalance* to *variable*. This let us add a white noise which strength is variable from 0 to 1. In addition, in this section, all the other Stimuli must be added such as the circles and the text boxes needed to reply to the questions.

Then, through the *List menu*, we created two lists of numerical values: left and right. We added the stimulus strength values previously presented in section 5.2.3 to each of the two lists, according to the sound intensities.

Subsequently we created a list of *blocks*. We set the total number to 300 and the trials for each block to 10. We set up two blocks: the first is the repetition one, the second is the alternation one. We set the probability to change list to 0.2 and 0.8, respectively.

Afterwards, we created all the sections that compose the experiment.

Intro

Once in this section the different scenes must be created: name, sex, age, hand, audio.

Training

This section consists of three scenes: waitTraining, soundPlayTraining and answerTraining.

Trials

In this section, three scenes are presented: wait, soundPlay and answer. *Wait* scene lasts until the participants press the dark grey circle. Then, it immediately goes from *Wait* to *SoundPlay*. In *SoundPlay* we set *startTime* at 0.5s; this time is what intervene between the press of the dark grey circle to the beginning of the sound. In the two versions of the experiment, we set the end of this section at 1s or 0.8s: indeed, the sound plays for 0.5s or 0.3s. In Answer section, the participant can give a response: to be considered right the subjects can reply only while the sound is playing.

Yellow, Red, Green

These sections will respectively show feedback for the given answers.

Pauses

It is the section in which it is shown to subjects that they can take a break from the experiment.

5.4. Data analysis

In order to analyze the data, we used Python programming language. We chose this language since its breadth of use all over the world, that makes the code be easily shared to other researchers. The generated script can be found at the link https://github.com/manuelmolano/psycho_priors and it has been created in collaboration with Manuel Molano-Mazón, researcher at the Brain circuits and behavior lab (IDIBAPS).

In this section they will be presented the main analysis conducted on the collected data.

5.4.1. Learning

To analyze the process of learning of the subjects, we computed the performance along the trials. In order to obtain a more visual value of the performance and a smoother curve we have executed the convolution of the performance values. The vector with the performance values is convolved with a vector of values $1/w_{conv}$ and length w_{conv} , following the discrete convolution formula:

$$(f * g)[n] = \sum_{m=-\infty}^{\infty} f[m]g[n - m]$$

In this formula f is the performance vector and g is the convolutional vector. w_{conv} , that is the convolution window, is set to 100. Performance has a value of 1 if the answer is correct and 0 if is incorrect or not given on time. This convolution has been performed using the Numpy function *convolve* in the *valid* mode, that indicates that the convolution product is only given for points where the signals overlap completely, while values outside the signal boundary have no effect. [46]

The performance figure has been computed for each subject in order to see the individual process learning; another one has been also created taking into account the average performance for all subjects.

5.4.2. Psychometric curve

Psychometric curves measure the probability that subjects choose the right-ward alternative, conditioned to the stimulus strength. [45] This graphic is useful to understand if subjects correctly learned the task, showing mostly correct choices for really clear stimuli.

In order to analyze this probability, trials are grouped by the stimulus strength values. Subsequently, for each stimulus strength, it is calculated the percentage to choose the right side over the left one. In this way it is obtained the percentage of times that the subject has chosen right according to a certain stimulus value. The curve is plotted according to this formula:

$$P_{\text{Rightwards}}(e) = \frac{1}{2} \left(1 + \operatorname{erf} \left(\frac{\beta e + b}{\sqrt{2}} \right) \right)$$

β is a sensitivity that quantifies the stimulus discrimination ability, e is the stimulus strength and b indicates the subject's tendency to repeat ($b>0$) or alternate ($b<0$) their previous choice.

5.4.3. Same choice repetition after correct or erroneous answers

In order to test the transition bias, it is relevant to create a graphic to compute the probability to repeat the same choice after correct answers or after erroneous ones. The curve is plotted according to this formula:

$$P_{\text{Repeat}}(\hat{e}) = \frac{1}{2} \left(1 + \operatorname{erf} \left(\frac{\beta' \hat{e} + B}{\sqrt{2}} \right) \right)$$

β' quantifies the stimulus discrimination ability, while B measures the subject's side preference for the left ($B<0$) or right choice ($B>0$). \hat{e} is defined as $\hat{e} = r_{t-1}e_t$ where t is a trial and r is a response; r is defined in the interval $\{-1, 1\}$, according to the response given in the previous trial (left or right, respectively). For example, a rightward stimulus with evidence $e_t = 0.4$ after a left response implies a repeating stimulus evidence equal to $\hat{e}_t = -0.4$.

5.4.4. Influence of stimulus strength on Reaction time and Motor time

We computed a graphic to analyze the dependencies between the stimulus strength and the reaction time values. We grouped by the same values of stimulus strength and, for each of them, we computed the median of the reaction time showed by the subject. We chose to consider the median and not the mean values because the mean can be distorted by unusual values, such as really long or short reaction time episodes, that, due to their sporadicity, do not have any relevance in the study.

Similar to the curve just presented, we aimed to evaluate the relation between stimulus strength and motor time, which is the time subjects need to give a response after moving from the initial position. After having grouped the same values of stimulus strength, we calculated the median of the motor time values.

5.4.5. Tachometric curve: reaction time vs accuracy

A tachometric curve is a graphic generated by the given reaction times for each subject, computed according to the accuracy for each reaction time interval. The accuracy is the percentage of correct answers on the total of the answers. This graphic is useful to determine the relation between how subjects do well according to the time they take to move from the initial position.

6. Results and Discussion

In this section, the results obtained from the experiments will be presented and analyzed.

To conduct this study, we recruited 18 subjects: 8 of them performed Version 1 while 9 of them performed Version 2; 1 subject carried out the first Version for 1000 trials and the second one for other 1000 trials. The difference between Version 1 and Version 2 is the stimulus length period; this amounts to 500ms and 300ms, respectively. The graphics created for the two versions of the experiment will be shown in this section.

6.1. Analysis of human behavior

6.1.1 Valid trials and learning

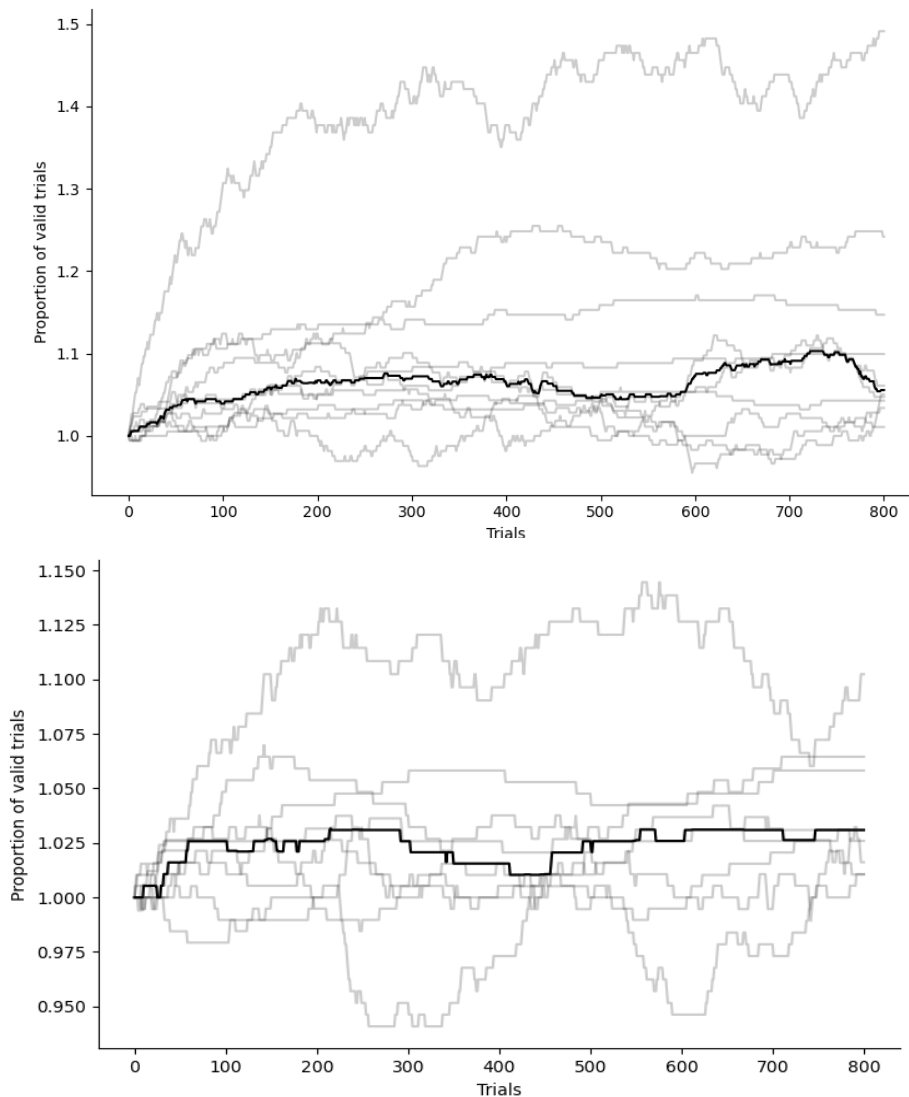


Fig 12: proportion of valid trials along the experiment. Version 1, 500ms (up), Version 2, 300ms (down)

In Fig. 12 they are represented the percentage of valid trials, that is the responses given on time. It can be noticed how the number of valid trials increases along the experiment, showing that participants became more familiar with the stimulus length period, understanding the window in which they have to respond.

