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Analysis of Knowledge Acquisition and Emotional Behaviour related to Autism in a 3D Virtual Reality Immersion

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ANALYSIS OF KNOWLEDGE ACQUISITION AND EMOTIONAL BEHAVIOUR RELATED TO AUTISM IN A 3D VIRTUAL REALITY IMMERSION

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Abstract

Introduction: ASD is a neurological and developmental disorder caused by differences in the brain from typical development individuals. These individuals have difficulties processing auditory and visual information. The age of the individual and his/her IQ level affect his/her ability to process this information. In addition, they show a reduced ability to acquire knowledge. An immersive virtual reality exposure was applied at the same time heart rate, EDA, and eye tracking measures were obtained to hit the mark if a typical development individual is capable to control his/her emotions and to acquire a specific knowledge in a realistic environment.

Methods: BITalino software is applied to obtain physiological measures of heart rate and EDA. HTC-Vive virtual reality glasses with an eye tracker incorporated were used to determine pupil dilation and gaze direction. A multiple-tests of the lesson taught during the virtual reality exposure was requested to obtained information about the acquired knowledge.

Results: Higher arousal in the activity of heart rate and EDA happened in conditioned participants with distractors in the virtual reality exposure, whereas control participants have a lower heart rate and EDA. Additionally, control participants have more correct responses on the posterior multiple tests than conditioned participants.

Conclusions: Auditory and visual distractors increase the arousal of heart rate and EDA, related to a change in participant emotion. The knowledge acquisition of conditioned participants was lower than from control ones. These facts lead to a harder acquisition of information and higher emotions from ASD individuals than from typical development.

Keywords

ASD individuals, typical development individuals, Heart rate, EDA, eye tracker, acquiring knowledge, virtual reality exposure and distractors.

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Chapter 1
Introduction

1.1 Autism Spectrum Disorder

Autism spectrum disorder (ASD) is a neurological and developmental disorder caused by differences from typical development individuals in the brain. It is defined as a Spectrum disorder due to a huge variety of the range symptoms that people with ASD can have [12]. Signs revealing an ASD appear during early childhood and last throughout a person's life, they affect a person's ability to communicate, behave and interact with others, also difficult to learn [11].

Brain differences are located in the temporal lobe, which function is involved in processing sensory input into derived meanings for the appropriate retention of visual memory, language comprehension and emotion association [2].

Lower-functioning autism individuals were impaired on a visual recognition task tapping medial temporal lobe function. Autism has specific impairments in the processing of the body movement, interpretation, use of gestures and formation of a Theory of Mind (ToM) [1]. ToM is the ability of an individual to succeed in social encounters, having skills to reason about the thoughts, beliefs, and feelings of others to predict behavioural responses [13] [14].

In spite of the fact, some people with ASD disorders do not need help in their daily lives because they are able to communicate, interact, behave and learn in same ways that people without ASD do. On the other hand, most ASD individuals have different ways to communicate, interact, behave and learn from typical development individuals [11].

In fact, the learning, thinking, and problem-solving abilities of ASD people can make a range of these people from capable to critically challenged. Basically,

the American Psychiatric Association describes three levels of severity using Diagnostic and Statistical Manual of Mental Disorder (DSM-V).

Level 1: *Requiring support*, difficulty changing between actions, social interactions and some troubles organizing plans and being independent. Level 2: *Requiring substantial support*, harder difficulty on switching between action or focusing attention, important deficits in verbal and nonverbal social and communication skills, and abnormal responses to social interactions. Level 3: *Requiring very substantial support*, severe deficits in verbal and nonverbal social and communication skills, extreme difficulty on switching between actions or focusing attention, and very limited responses to social interactions [11].

Smith and Williams (2005) found that 4–12-year-olds judged students exhibiting inattention and overactivity (Attention Deficit Hyperactivity Disorder [ADHD] vignette) or avoiding eye contact (Lacking social skills vignette) as doing so unintentionally. These difficulties are related to some characteristics of autism people about sensory overload, an over-stimulation of one or more body sensors giving the brain a huge amount of information that cannot be processed [15].