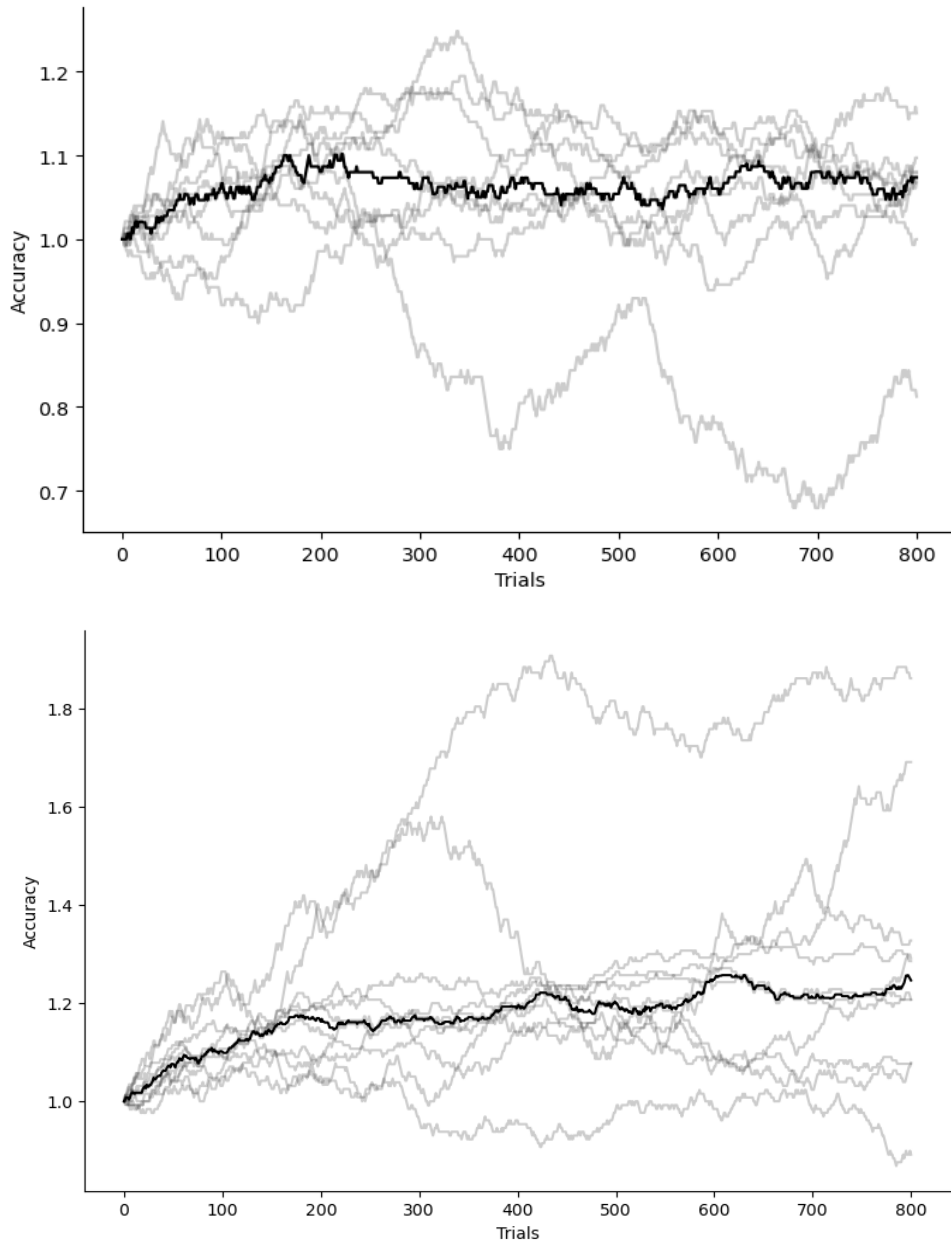


Fig 13: on x-axis is shown the total number of trials, on y-axis the accuracy. In black it is indicated the accuracy of the subjects, calculated as the percentage of correct trials on the total number of trials, respectively on Version 1, 500ms (up) and on Version 2, 300ms (down)

Subsequently, we have analyzed the accuracy throughout the experiment for each subject (Fig. 13). We conducted this analysis with the aim of verifying if subjects learned how to perform the trials along the execution of the experiment and, eventually, which factors triggered the learning process.

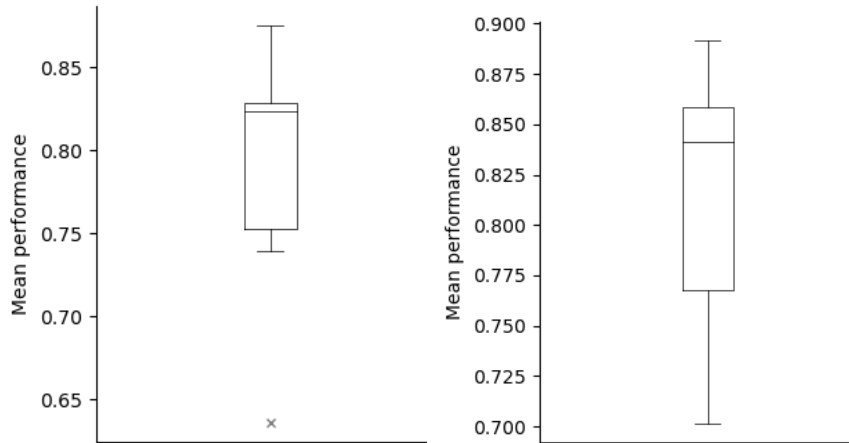


Fig 14: the figures show the mean performance obtained by the subjects, respectively on Version 1 (left) and on Version 2 (right)

As shown in Fig. 14, participants showed an average accuracy of 80%.

At the beginning, most of the subjects presented a performance lower than 60%; on average they needed around 200 trials to learn how to perform the task (Fig. 13).

This improvement both in the performance and in the number of valid trials was associated to three factors. The first one is related to the fact that participants presented issues due to inexperience in carrying out this kind of experiments, which was resolved after becoming familiar with the structure and acquiring a motor execution skill. The second factor is related to the categorization of the stimulus: subjects learned to recognize the intensities of stimuli presented. Another factor, confirmed by further analysis, is that the subjects recognized the patterns present and they used them to their advantage to perform better.

Moreover, we noticed a direct proportionality between fatigue and low performance. This is the reason why it is fundamental for subjects to take a break between the sections.

6.1.2 Variability among stimulus perception: psychometric curve

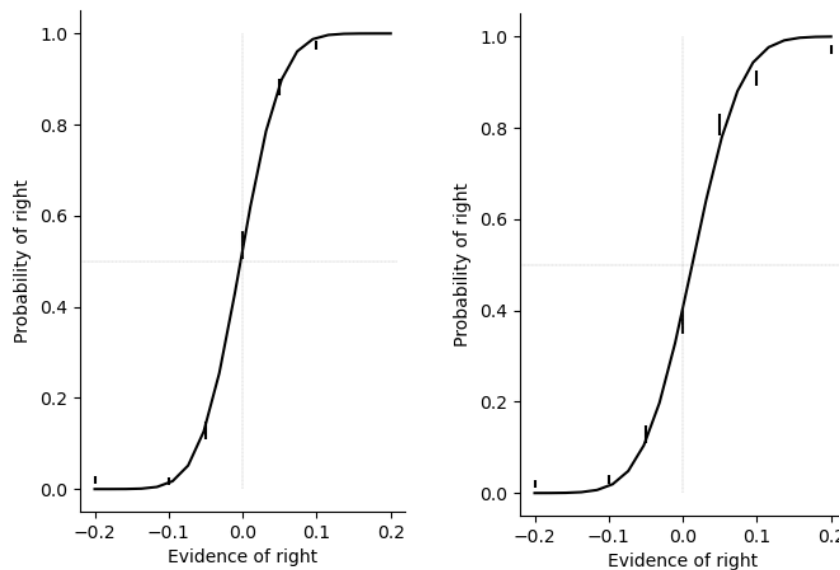


Fig 15: examples of psychometric curve for two subjects that did not present history-independent bias. It shows the proportion of rightward responses vs. stimulus evidence.

Aiming to quantify the history-independent bias, we created a psychometric curve, that shows the proportion of rightward responses according to the stimulus strength (evidence of right).

The horizontal shift of the psychometric curve measures the history-independent preference toward one side manifested by the subjects. Since it shows the percentage of right choices for each stimulus, it is useful to understand if subjects learned the task. Therefore, if the stimulus evidence is clear, they would mostly make correct choices; this is represented in the graphic as a flat curve at the extreme values.

In Fig. 15 is shown a psychometric curve for two subjects. As it is possible to notice, the curve is flat at the extremes and there is not a horizontal shift. This shows that the subjects in question did not present a preference toward one side, and they correctly performed the task. After analyzing the single subjects results we found that in Version 1, 7 subjects out of 9 did not present any bias toward one side; in Version 2, 7 subjects out of 10.

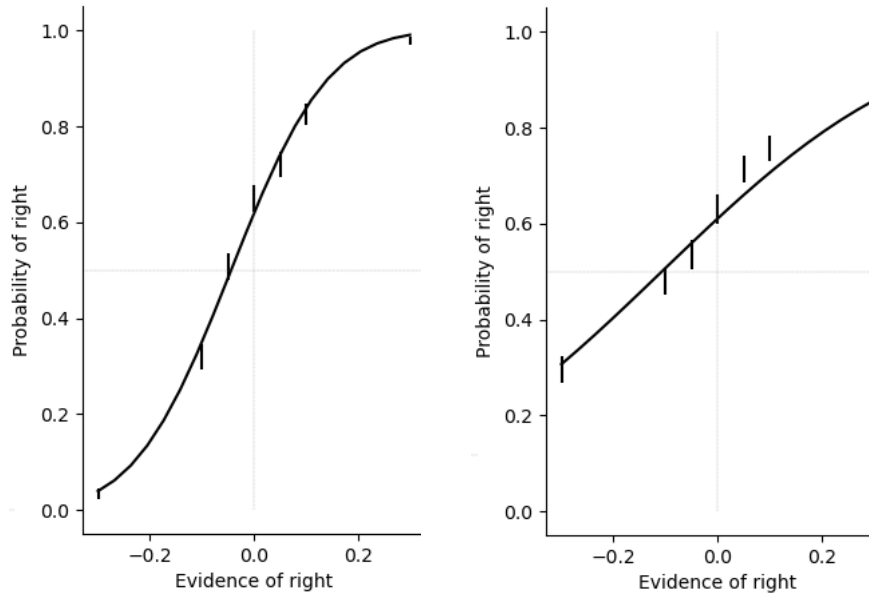


Fig 16: examples of psychometric curve for two subjects that presented history-choice bias. It shows the proportion of rightward responses vs. stimulus evidence.

In Fig. 16, instead, it is possible to notice the psychometric curve for two subjects who presented bias towards the right-ward choice. Even when the stimulus strength is clear on the left, the subject presents a considerable percentage of right-ward choices, independent on the choice history. This shows that the subjects presented some bias in the perception of the stimuli. However, we have hypothesized that some motor execution problems may have occurred: some of right-handed subjects showed difficulties to reach the left side circle since it required a further movement of the arm, making them more likely to choose right. However, this hypothesis needs to be proved by further analysis. No results of left-ward choice bias have been observed.

6.1.3 Same choice repetition after correct answers

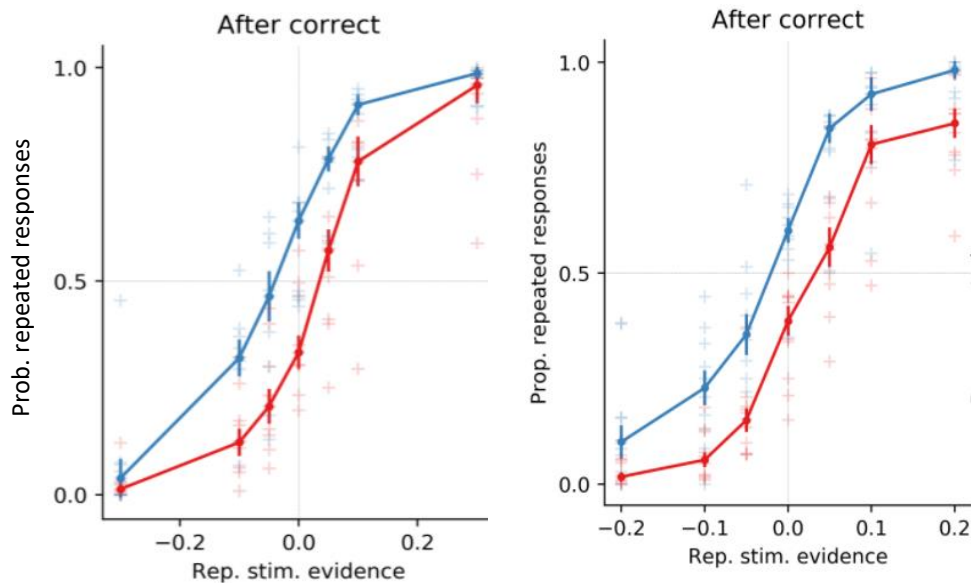


Fig. 17: Version 1, 500ms (left), Version 2, 300ms (right). On the x-axis the stimulus strength of the repeated stimulus, on the y-axis the probability to repeat responses. Average results.

The curve presented (Fig. 17) shows the probability to repeat the same choice after a correct response according to the block; in blue it is represented the repeating block, in red the alternating one.

As it is possible to notice, subjects showed a general tendency to repeat the same correct choice in a repeating environment; in the alternating one they tended to alternate, as it is shown by the horizontal shift in the two curves. This means that subjects generally noticed the present patterns and followed them in order to give faster replies. This happens, especially, when the stimulus evidence is not really clear, making subjects rely more on the previously given response rather than on the stimulus itself. This behavior is defined *transition bias*: it shows the tendency of the subject to repeat or alternate their response according to the previous correct answer. Humans presented almost the same results as rats [15]. They both showed dependencies on the choice history given by the repetition or alternation of the same pattern.

In addition, transition bias showed to be adaptive in the task: subjects rapidly updated their expectancies according to the evidence of repetition or alternation and allowed them to take advantage of the correlations in the stimulus sequences in both types of blocks. This is confirmed by the finding that after longer sequences of repetitions or alternations, subjects need less time to develop expectations for the coming trial.

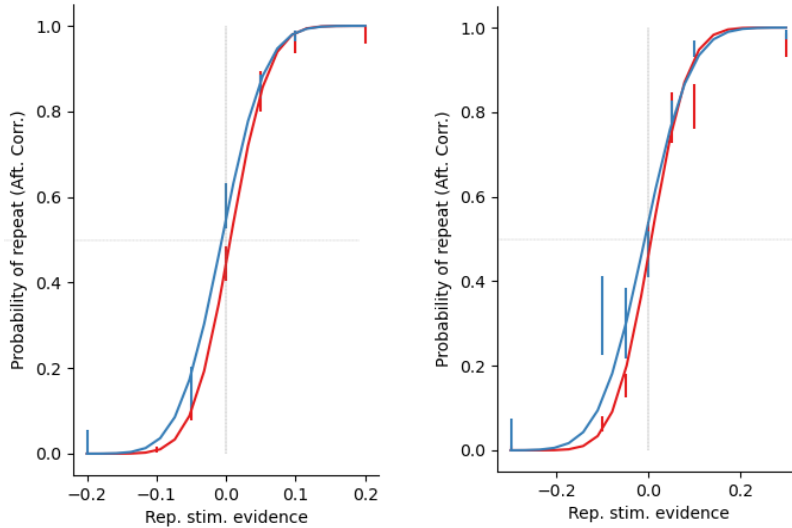


Fig. 18: examples of “Same choice repetition after correct answers” for two subjects who did not show transition bias.

However, as shown in Fig. 18, some participants did not recognize the patterns and their choices were not influenced by the previous ones. We conducted some preliminary observations and we found that 7 participants out of 9 in Version 1 and 7 out of 10 in Version 2 presented bias after correct choices.

As we are commenting in the next section, participants showed this bias only after correct choices.

6.1.4 Same choice repetition after erroneous answers

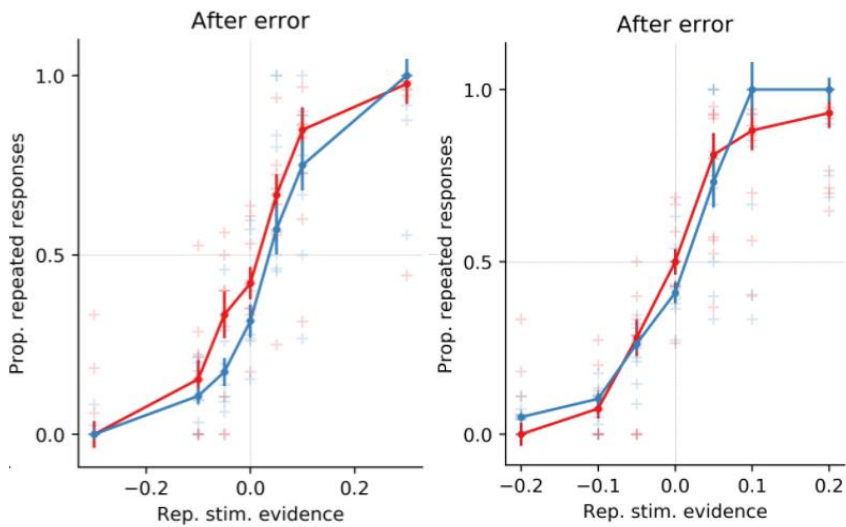


Fig 18: “Same choice repetition after erroneous answers”. Version 1, 500ms (left), Version 2, 300ms (right). On the x-axis the stimulus strength of the repeated stimulus, on the y-axis the probability to repeat responses. Average results.

In these graphics (Fig. 18) it is represented the probability to repeat the same answer after an erroneous choice, both in a repeating environment (blue) and in an alternating one (red).

As it emerges from the Fig. 18, participants showed on average almost the same probability to repeat the same choice in both types of blocks. Differently from section 6.1.3, after an error, participants seem to ignore the previously accumulated choice history and they switch to a so-called expectation-free mode in which the prior is not used. This behavior emerges from an average analysis of the subjects, and it has been identified as *reset strategy*. Indeed, in general, participants, after an erroneous choice, start relying only on the stimulus and on the sensory information. However, after a correct choice, they recover again their previous bias. This behavior has been previously identified in rats. [15] Therefore, we hypothesized that the reset strategy is the result of a structural prior that adapted to a multiple alternatives environment, where identifying the best exploitation strategy after a change may require exploration.

However, when analyzing subject by subject, we found variability in terms of different strategies. Some of them did not present a reset effect, keeping the bias accumulated. As it is noticed in Fig. 19, the participants showed a tendency to repeat the same choice in the Alternating environment and to alternate the choice in a Repeating environment, since the previous choice was incorrect. This is a more optimal strategy which is known as *reverse strategy* [13].

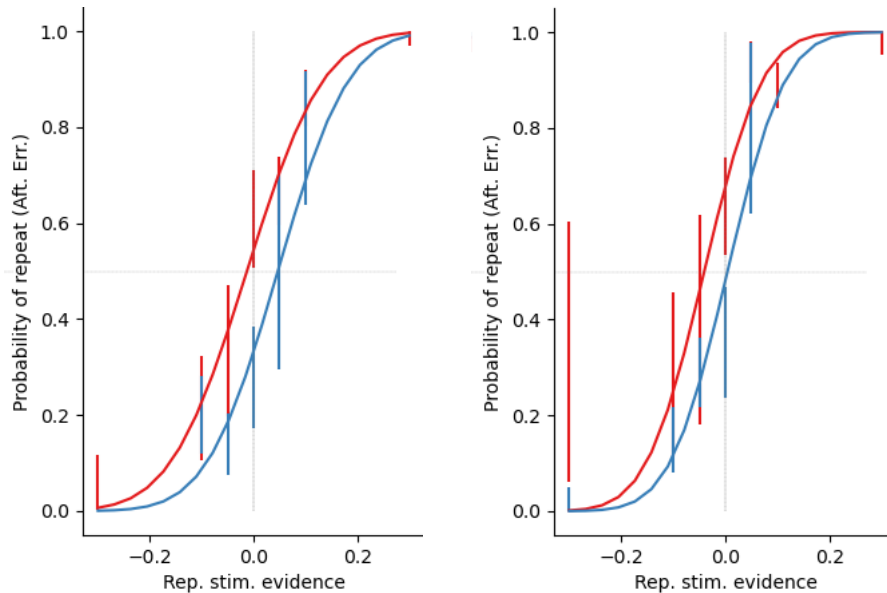


Fig 19: examples of "Same choice repetition after error" graph for two subjects who presented a reverse strategy. On the x-axis the stimulus strength of the repeated stimulus, on the y-axis the probability to repeat responses.

Considering this section and 6.1.3, it is important to notice the relevant impact that feedback have on the bias towards the different options, showing that subjects do not process success and failure just as simple symmetric outcomes.

6.1.5. Influence of stimulus strength on Reaction time and Motor time

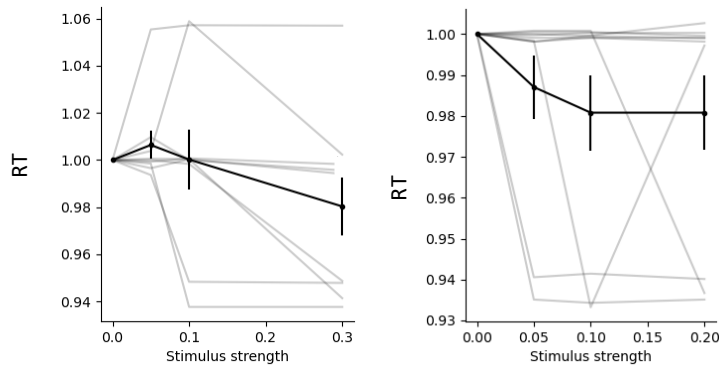


Fig 20: on the x-axis stimulus strength, on the y-axis reaction time. Version 1 (left), Version 2 (right)

First, we analyzed the relation between reaction time and stimulus strength. (Fig. 20) It means the time subjects take to move from the initial position according to the stimulus evidence. The presented RT values are normalized. It has been found that RT values are higher for stimuli that have a low strength. This means that subjects need more time to listen to the stimulus and, subsequently, to move the circle if the stimulus is not really clear.

In addition, preliminary observations show that missed trials are strictly linked to the stimulus difficulty: if the coherence is closer to 0.5 - that means a sound not completely clear on only one side – subjects take more time to give an answer and this lead them not to reply on time.

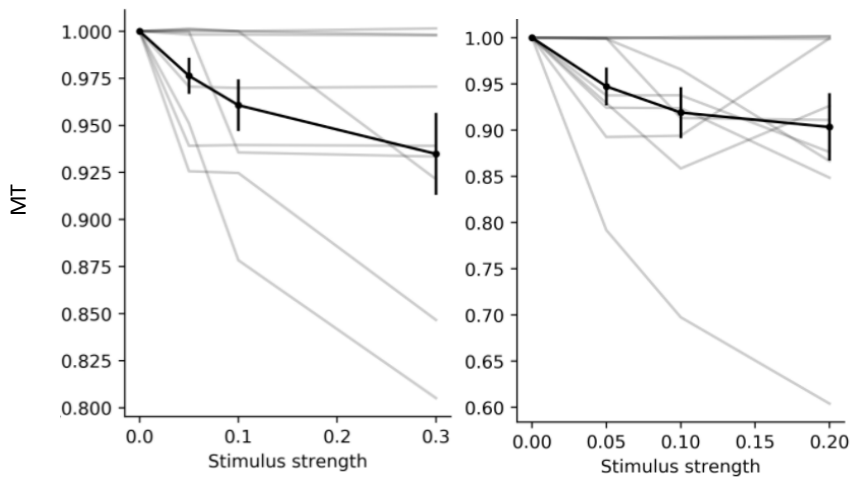


Fig 21: x-axis stimulus strength, y-axis motor-time

Subsequently, we analyzed the stimulus strength in relation to the motor time. (Fig. 21)

An analogous conclusion to the previous presented can be taken. Indeed, if the sound is not completely clear subjects take more time to give a response. If they are sure about which is the correct choice they show a higher confidence and they are likely to be faster.