People with autism had abnormal auditory, visual, touch, and oral sensory processing that was significantly different from controls [32]. These, sensory abnormalities are generalized, multimodal and persistent across age and ability for adults with autism. The age and IQ levels affect some sensory symptoms, however [33] [34]. The results extracted from people with autism in relation with their memory abilities were characterized by relatively poor memory for complex visual and verbal information and spatial working memory with relatively intact associative learning ability, verbal working memory, and recognition memory [35].

Those studies generalize that visual and auditory distractors affect the sensory and recognition memory of ASD individuals. Leading to the higher effect of these distractors in ASD individual's emotions and the ability to

acquire knowledge. However, an increase in the quotidian distractors in typical development individuals can cause the same effect.

Some of the aspects that could affect autism people are:

- Visual angle and intensity
- Intensity or pitch of the sound
- Variety of touch sensitivity
- Variety of flavours

It is not known yet with exactitude what are the causes of these differences for most people with ASD, but knowing where it comes from an accurate cause is formed. However, several people with ASD have a known and common difference, such a genetic condition, which can underlie a neurological and developmental disorder on the subject. There are multiple and a lot of causes for ASD, whereas the majority of them are not yet discovered.

1.1.1 Diagnostic

Nowadays, the diagnosis of an ASD includes several conditions that need to be diagnosed separately in order to reach a complete and reliable diagnostic. Diagnosing autism spectrum disorder can be extremely difficult since there is no medical test to diagnose the disorders.

There are two steps during the diagnosis; the first one is a developmental screening of the subject, the second a comprehensive diagnostic evaluation for the doctor to have a complete diagnosis of the disorder. Developmental screening is known as a short test to identify if children have basic learning skills, consisting of an exam to see how children learn, speak, behave and move [18]. A delay in any of these areas could be a sign of a problem, and an evidence of an Autism spectrum disorder.

The second step of the diagnosis is known as a comprehensive evaluation. In fact; this part is more complex and complete cause it includes a hearing and

vision screening, genetic testing, neurological testing and other medical testing evaluations while looking at the child's behaviour and development and interviewing the parents.

Specialists derived from the primary care doctor diagnose most of the cases. These specialists can be developmental Pediatricians, child Neurologist or child Psychologists/ Psychiatrists. They are who can determine in a more reliable way the symptoms and skills learning delays of children, giving a complete diagnostic for autism spectrum disorder.

Furthermore, diagnosis by an experienced professional can be considered reliable. However, most of the children do not obtain a final diagnosis until they are much older. This is due to the fact that no available test is applicable and behaviour development in childhood is too complex to reach a diagnosis of this type.

For instance, an example, head banging could be a symptom of the ASD, or it may be related to a sign that the child is having headaches, that is why paying attention to the physical and mental health of children in regular medical and dental exams are an important part of the diagnosis.

Some of the symptoms that need to be diagnosed are:

- Difficulties making eye contact.
- Problems in learning languages.
- Difficulty in holding a conversation.
- Problems with executive functioning.
- No interest in peer relationships.
- Persistent fixation on parts of objects.

1.1.2 Treatment

There are no medications that can cure autism spectrum disorder or treat the core symptoms. Nevertheless, there are medications that can provide some help to people with ASD by contributing to enhancing their functional abilities, as an example, there are some medications that can help to manage high energy levels, inability to focus on problems, movements or specific situations, depression or seizures [6].

It is important to know that medications can affect children in some different ways depending on his personalities. For that reason, it is determining to work with a health-care professional who has a big knowledge and experience in treating children with ASD. Parents and health-care professionals must be closely monitoring the child's progression and reactions while the patient is taking medication to be sure that any negative side effect of the treatment do not outweigh the benefits that the medication provide for the child [6].

Giving an early intervention treatment can hugely improve a child's development, as this intervention could help children to learn important skills. These services, which are considered as a therapy to ASD, include the ability to help the child talk, walk, and interact with others with less difficulty they have before [16].

Furthermore, if ASD individuals are presenting specific difficulties or problems with the most important abilities like as language delays, a treatment for particular symptoms, in this case, a speech therapy with a specialist, does not need to wait until a final formal and complete ASD diagnostic is performed [5] [6].

Another way to help autism spectrum disorder children that is not with medication is with behaviour and communication approaches, which are approved by the American Academy of Pediatrics and the National Research

Council. Those approaches are able to provide children structure, direction, and organization, with also family participation [16].