6.1.6. Reaction time vs accuracy conditioned to stimulus strength

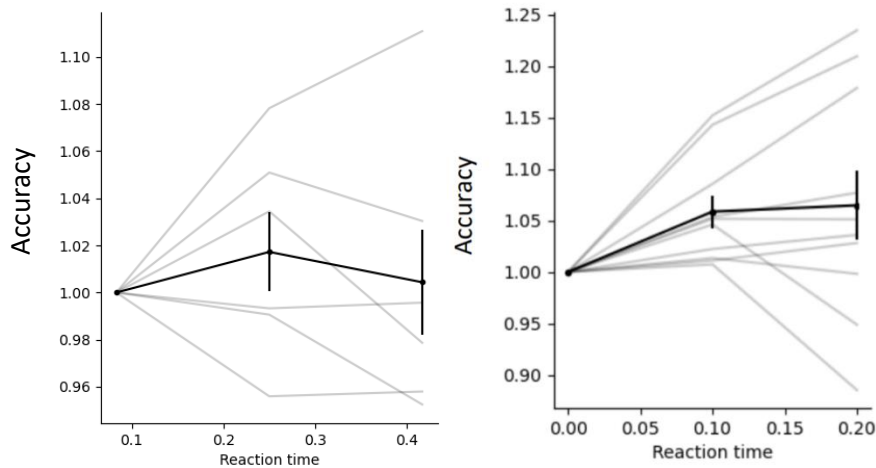


Fig 22: on x-axis reaction time, on y-axis accuracy. Version 1 (left), Version 2 (right).

In these graphics it is represented the reaction time intervals (x-axis) versus accuracy (y-axis), conditioned to the stimulus strength. (Fig. 22)

At the beginning, we created a graphic that considered only the reaction times intervals and the related values of accuracy. However, this led to a misleading result where it looked not to be dependence between the two factors. This happened because the different reaction times were, in turn, directly related to the stimulus strength, which had an impact also on the accuracy (accuracy was higher for clearer stimuli and vice versa).

Taken this into account, we have decided to condition the different reaction time intervals to the stimulus strength and to compute the main accuracy for each value obtained.

It is true that, if the stimulus was really clear subjects were more confident about the response and for this reason they were faster to move from the initial position; however, as it is shown in the graphic, this did not lead to an high performance. In fact, in Version 2, it can be ascertained an increase in accuracy for fast reaction times (RT < 100 ms); then it is present a plateau starting from 100ms showing a similar accuracy for different RT values. An explanation of this can be given by the PSIAM model presented in section 2.2.3. Fast RTs are generated by proactive response, that are responses given regardless of the time of the stimulus and they can be driven by choice bias. In this case, longer RTs allow the development of longer integration of stimulus evidence which leads to higher accuracy. Intermediate RTs were dominated, instead, by reactive responses. In this case accuracy is the same for every RT value since the subjects reply only after gathering enough evidence about the right choice.

Regarding Version 1 of the experiment, similar results can be noticed; however, due to the lack of data, it presents some noises and not a really clear plateau.

6.1.7 Correlation between patterns and missed trials

Preliminary observations seem to indicate that subjects who detected the patterns were also the ones that presented the lowest number of missed trials. This is due to the fact that this category of participants is more confident about which is the right response and, eventually, they do not rely on the stimulus itself, giving faster responses. To analyze this matter, I have taken into account the valid trials graph – to check the percentage of missed trials - and the Same choice repetition after correct, graph - to check if they presented some block-related bias. A couple of examples are shown in Fig 22:

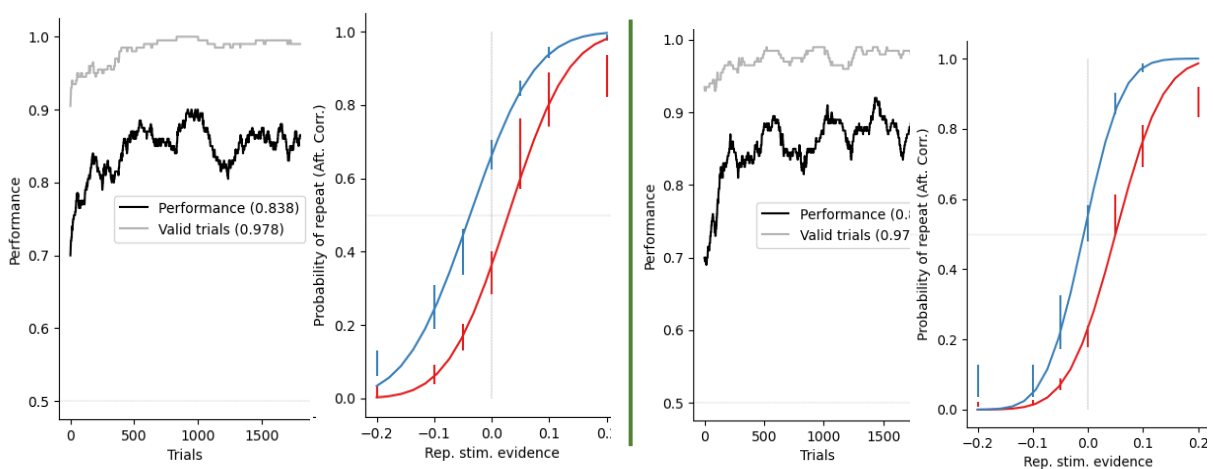


Fig 23: two examples of “Valid trials” graphs and “Probability to repeat the same choice after correct”.

As it is possible to notice, the number of missed trials is around 3% for both subjects. In addition, the two of them showed consistent bias depending on the block.

In Fig. 24, instead, they are shown the graphics of a subject who did not recognized the patterns and showed a number of missed trials of 11%.

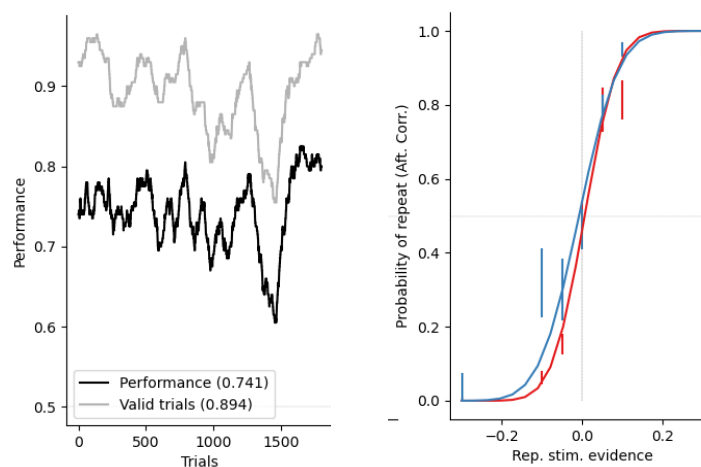


Fig. 24: an example of “Valid trials” graphs and “Probability to repeat the same choice after correct”.

However, further analysis is required to prove this hypothesis. In the future, it will be interesting to test this possibility more in depth by analyzing more subjects.

7. Execution Chronogram

In this chapter it will be analyzed the temporal organization of the project and the completed tasks.

The study started on the 13th of September and it lasted until the 28th of January, having a complex duration of 300 hours.

To show how tasks have been performed during these months and their chronological order I created a GANTT diagram (Table 2). General tasks are divided into specific subtasks and for each of them are indicated the dates in which they have been carried out.

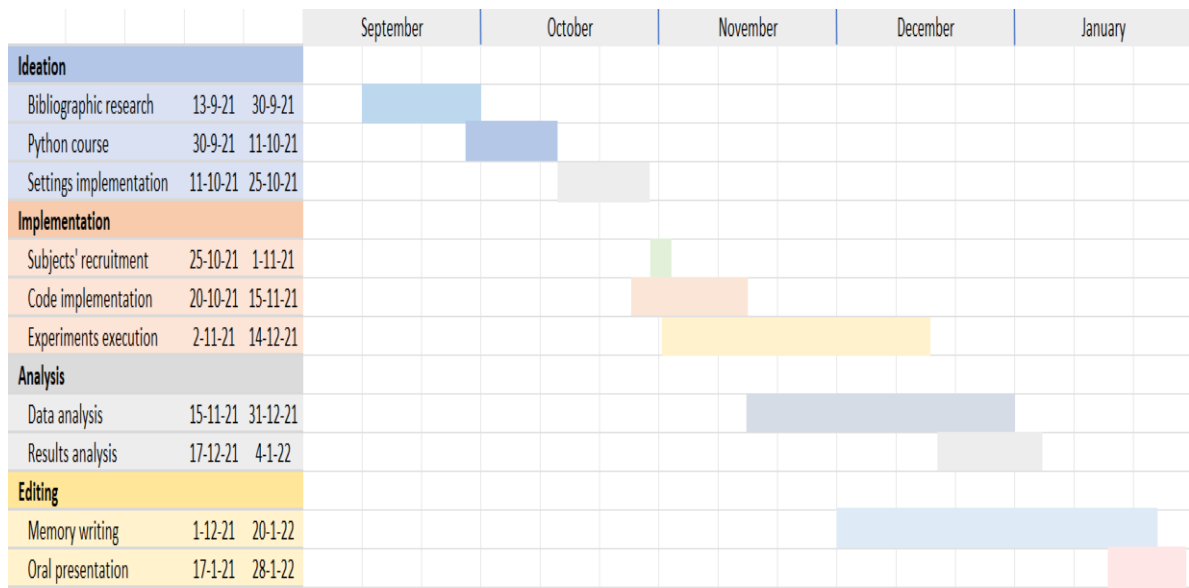


Table 2: GANTT diagram

8. Technical feasibility

In this chapter we will evaluate and present the technical complexity of the experiment, showing that it is performable and verifying that there are no reproduction barriers.

8.1 Technical Aspects

In this section, we will discuss the **infrastructures, software, specialist support** and **equipment** needed for the project development.

This project has been carried out at the Center Esther Koplowitz (CEK), where IDIBAPS is based. It has been fundamental the use of an experimental room located at the laboratory, where subjects could perform the task. The room is situated on the basement of CEK, it has no windows and it is provided with a desk and a chair facing the wall, so that participants would not be distracted by the surrounding environment.

This study could not be actualized without the contribution of **professional researchers** at the laboratory. It is important to mention the director of the project, Manuel Molano, who has supported me throughout the realization of the study and has taught me several information about computational neuroscience and coding. Additionally, Jaime De la Rocha, principal investigator and co-director of this project, has shared with us his massive experience in the field, giving us valuable advice on the carrying out of the experiment and the analysis of the data collected. Moreover, all the team of researchers at the laboratory has been fundamental for my study; they gave me detailed explanations about their projects – personally and at laboratory meetings - letting me build a background on neuroscience.

Concerning **software**, several programs, applications and toolboxes have been used. They have all **free access**. It is relevant to mention StimuliApp, the application used to run the experiments without which the entire study would not be achievable. This is free and easily downloadable on the App store (iPad and iPhone). In addition, it has been used Anaconda platform to run Python codes. To share, manage and save the code it has been used and downloaded GitHub. To handle and share the experiment results and the to-do list it has been used Asana. All the collected data have been saved on Dropbox and OneDrive folders. They have also been used Canva and InkScape for the images' creation.

The access to the articles present in the literature has been possible thanks to “Politecnico di Milano” university credentials; it was sufficient to sign up on the scientific literature research websites to have a free access on the complete articles.

Relating to **equipment**, it has been used Chuwi Ubook Pro laptop. It proved to be suitable for the data analysis, the writing of the project, the image creation and the data storage and collection. However, due to the 8 GB RAM and Intel(R) Celeron(R) N4100 processor, sometimes it was overloaded and it could not rapidly perform the requests. It has also been used a 5th generation iPad to run the experiment, furnished by the laboratory. It presents these characteristics: 32GB and 2GB RAM.

The headphones used and provided by the IDIBAPS are SRS-3170 STAX, composed by an electrostatic ear speaker and a driver unit for ear speaker.

8.2. SWOT

Strengths, weaknesses, opportunities and threats

Every time a project is carried out it is important to do a full analysis of the intrinsic characteristics of the latter, in order to identify the areas that are performing well and the ones that need an improvement.

In this section we will present a SWOT analysis of the project (Table 3). They are presented the internal aspects - such as strengths and weaknesses - and the external ones - such as opportunities and threats.

<ul style="list-style-type: none"> - support of expert researchers - opportunity to work with a specialized team in this field - availability of IDIBAPS equipment and infrastructures (headphones, laptop, experiment room) 	<ul style="list-style-type: none"> - limited prior knowledge of computational neuroscience - lack of knowledge of Python coding
S	W
O	T
<ul style="list-style-type: none"> - improvement of programming skills - contribution to human experimental data collection for the laboratory - work in a highly specialized laboratory in neuroscience field 	<ul style="list-style-type: none"> - limited availability of time to finish the project - Breadth of the topic

Table 3: SWOT analysis

Regarding the **internal factors**, I considered the *strengths* and the *weaknesses* of the project.

Surely, a relevant asset to take into account is the constant support of expert researchers, highly specialized in this field and in this kind of experiments. Their previous works have been really valuable for me and working in this team has been inspirational and useful for the realization of this project.

In addition, having access to the IDIBAPS equipment and infrastructures has been a great strong point. We could use professional headphones, essential for the success of the experiment and an appropriate experiment room where subjects could properly perform the task.

Talking about the *weaknesses*, it is relevant to point out the lack of knowledge in Python coding, fundamental to analyze the obtained data; indeed, no related courses have been covered throughout the degree. In addition, also the limited prior knowledge of computational neuroscience presented an issue, manifesting inexperience on the implementation of this type of experiments.

Concerning the **external factors**, I analyzed *opportunities* and *threats*.

An important opportunity I obtained from the experiment is the improvement of my programming skills. I could learn how to code in Python, a language that is becoming fundamental nowadays, due to its large standard library and its breadth of use all over the world.

Moreover, by conducting this experiment, I could collect data about human experiments that can be used by the IDIBAPS team for additional research, giving a small contribution to further studies.

Furthermore, it has been a great opportunity for me to work in such a high specialized laboratory in neuroscience field, both for my future career and my personal interests.

Regarding the threats it is important to highlight the limitation of time to carry out the experiment. Only four months have been available and this did not make it possible to conduct more detailed and advanced studies. In addition, the topic is really wide and it has been difficult to select only the relevant information about it.

9. Economic Feasibility

In this section it will be discussed the financial viability of the study, presenting the different costs that incurred. They mainly concern hardware costs, participants and staff payments. Then, it will be presented the total amount that it is needed to carry out this kind of project. At the end of this section, they will be presented the financial resources that made possible the realization of the present project. In table 4 it is presented the cost of each element and the total.

9.1 Costs

	ITEM	PRICE
Licenses	Spyder Asana GitHub Excel Inkscape Canva	€0
Hardware	iPad	€350
	Headphones	€1000
	Laptop	€500
Staff	Junior engineer	€4500
	Project supervisor's	€2000
Staff training	EdX Udacity FreeCodeCamp	€0
Additional costs	Subjects' payment	€610
Total		€8960

Table 4: Costs summary table

In order to carry out the experiment, it has been necessary the presence of a junior and an experienced engineer. The salary amounts to 15€/hour and 20€/hour, respectively. Since the junior engineer was involved for 300 hours and the supervisor for 100 hours, the total for the specialist activity amounts to €6500. However, since this project is part of a degree course, the student does not receive any remuneration. In addition, the engineer needs to have specific knowledge about the treated topic; this education has been imparted through online courses. They have been attended on EdX, Udacity and FreeCodeCamp platforms. EdX courses have a cost of €99 each, while €359 was requested for a month access to Udacity; FreeCodeCamp courses were totally free. However, to avoid training costs, they have all been attended through the auditing mode, which let to have a complete access to the material but not releasing any certificate of attendance.

Moreover, it is important to point out that this is a project that includes paid human participants: indeed, the payment of the subjects represents a relevant part in it. Participants are paid 10€/hour

and they are involved for a total of two hours. In addition, a reward of €0.01 is set for every correct answer: since the total of trials is 2000, participants can gain maximum €20 more. We recruited 18 subjects. Considering the hours spent and the reward obtained, the total amounted to €610.

Regarding the equipment, they have been needed a computer, an iPad and professional headphones. In order to have the proper characteristics for the realization of the experiment it is needed an appropriate computer processor: computers that are suitable for this have a cost of at least €500. The iPad has a starting cost of €350; specific characteristics are not required. The headphones used have a cost of €1000; we remind that having proper headphones is essential for the good success of the experiment.

The software used are Python 3.8 in the Anaconda environment (Spyder), Excel for the development of the Gantt diagram, GitHub for the management and saving of the code, InkScape and Canvas for the images creation, Asana to handle and share the experiment results and for the to-do list. All of them are free, accessible or downloadable online; this means they do not have any associated costs.

They have also been conducted research based on published articles that require a paid subscription to get access. However, thanks to “Politecnico di Milano”, it has been possible to get free access to most of the literature articles online.

Last, for completeness, they need to be mentioned also the costs related to the use of the facilities at Centre Esther Koplowitz (IDIBAPS), such as electrical power, Internet access, illumination and the services related to the office maintenance. However, calculating the total amount of these costs has not been possible.

9.2 Funding

The funding of this project comes from both institutions that take part in this project: the University of Barcelona and the IDIBAPS, the institution where this project has been carried out. IDIBAPS has received the fundings by the European Research Council (ERC). Therefore, financial issues derived by the project, such as the payment of the subjects or the purchase of needed equipment have been expensed by the IDIBAPS. The student’s work insurance has been covered by the University of Barcelona as a partner of “Politecnico di Milano”, university where the student is enrolled, thanks to the existing academic cooperation agreement between both institutions and the placement program.

10. Regulations and Legal Aspects

Since the study has involved human subjects, it has been fundamental to define the regulations and the legal aspects. They have all been communicated to the participants before taking part in the study. An information consent was presented and the subjects had to sign it to prove their agreement. In addition, they all could refuse to participate and withdraw from the study at any time without any type of penalty.

The treatment, communication and transfer of personal data of all participants comply with the provisions of Organic Law 15/1999, of December 13, on the protection of personal data and the Royal Decree that develops it (RD 1720/2007). Although the results obtained from the research carried out are published in scientific fields, their identity will never be disclosed.

Personal data become part of the Investigations and Clinical Trials File, which is responsible for the Consortium of the Institut de Investigacions Biomèdiques August Pi i Sunyer and are processed solely and exclusively within the framework of the subjects' participation in this study.

All the data of this study are stored in electronic format and never in hard copies. In addition, the data collected are pseudonymised, so that during its treatment, analysis or publication in the scientific field, only those responsible for this study can identify the people who have participated in this study. The pseudonymised data may be transmitted to third parties and to other countries but in no case will they contain information that can identify the subjects, such as name and surname, initials, address, etc. In the event that this assignment occurs, it will be for the same purposes of the study described or for use in scientific publications. The promoter undertakes to establish the necessary measures to guarantee the same level of confidentiality as in Spain. Participants have the right of access, rectification, cancellation and opposition to said data by contacting the person in charge of the study.

In addition, different software have been used for the development of this study. However, they all have open-source licenses, which means that they are allowed to be freely used, modified, and shared. In particular, it has been used the programming language Python, that is protected by the General Public License (GNU) [47]. The GNU is a set of commonly used free software licenses that give users the right to run, study, distribute, and change the software.

11. Conclusions

After analyzing human behavior, we found that roughly 70% of the subjects were influenced by their previous choices when taking a decision. Indeed, humans were able to use transition history after correct trials, showing similarities with rats' behavior. After an erroneous response, differently from rats, humans showed more variability in their strategies: some of them completely ignored the influence of prior experience (reset effect) – as rats did –, some presented, instead, a more optimal strategy that took into account the patterns (reverse strategy), others showed to adopt both strategies. Moreover, participants showed to learn really fast, taking 200 trials to learn, differently from rats who usually take 80000. In addition, regarding reaction times and motor effects, we found a positive correlation with stimulus strength and accuracy.

The project has showed to be economically and technically viable. Moreover, the method used to carry out the experiment has showed to be really effective to detect sequential effects, making it the perfect candidate to conduct further studies.

According to the studies and results presented, it is noticeable how sequential effects play a ubiquitous role in our lives. Our actions are constantly influenced by our recent experiences, making the difference between the manifestation of different and, at times, opposite outcomes.

The reasons why sequential effects dominate our behavior are still a matter of study. However, they showed to be an intrinsic characteristic not only for animals but also for humans, manifesting really similar behaviors between them. For this reason, we can hypothesize that these behaviors derive from a long evolutionary process in which animals – and then humans – tempted to adapt to the surrounding circumstances.

Sequential effects can be understood as an efficient solution to the challenges we all face, reflecting the attempt to predict future events in a dynamic environment. In fact, when a choice leads to a reward it can be beneficial to repeat it and, likewise, when it leads to failure it is more profitable to avoid it. This makes many researchers abandon the idea that sequential effects are a cognitive deficiency; in reverse, they seem to reflect intelligence which leads to the generalization of knowledge from the recent past to new experiences.

11.1. Future directions

There is still a lot unknown about this field and a lot still need to be studied.

Regarding our project, it would be interesting to test a larger number of subjects in order to detect similarities and differences between different categories of participants, by considering, for example, important factors such as age, sex, pathologies or different approaches and strategies according to distinct settings.

Moreover, further research needs to be conducted on the study of trajectories. Indeed, it would be interesting to analyze them in order to detect different movement strategies used by the participants, such as distinct paths to reach faster the big circles or stops to have more time to think about the answer. Studying trajectories would be also relevant in order to analyze changes of mind, that means, for example, when subjects are about to reach one of the two big circles but they move to the other one right before responding.

Moreover, some additional features are aimed to be added to StimuliApp: surely, it would be important the releasement of an Android version, in order to make it more accessible to different users. Moreover, the addition of a facial recognition system would be useful to measure the distance from which the participants are performing the task and alert them if it does not remain constant during the test or to analyze and track eye movements. Moreover, this application paves the way for a different and revolutionary way of conducting experiments, where tasks can be carried out directly from home without requiring a laboratory setting. This would lead to an increase of the number of subjects and, therefore, a larger number of data can be analyzed.