An important approach for people with autism spectrum disorder is Applied Behaviour Analysis (ABA), consisting on encouraging positive behaviours and discouraging negative behaviours in order to have an improvement in a variety of the child skills. The progression of the child is tracked and measured [6].

In addition, there are other therapies. Occupational therapy allows children to improve skills that help people live as independently as possible, it may include dressing, eating, bathing and having relations with others, giving the children ways to reach solution alone in the near future.

Sensory integration therapy, which allows children to improve skills in order to deal with sensory information, such as, perturbation sounds, light intensity, weird smells. Speech therapy mentioned before in order to improve verbal communication skills [17].

1. 2 Virtual Reality Model

An advanced human-computer interface, which performs a simulation including a realistic environment and allowing participants to interact between it, is virtual reality. Along the years' experimental psychology and physiology provide the foundation for applying in computer software's, systems concepts related to humans and its proximity, allowing a formation of a realistic environment [3].

Virtual reality involves some crucial aspects, the creation and experience of environments, focused on its central objective, which is to provide the participant with a location in an environment. This objective is highly satisfied by implementing a good relationship between the virtual reality created environment and the participant.

An interaction between participant and virtual reality environment is based on devices from the virtual reality hardware that in our case is done directly. From the 3D virtual reality environment to the participant of the study. These devices can include, for example, a head-mounted display, through which the system can provide to the participant a 3D immersive environment.

A human centre view characterizes the participant in the centre of the environment. The perceptual system of the human body, meaning visual and heard stimulus acts as inputs to the human brain giving them the feeling desired. Then muscle activity acts as an output. As an example eye movement or heartbeat gave from the individual the response to the stimulus presented.

The ability to quantify the relationship between the stimuli of the effectors and the responses give it by the sensors with each individual experience of participation have a limited range. This quantification provides a better design for the virtual reality model system.

Each participant will consciously or unconsciously evaluate and evoke the participation with different criteria, so this will provide different factors to each participant that needs to be adequate personally.

Virtual reality uses sensors and effectors to create, proportionate and receive data from and to the participant in order to improve the experience. Three types of effectors are used.

A shell, a stationary enclosure designed which have an environmental and participatory objective. A fixture, which is a device used with the aim to create sensory stimulations to the participant in order to provide an experience. An appliance, which is a component that stimulates senses.

Sensors and effectors are working together to allow interaction with the environment created. Tracking devices interface to detect participant reactions that occurs during the experience will provide data to understand the relationship between the participant and the virtual reality environment and also to improve the current simulation o alter it in order to obtain what we will be looking for.

A design of an Immersive virtual reality system where the user is completely immersed in a computer-generated world will give them the impression that they are inside a specific virtual environment. This offers in a controlled and safe way a three-dimensional representation of real environments in order to obtain the desired results. This virtual reality environment enables the participant to practice and expand a specific social situation, in a different way, visual and continuous [28].

In addition, this virtual reality mode, where the immersive system is provided will be divided into different parts [7]. The first one is the interface, where the created environment model will be displayed and the participant will be immersed. Next, is the virtual reality generation module, where the creator designs all environments that will take place during the virtual reality exposure. The last one is the data capture module, which provides information about the child's data desired by the performer.

In order to have an interaction between the participant and the virtual reality model, the collection of data from the participant is crucial. One of the most sensitive markers of emotional arousal is heart rate, which will allow us to know the significant stress of the participant. Another emotional marker is an electrodermal activity (EDA).

Having data from this to sensory markers an estimation of the emotional state of the participant can be determined. But, also the attention they have during the experiment needs to be quantified, for this reason, eye tracking system will be activated in order to know in which moments the participant is distracted from the virtual reality environment.

1. 3 Heart Rate

Knowledge about everybody heart rate can help us to monitor and control normal levels, allowing us to detect possible health problems. Heart rate or pulse is known as the number of times that the heart beats per minute. Each heartbeat differently, so each person and heart rate will vary. A normal heart rate is normally between 60-100 beats per minute in a resting state, after sport or emotional conditions these should increase [20].

The best places to control your heart are, wrists, inside of the elbow, the side of the neck and the top of the foot, places where big arteries are, like carotid artery, or places where the arteries are near like the wrists [21].