Finally, future directions at the IDIBAPS laboratory are aimed at applying psychophysical experiments to the study of neurodegenerative diseases, investigating behaviors that can be recognized as risk factors for such pathologies.

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ANNEX 1

Code to analyze the data:

```
import pandas as pd
import helper_functions as hf
# import plotting_functions as pf
from scipy.optimize import curve_fit
import numpy as np
import matplotlib.pyplot as plt
import glob
import os
FIX_TIME = 0.5
NUM_BINS_RT = 4
NUM_BINS_MT = 7
MT_MIN = 0.05
MT_MAX = 1

def box_plot(data, ax, x, lw=.5, fliersize=4, color='k', widths=0.15):
    bp = ax.boxplot(data, positions=[x], widths=widths)
    for p in ['whiskers', 'caps', 'boxes', 'medians']:
        for bpp in bp[p]:
            bpp.set(color=color, linewidth=lw)
    bp['fliers'][0].set(markeredgecolor=color, markerfacecolor=color, alpha=0.5,
                        marker='x', markersize=fliersize)
    ax.set_xticks([])

def get_data(subj, main_folder):
    # subject folder
    folder = main_folder+subj+'/'
    # find all data files
    files = glob.glob(folder+"*trials.csv")
    # take files names
    file_list = [os.path.basename(x) for x in files
                 if x.endswith('trials.csv')]
    # sort files
    sfx = [x[x.find('2021'):x.find('2021')+15] for x in file_list]

    sorted_list = [x for _, x in sorted(zip(sfx, file_list))]
    print(sorted_list)
    # create data
    data = {'correct': np.empty((0,)), 'answer_response': np.empty((0,)),
           'soundPlay_object1_leftRightBalance': np.empty((0,)),
           'respondedInTime': np.empty((0,)), 'block': np.empty((0,))}
```

```

'soundPlay_responseTime': np.empty((0,)),
'soundPlay_duration': np.empty((0,)),
'answer_responseTime': np.empty((0,))}
# go over all files
for f in sorted_list:
    # read file
    df1 = pd.read_csv(main_folder+subj+'/'+f, sep=',')
    for k in data.keys():
        values = df1[k].values
        if k == 'soundPlay_object1_leftRightBalance':
            values = values-.5
            values[np.abs(values) < 0.01] = 0
        data[k] = np.concatenate((data[k], values))
return data

```

```

def plot_learning(perf, valid, ax, w_conv=200):
    m_p = np.mean(perf)
    learning_curve = np.convolve(perf, np.ones((w_conv,))/w_conv, mode='valid')
    ax.plot(learning_curve,
            'k', label='Performance ('+str(np.round(m_p, 3))+')')
    m_v = np.mean(valid)
    valid_curve = np.convolve(valid, np.ones((w_conv,))/w_conv, mode='valid')
    ax.plot(valid_curve,
            color=(.7, .7, .7), label='Valid trials ('+str(np.round(m_v, 3))+')')
    tune_panel(ax=ax, xlabel='Trials', ylabel='Performance')
    ax.axhline(y=0.5, linestyle='--', lw=0.2, color=(.5, .5, .5))
    ax.legend()
    return learning_curve, valid_curve

```

```

def plot_ws_lsw_pscho_curve(choice_12, ev, prev_perf, lbs, ws_lsw_panel):
    colors = [(0.5, 0.5, 0.5), (0, 0, 0)]
    mean_rep_prop = [] # XXX: this is actually the bias and the std is not used
    for ip, p in enumerate([0, 1]):
        # WS/LS
        popt, pcov, ev_mask, repeat_mask = \
            hf.bias_psychometric(choice=choice_12.copy(), ev=-ev.copy(),
                                mask=(prev_perf == p), maxfev=100000)
        hf.plot_pscho_curve(ev=ev_mask, choice=repeat_mask, popt=popt,
                            ax=ws_lsw_panel, color=colors[ip], label=lbs[ip],
                            plot_errbars=True)
        # STORE BIAS
        mean_rep_prop.append(popt[1])
    tune_panel(ax=ws_lsw_panel, xlabel='Rep. stim. evidence',
              ylabel='Probability of repeat')

```

```

ws_lsw_panel.axhline(y=0.5, linestyle='--', lw=0.2, color=(.5, .5, .5))
ws_lsw_panel.legend() # bbox_to_anchor=(1, 1.5))
return mean_rep_prop

```

```

def plot_rep_alt_pscho_curve(choice_12, ev, prev_perf, blocks,
                             rep_alt_panel, lbs):
    colors = [hf.rojo, hf.azul]
    all_means = []
    all_xs = []
    for i_b, blk in enumerate([1, 2]):
        for ip, p in enumerate([0, 1]):
            plt.sca(rep_alt_panel[ip])
            alpha = 1 if p == 0 else .5
            lnstyl = '-' if p == 0 else '--'
            plt_opts = {'color': colors[i_b], 'alpha': alpha, 'linestyle': lnstyl}
            # rep/alt
            popt, pcov, ev_mask, repeat_mask =\
                hf.bias_psychometric(choice=choice_12.copy(), ev=-ev.copy(),
                                    mask=hf.and_(prev_perf == p, blocks == blk),
                                    maxfev=100000)
            ev_mask = np.round(ev_mask, 2) # this is to avoid rounding differences
            means, _, xs, _, _, _ =\
                hf.plot_pscho_curve(ev=ev_mask, choice=repeat_mask,
                                   popt=popt, ax=rep_alt_panel[ip],
                                   label=lbs[ip], plot_errbars=True,
                                   **plt_opts)
            all_means.append(means)
            all_xs.append(xs)
    return all_means, all_xs

```

```

def tune_panel(ax, xlabel, ylabel, font=10):
    ax.set_xlabel(xlabel, fontsize=font)
    ax.set_ylabel(ylabel, fontsize=font)
    ax.spines['right'].set_visible(False)
    ax.spines['top'].set_visible(False)

```

```

def get_hist(values, bins):
    hist, x_hist = np.histogram(values, bins=bins)
    hist = hist/np.sum(hist)
    return hist, x_hist

```

```

def extract_vars_from_dict(data, steps=None):

```

```

steps = get_steps(steps, num_tr=len(data['correct']))
ev = data['soundPlay_object1_leftRightBalance'][steps[0]:steps[1]]

choice = data['answer_response'][steps[0]:steps[1]]
perf = data['correct'][steps[0]:steps[1]]
valid = data['respondedInTime'][steps[0]:steps[1]] == 1
reaction_time = data['soundPlay_responseTime'][steps[0]:steps[1]]-FIX_TIME
answ_rt = data['answer_responseTime'][steps[0]:steps[1]]
sound_dur = data['soundPlay_duration'][steps[0]:steps[1]]-FIX_TIME
blocks = data['block'][steps[0]:steps[1]]
return ev, choice, perf, valid, reaction_time, blocks, answ_rt, sound_dur

```

```

def get_fig(figsize):
    f, ax = plt.subplots(nrows=2, ncols=5, figsize=figsize)
    return f, ax[0][0], ax[0][1], ax[1][0], [ax[1][2], ax[1][1]], ax[0][2], \
        ax[0][3], ax[1][3], ax[0][4], ax[1][4]

```

```

def get_steps(steps, num_tr):
    if steps is None:
        steps = [0, num_tr]
    else:
        if steps < 0:
            steps = [num_tr+steps, num_tr]
        else:
            steps = [0, steps]
    return steps

```

```

def process_subject(main_folder, subj, steps=None, conv_w=2, min_num_samples=50,
    figsize=(12, 6)):

```

''''''

Process subject data.

Parameters

main_folder : TYPE

DESCRIPTION.

subj : TYPE

DESCRIPTION.

steps : TYPE, optional

DESCRIPTION. The default is None.

conv_w : TYPE, optional

DESCRIPTION. The default is 2.

figsize : TYPE, optional

DESCRIPTION. The default is (5, 5).

margin : TYPE, optional

DESCRIPTION. The default is 0.1.

top_row : TYPE, optional

DESCRIPTION. The default is 0.55.

Returns

TYPE

DESCRIPTION.

mean_rep_prop : TYPE

DESCRIPTION.

"""

pre-process data

data = get_data(subj=subj, main_folder=main_folder)

get relevant variables

ev, choice, perf, valid, _, _, _, _ = \

extract_vars_from_dict(data, steps=steps)

ev = ev[valid]

choice = choice[valid]

perf = perf[valid]

print('Percentage of invalid trials:')

print(np.sum(valid == 0)/len(valid))

print('Performance:')

print(np.sum(perf == 1)/len(perf))

f, learning_panel, psycho_panel, ws_lsw_panel, rep_alt_panel, rt_panel, \

rt_vs_perf, rt_vs_ev, mt_vs_ev, mt_vs_perf = get_fig(figsize=figsize)

LEARNING

learning_curve, valid_curve = plot_learning(perf=perf,
valid=valid, ax=learning_panel)

learning_curve = learning_curve/learning_curve[0]

valid_curve = valid_curve/valid_curve[0]

learning_panel.set_title(subj)

PSYCHO-CURVE

popt, pcov = curve_fit(hf.probit_lapse_rates, ev, choice, maxfev=10000)

hf.plot_psycho_curve(ev=ev, choice=choice, popt=popt, ax=psycho_panel,
color='k', plot_errbars=True)

tune_panel(ax=psycho_panel, xlabel='Evidence of right',
ylabel='Probability of right')

psycho_panel.axhline(y=0.5, linestyle='--', lw=0.2, color=(.5, .5, .5))

ev, choice, perf, valid, reaction_time, blocks, answ_rt, sound_dur = \

extract_vars_from_dict(data, steps=steps)

_, ax = plt.subplots(ncols=3)

ax[0].hist(sound_dur-reaction_time, 20)

tune_panel(ax=ax[0], xlabel='Sound duration - resp. time', ylabel='Counts')

```

ax[1].hist(reaction_time, 20)
tune_panel(ax=ax[1], xlabel='Resp. time', ylabel='Counts')
ax[2].hist(answ_rt, 20)
tune_panel(ax=ax[2], xlabel='Answer time', ylabel='Counts')
prev_perf = np.concatenate((np.array([0]), perf[:-1]))
choice_11 = 2*(choice-0.5)
perf_11 = 2*(perf-0.5)
gt = choice_11*perf_11
# CHECK REP. PROBS.
gt_blk1 = gt[blocks == 1] # alternating block
reps = hf.get_repetitions(gt_blk1)
print('Rep. Prob. in Alt. block: ', np.round(np.mean(reps), 3))
gt_blk2 = gt[blocks == 2] # repeating block
reps = hf.get_repetitions(gt_blk2)
print('Rep. Prob. in Rep. block: ', np.round(np.mean(reps), 3))
choice_12 = choice + 1
choice_12[~valid] = 0
lbs = ['after error', 'after correct']
# WIN-STAY/LOSE-SWITCH, REACTION TIMES AND ZERO-COHERENCE ANALYSIS
mean_rep_prop = plot_ws_lsw_pscho_curve(choice_12=choice_12, ev=ev,
                                       prev_perf=prev_perf, lbs=lbs,
                                       ws_lsw_panel=ws_lsw_panel)

# RT
median_rt = np.median(reaction_time)
motor_time = answ_rt+(sound_dur-reaction_time)
m_str = str(np.round(median_rt, 3))
rt_panel.hist(reaction_time, 40, label='Median RT: '+m_str)
rt_panel.axvline(x=0, linestyle='--', color='k', lw=0.5)
rt_panel.axvline(x=RESP_W, linestyle='--', color='k', lw=0.5)
rt_panel.set_xlim([0.3, 1.5])

tune_panel(ax=rt_panel, xlabel='RT (s)', ylabel='Counts')
rt_panel.legend() # bbox_to_anchor=(1, 1.5))
# tune_panel(ax=rt_panel, xlabel='Reaction time (s)', ylabel='Frequency')
# rt_panel.legend()

# REP/ALT
# plt.figure()
# plt.plot(choice)
# plt.plot(blocks)
all_means, all_xs =\
    plot_rep_alt_pscho_curve(choice_12=choice_12, ev=ev,
                             prev_perf=prev_perf, blocks=blocks,
                             rep_alt_panel=rep_alt_panel, lbs=lbs)
for ax, tag in zip(rep_alt_panel, ['(Aft. Err.)', '(Aft. Corr.)']):
    tune_panel(ax=ax, xlabel='Rep. stim. evidence',

```

```

        ylabel='Probability of repeat '+tag)
    ax.axhline(y=0.5, linestyle='--', lw=0.2, color=(.5, .5, .5))

if steps is not None:
    steps = get_steps(steps=steps, num_tr=len(data['correct']))
    steps = '_' .join([str(stp) for stp in steps])
else:
    steps = 'whole_exp'

ev_abs = np.round(np.abs(ev), 3)
ev_vals = np.unique(ev_abs)
rt_bins = np.linspace(0, RESP_W, NUM_BINS_RT)
mean_perf_rt = []
for ev_fix in ev_vals[1:]:
    mean_perf_rt_temp = []
    for i_rt in range(len(rt_bins)-1):
        indx = np.logical_and.reduce((reaction_time > rt_bins[i_rt],
                                     reaction_time < rt_bins[i_rt+1],
                                     ev_abs == ev_fix))
        print(np.sum(indx))
        if np.sum(indx) == 0:
            print('XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX')
            print('NON VALID')
            print('XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX')
            mean_perf_rt_temp.append(np.mean(perf[indx]))
        mean_perf_rt_temp = np.array(mean_perf_rt_temp)
        mean_perf_rt_temp = mean_perf_rt_temp/mean_perf_rt_temp[0]
        mean_perf_rt.append(mean_perf_rt_temp)
    mean_perf_rt = np.array(mean_perf_rt)
    sem_perf_rt = np.nanstd(mean_perf_rt, axis=0)/np.sqrt(3)
    mean_perf_rt = np.nanmean(mean_perf_rt, axis=0)
    rt_vs_perf.errorbar(rt_bins[:-1]+(rt_bins[1]-rt_bins[0])/2,
                       mean_perf_rt, sem_perf_rt, marker='.')
    tune_panel(ax=rt_vs_perf, xlabel='RT (s)', ylabel='Accuracy')

median_rt_coh = []
sems_rt_coh = []
for e in ev_vals:
    indx = ev_abs == e
    median_rt_coh.append(np.median(reaction_time[indx]))
    sems_rt_coh.append(np.std(reaction_time[indx])/np.sqrt(np.sum(indx)))
rt_vs_ev.errorbar(ev_vals, median_rt_coh, sems_rt_coh, marker='.')
tune_panel(ax=rt_vs_ev, xlabel='Stimulus strength', ylabel='Reaction time (s)')

```



```

median_mt_coh = []
sems_mt_coh = []
for e in ev_vals:
    indx = ev_abs == e
    median_mt_coh.append(np.median(motor_time[indx]))
    sems_mt_coh.append(np.std(motor_time[indx])/np.sqrt(np.sum(indx)))
mt_vs_ev.errorbar(ev_vals, median_mt_coh, sems_mt_coh, marker='.')
tune_panel(ax=mt_vs_ev, xlabel='Stimulus strength',
           ylabel='Motor time (s)')

mt_bins = np.linspace(MT_MIN, MT_MAX, NUM_BINS_MT)
print('Number of MT below MIN', np.sum(motor_time < MT_MIN))
print('Number of MT above MAX', np.sum(motor_time > MT_MAX))
print('Minimum MT', np.min(motor_time))
print('Max MT', np.max(motor_time))
mean_mt_perf = []
sem_mt_perf = []
for i_mt in range(len(mt_bins)-1):
    indx = np.logical_and(motor_time > mt_bins[i_mt],
                          motor_time < mt_bins[i_mt+1])
    print(np.sum(indx))
    if np.sum(indx) > min_num_samples:
        mean_mt_perf.append(np.mean(perf[indx]))
        sem_mt_perf.append(np.std(perf[indx])/np.sqrt(np.sum(indx)))
    else:
        mean_mt_perf.append(np.nan)
        sem_mt_perf.append(np.nan)

mt_vs_perf.errorbar(mt_bins[:-1]+(mt_bins[1]-mt_bins[0])/2,
                    mean_mt_perf, sem_mt_perf, marker='.')
tune_panel(ax=mt_vs_perf, xlabel='MT (s)', ylabel='Accuracy')

f.savefig(main_folder+subj+'/psycho_curve_'+steps+'.svg', dpi=400,
          bbox_inches='tight')
plt.close(f)
return np.mean(perf[valid]), mean_rep_prop, median_rt, all_means,\
       all_xs, mean_perf_rt, median_mt_coh, median_rt_coh, mean_mt_perf, ev_vals,\
       motor_time, learning_curve, valid_curve

def psycho_analysis(main_folder, subjects, steps=[None], name=""):
    """
    Go over all subjects and plot summary figs.

```

Parameters

main_folder : str

folder where the data for all subjects is.

subjects : list

list with the name of the folders corr. to each subject.

steps : list, optional

timesteps to process subject for different periods during training ([None])

Returns

None.

"""

create figure

```
f, ax = plt.subplots(nrows=2, ncols=4, figsize=(15, 9))
```

```
ax = ax.flatten()
```

```
m_rep_probs = []
```

```
m_perf = []
```

```
m_rt_VS_perf = []
```

```
m_stimStr_VS_rt = []
```

```
m_stimStr_VS_mt = []
```

```
m_reaction_times = []
```

```
m_mt_VS_perf = []
```

```
median_rep_alt = []
```

```
cohs_rep_alt = []
```

```
all_mt_mat = []
```

```
all_learn_curv = []
```

```
all_valid_curve = []
```

```
for i_s, subj in enumerate(subjects):
```

```
    print('-----')
```

```
    print(subj)
```

```
    # lbls = ["", subj]
```

```
    # go over steps to get psychometric curves for different periods
```

```
    for i_stp, stp in enumerate(steps):
```

```
        print('---')
```

```
        m_p, m_r_prop, m_rt, m_repalt, c_repalt,\
```

```
            m_perf_rt, m_mt_coh, m_rt_coh, m_perf_mt, ev_vals, all_mt,\
```

```
            l_c, v_c = process_subject(main_folder, subj, steps=stp)
```

```
        m_perf.append(m_p)
```

```
        m_rep_probs.append(m_r_prop)
```

```
        m_rt_VS_perf.append(m_perf_rt)
```

```
        m_stimStr_VS_rt.append(m_rt_coh)
```

```
        m_stimStr_VS_mt.append(m_mt_coh)
```

```

m_mt_VS_perf.append(m_perf_mt)
m_reaction_times.append(m_rt)
median_rep_alt.append(m_repalt)
cohs_rep_alt.append(c_repalt)
all_mt_mat.append(all_mt)
all_learn_curv.append(l_c)
all_valid_curve.append(v_c)
median_rep_alt = np.array(median_rep_alt)
cohs_rep_alt = np.array(cohs_rep_alt)
m_rt_VS_perf = np.array(m_rt_VS_perf)
m_stimStr_VS_rt = np.array(m_stimStr_VS_rt)
m_stimStr_VS_mt = np.array(m_stimStr_VS_mt)
m_mt_VS_perf = np.array(m_mt_VS_perf)
# learning
min_l = np.min([len(x) for x in all_learn_curv])
all_learn_curv = [x[:min_l] for x in all_learn_curv]
all_learn_curv = np.array(all_learn_curv)
# valid
min_l = np.min([len(x) for x in all_valid_curve])
all_valid_curve = [x[:min_l] for x in all_valid_curve]
all_valid_curve = np.array(all_valid_curve)
# m_stimStr_VS_rt
first_value_Str_rt = m_stimStr_VS_rt[:, 0]
m_stimStr_VS_rt = m_stimStr_VS_rt/first_value_Str_rt[:, None]
# m_stimStr_VS_mt
first_value_Str_mt = m_stimStr_VS_mt[:, 0]
m_stimStr_VS_mt = m_stimStr_VS_mt/first_value_Str_mt[:, None]
# m_rt_VS_perf
first_value_m_rt_VS_perf = m_rt_VS_perf[:, 0]
m_rt_VS_perf = m_rt_VS_perf/first_value_m_rt_VS_perf[:, None]

# MEAN PSYCHO-CURVES FOR REP/ALT, AFTER CORRECT/ERROR
counter = -1
colors = [hf.rojo, hf.azul]
ttls = ['After error', 'After correct']
for i_b, blk in enumerate([1, 2]):
    for ip, p in enumerate([0, 1]):
        counter += 1
        if i_b == 0:
            ax[3-ip].axvline(x=0., linestyle='--', lw=0.2,
                             color=(.5, .5, .5))
            ax[3-ip].axhline(y=0.5, linestyle='--', lw=0.2,
                             color=(.5, .5, .5))
            ax[3-ip].set_title(ttls[ip])
            ax[3-ip].set_yticks([0, 0.5, 1])
            tune_panel(ax=ax[3-ip], xlabel='Rep. stim. evidence',

```

```

        ylabel='Prop. repeated responses')
ax[3-ip].plot(cohs_rep_alt[:, counter, :].flatten(),
             median_rep_alt[:, counter, :].flatten(),
             color=colors[i_b], alpha=0.2, linestyle="", marker='+')
medians = np.median(median_rep_alt, axis=0)[counter]
sems = np.std(median_rep_alt, axis=0)[counter] ^
    np.sqrt(median_rep_alt.shape[0])
ax[3-ip].errorbar(cohs_rep_alt[0][0], medians, sems,
                 color=colors[i_b], marker='.') # , linestyle=""
box_plot(data=m_perf, ax=ax[0], x=0, lw=.5, fliersize=4, color='k',
         widths=0.15)
box_plot(data=m_reaction_times, ax=ax[1], x=0, lw=.5, fliersize=4, color='k',
         widths=0.15)
tune_panel(ax=ax[0], ylabel='Mean performance', xlabel="")
tune_panel(ax=ax[1], ylabel='Median reaction times', xlabel=")

rt_bins = np.linspace(0, RESP_W, NUM_BINS_RT)
# ev_abs = np.round(np.abs(ev), 3)
# ev_vals = np.unique(ev_abs)
mt_bins = np.linspace(MT_MIN, MT_MAX, NUM_BINS_MT)
ax[5].plot(rt_bins[:-1]+(rt_bins[1]-rt_bins[0])/2,
          m_rt_VS_perf.T, alpha=0.2, color='k')
ax[5].errorbar(rt_bins[:-1]+(rt_bins[1]-rt_bins[0])/2,
              np.nanmean(m_rt_VS_perf, axis=0),
              np.nanstd(m_rt_VS_perf, axis=0)/np.sqrt(m_rt_VS_perf.shape[0]),
              marker='.', color='k')
ax[6].plot(ev_vals, m_stimStr_VS_rt.T, alpha=0.2, color='k')
ax[6].errorbar(ev_vals, np.mean(m_stimStr_VS_rt, axis=0),
              np.std(m_stimStr_VS_rt, axis=0)/np.sqrt(m_rt_VS_perf.shape[0]),
              marker='.', color='k')
ax[7].plot(ev_vals, m_stimStr_VS_mt.T, alpha=0.2, color='k')
ax[7].errorbar(ev_vals, np.mean(m_stimStr_VS_mt, axis=0),
              np.std(m_stimStr_VS_mt, axis=0)/np.sqrt(m_rt_VS_perf.shape[0]),
              marker='.', color='k')
mt_num_bins = 20
mt_bins = np.linspace(0, 1.5, mt_num_bins) # vals inferred by looking at histos
for atm in all_mt_mat:
    atm_hist, atm_bins = np.histogram(atm, mt_bins)
    atm_hist = atm_hist/np.sum(atm_hist)
    ax[4].plot(atm_bins[:-1]+(atm_bins[1]-atm_bins[0])/2, atm_hist, color='k')

tune_panel(ax=ax[4], xlabel='MT', ylabel='Proportion')
tune_panel(ax=ax[5], ylabel='Accuracy', xlabel='Reaction time')
tune_panel(ax=ax[6], ylabel='RT', xlabel='Stimulus strength')
tune_panel(ax=ax[7], ylabel='MT', xlabel='Stimulus strength')
f.savefig(main_folder+'rep_props_'+name+'.svg', dpi=400, bbox_inches='tight')

```

```

f.savefig(main_folder+'rep_props_'+name+'.png', dpi=400, bbox_inches='tight')
f, ax = plt.subplots(nrows=1, ncols=1, figsize=(4, 2))
ax.plot(all_learn_curv.T, color='k', alpha=0.2)
ax.plot(np.median(all_learn_curv, axis=0), color='k')
tune_panel(ax=ax, ylabel='Accuracy', xlabel='Trials')
f, ax = plt.subplots(nrows=1, ncols=1, figsize=(4, 2))
ax.plot(all_valid_curve.T, color='k', alpha=0.2)
ax.plot(np.median(all_valid_curve, axis=0), color='k')
tune_panel(ax=ax, ylabel='Proportion of valid trials', xlabel='Trials')

```

```
# --- MAIN
```

```

if __name__ == '__main__':
    plt.close('all')
    # import sys
    folder = \
"C:\Users\Debora\OneDrive - Politecnico di Milano\uni\TFG\80_20\"

    subjects = [['alice', 'sophia', 'alessia_03', 'carlo', 'valeria', 'richard',
                'luca', 'ilaria', 'eugenia', 'lorenzo2'],
                ['patryk', 'taia', 'lavinia', 'lorenzo', 'laurin', 'francesco', 'alessia_05', 'maria', 'vita']] # 'laurin',
    names = ['resp_w_300ms_test', 'resp_w_500ms_test']
    resp_duration = [0.3, 0.5]

    for subj, nm, rd in zip(subjects, names, resp_duration):
        RESP_W = rd
        if len(subj) == 0:
            subj = glob.glob(folder + '*')
            subj = [os.path.basename(sbj) for sbj in subj
                    if not sbj.endswith('prev_versions') and
                    not sbj.endswith('.png') and not sbj.endswith('all_figs')]
            steps = [None] # [800, -800] # [800, -800]
            psycho_analysis(main_folder=folder, subjects=subj, steps=steps, name=nm)

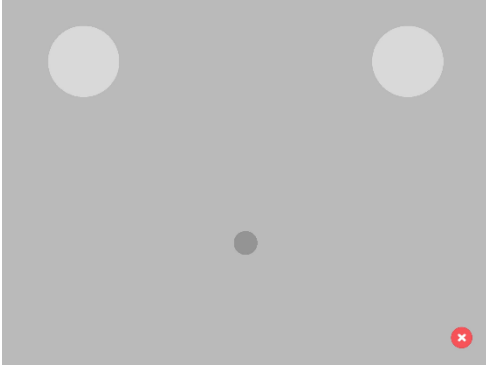
```

ANNEX 2

Instructions showed to the subjects. Giving everyone the same information is fundamental not to get false results.

Instructions

STEPS:



1. Answer to some **personal questions** (name, sex, age, hand, auditory problems).
2. Put on the **headphones** provided by the experimenter.
3. **Task.** The task is divided into trials. In each trial you have to:
 - **Place and hold** your finger on the small dark grey circle.
 - **Sound** will be played with different intensities from the left and from the right side.
 - **Drag the dark grey circle** to the light circle associated with the most intense sound.
 - Always finish the trials (even if sound is not played).



You will receive feedback about your answer:
If the response is correct the screen will turn **green**.
If you do not respond in time or respond too early it will turn **yellow**.
If the response is incorrect the screen will turn **red**.



Please always respond with the same hand and use your **index finger**.



Please be **focused**, avoid responding randomly.



You will have a break every 100 trials to rest and recover.

ANNEX 3

Consent form in which the experiment was presented and all the bureaucratic details have been explained.

Information sheet for volunteer subjects

for the Informed Consent of their participation in the Study of Psychophysics

1. Study title: Investigating sequential effects in humans performing a 2AFC task presenting trial-to-trial correlations.

2. Promotors: Dr. Jaime de la Rocha Vázquez, Principal Investigator at Brain Circuits and Behavior Laboratory. Institut d'Investigacions Biomèdiques August Pi i Sunyer (IDIBAPS, Barcelona) is the coordinator of this study financed by the European Research Council (ERC).

3. Introduction: we would like to invite you to take part in a psychophysical experiment consisting of an auditory task run on an iPad. This research is conducted by Dr. Manuel Molano, investigator at IDIBAPS, Debora Lombardo, Biomedical Engineering student and it is directed by Dr. Jaime de la Rocha, principal investigator at IDIBAPS. Before you decide to participate it is necessary that you understand the reason why this research is carried out and how it affects the participants. Please, take your time to read the information included in this document. Do not hesitate to ask any questions if you do not understand something or if you need more information. If you decide to participate in this study we will give you a copy of this document and of the consent for you to keep it.

4. Study goals: the main goal of this research is testing how humans react when exposed to a perceptual stimulus (auditory stimulus) investigating the extent to which perceptual decisions are influenced by expectations built from recent experiences. This research will help to understand the mechanisms behind perceptual decision making. The data collected in this study will be used solely for scientific and non-profit purposes.

5. Descripción: we expect 10-20 people to take part in this experiment. The duration of this study is 2000 trials; it will take roughly two hour to complete them. The subjects can participate according to their time and date availability: it will be possible to complete the task in one session or more. In every trial the participants have to listen to a sound through headphones provided by the experimenter and respond to a question about them.

6. Purpose of the data collected in the study: the data collected in this study will only have the purpose of advancing research in neuroscience and in no case they will be used for commercial purposes. The results of this study will be disseminated to the scientific community but in no case this entails the revealing of the identity of the people who have participated in this study, since all data will be published in a pseudonymised manner [1]. Since there is no scientific reason to preserve the identity of the participants, all the data will be anonymized at the end of the study or in five years at the maximum, definitively preventing the identification of any of the participating people. In this anonymous way, the data will be saved for later analysis by our group or another collaborating research group, for a period of 10 more years.

7. Risks and discomforts

There is no risk from participating in the study. Participants will be sitting in a chair and they will perform a task run on an iPad wearing headphones. They will only have to listen to a sound and detect it.

8. Protection of confidentiality

The treatment, communication and transfer of personal data of all participants will comply with the provisions of Organic Law 15/1999, of December 13, on the protection of personal data and the Royal Decree that develops it (RD 1720/2007).

Although the results obtained from the research carried out are published in scientific fields, their identity will never be disclosed. Personal data will become part of the Investigations and Clinical Trials File, which is responsible for the Consortium of the Institut de Investigacions Biomèdiques August Pi i Sunyer and will be processed solely and exclusively within the framework of your participation in this study. This file is registered with the Catalan Authority for the Protection of Dades (APDCAT; June 6, 2012). All the data of this study will be stored in electronic format and never in hard copies. The data collected will be pseudonymised, so that during its treatment, analysis or publication in the scientific field, only those responsible for this study can identify the people who have participated in this study. The pseudonymised data may be transmitted to third parties and to other countries but in no case will they contain information that can identify you, such as name and surname, initials, address, etc. In the event that this assignment occurs, it will be for the same purposes of the study described or for use in scientific publications. The promoter undertakes to establish the necessary measures to guarantee the same level of confidentiality as in Spain. You have the right of access, rectification, cancellation and opposition to said data by contacting the person in charge of the study indicated in this document in accordance with the LOPD.

9. Voluntary participation and right of participants to withdraw.

Participation in this research study is voluntary. You can refuse to participate and withdraw from the study at any time. There is no type of penalty for doing so. Participation in the study will be rewarded with a remuneration of €10 per hour.

10. Información de contacto.

If you have any question or comment about this study you can contact:

Dr. Jaime de la Rocha Vázquez

Email: jrochav@clinic.cat; Telf. 932275400 (4307).

Dirección postal: IDIBAPS, c. Rosselló 149-153, Barcelona 08036

We recommend you to keep a copy of this document to consult it in the future.

^[1] Pseudonymization is the procedure by which the data collected is dissociated from the identity of the person who has transferred the data so that any information derived from it cannot be associated with an identified or identifiable person.

^[2] Anonymized or irreversibly dissociated data refers to those data that cannot be associated with an identified or identifiable person because the link with all information that identifies the subject has been destroyed, or because said association requires an unreasonable effort, understood as the use of a disproportionate amount of time, expense and work.

Informed consent form

1. Study title: Investigating sequential effects in humans performing a 2AFC task presenting trial-to-trial correlations.

2. Promotors: Dr. Jaime de la Rocha Vázquez, Principal Investigator at Brain Circuits and Behavior Laboratory. Institut d'Investigacions Biomèdiques August Pi i Sunyer (IDIBAPS, Barcelona) is the coordinator of this study financed by the European Research Council (ERC).

(participant's name and surname)

With my signature at the end, I declare that:

- I talked to ___Debora Lombardo___ (name of researcher), who has explained the Information Sheet point by point.
- I have read the Information Sheet.
- I have had the opportunity to ask questions about the study and they have been answered.
- I understand that my participation in this study is voluntary and that I can withdraw from the study at any time, without the obligation to give explanations and without any prejudice.
- I authorize the use and transmission of the data as described in the Information Sheet.
- For all of which, I agree to participate in the study

Date and participant's signature
signature

Date and experimenter's