There are some factors that can affect the heart rate, such as air temperature, body position, body size, use of medicaments and emotions. Having an interest in emotions, being stressed, anxious, or extremely happy or sad, the emotions can increase the pulse. The interest in this affecting factor forces the others to be controlled, in order that all the others factors need to be equal for all the participants [8].

Heart rate is basically based on the cyclic contraction of the ventricles prompts by the electrical activity of the heart. This cycle activity is characterized by a time-varying pattern of frequencies, giving the measures of different waves. P, QRS, and T are the waves formed by the electrical activity of the heart, producing heart rate.

First of all, starting by the contraction of the atria, which corresponds to the wave P. Then the complex QRS related to the contraction of the ventricles, having its maximum accurate detection on wave R. At the end the wave T, which corresponds to the depolarization of the ventricles [27].

1. 4 Electrodermal Activity

As mentioned before the electrodermal activity is one of the most sensitive markers of emotions and modulates the amount of sweat secretion from sweat glands. Like heart rate, EDA quantifies all sweat glands that can secrete vary across each human body. Being hands and feet the regions where the highest secretions in the body occur, they have between 200-600 sweat glands in each cm^2 [23].

Skin conductance is under unconscious control of the brain, being modulated autonomously by the sympathetic activity of the brain, which approaches the human behaviour, cognitive and emotional states in a subconscious way. Sweating is under the control of the sympathetic nervous system if the arousal of that way increases provokes a higher production of sweat, which means an increase in skin conductance [22]. Knowing that fact, a measured from skin conductance can determine and emotional state of the participant.
Skin conductance response data can be decomposed into two components, tonic and phasic skin conductance responses (SCR), both of them overlie the other, producing additive data. Tonic base level fluctuates slowly, is a quasi-steady state component and is only visible in absence of phasic base level, which has a faster-varying component. The real-time component that can be analysed is the phasic component; tonic component could be maintained during the whole experiment [19].

Despite the fact that sweat secretion has a major role in thermoregulation and sensory discrimination, the skin conductance derived by the sweat produced is also a triggered by emotional states. As in heart rate, being stressed, anxious or extremely happy or sad, result in an increase in arousal activity of skin conductance, so the higher the arousal is, the higher the skin conductance is, that is related the higher the emotion is [9].

1. 5 Eye Tracking

The analysis of human visual information and detection of eye movements for interactive and diagnostic applications is the reason why eye tracking technologies field are growing in order to be used to this phenomenon. There are different domains in scientific research that can benefit from eye tracking methods and techniques to without problems investigate quantitative evidence on visual processes; for example neuroscience, experimental psychology, computer science and human factors.

The attention provided to the experiments by the participants is important, knowing that ASD participants will pay attention in different ways for different situations. For this reason, eye tracking is crucial in the experiment, measuring the attention the participant is giving to the environment and its stimulus.

Eye tracking measures the activity of eye, where the eye looks in every moment, what the participant ignore and to what pays attention, when the participant blinks and when the pupil reacts to different stimuli. Pupil size depends on the activity of two muscles. The parasympathetic nervous system controls a muscle in the iris which contraction provides a constriction pupillary response (miosis), whereas the sympathetic nervous system controls a muscle radial muscle which contraction provides a dilation pupillary response (mydriasis) [24].

Contraction and dilation of the pupil are controlled by the autonomic nervous system, which regulates unconscious actions. However, the pupillary response can be derived from emotions with high arousal in brain activity [25].

Collecting data from the participant with an eye tracker connected to a computer needs generally and basically two components. A light source that is directly pointed toward the eye and a camera that tracks the reflection of

the light with visible ocular features like the pupil, which performs the data tracked.

The rotation of the eyes, the direction of gaze and the dilation of the pupil are data extracted from the extrapolation of the data tracked during the experiment. In order to obtain results from data collection, a simple analysis is to translate each eye data into a pixel coordinate that relates to the interface environment [10].

1. 6 Objectives

Eventually, study how humans react to different signals related to sensory emotions of the temporal lobe starts by recording data from typical development people from the brain, physiological signals, and behavioural data analysis. Ideally, performing a virtual reality scenario, in a common specific situation, in which people can have an immersive experience such as they are autism.

Individuals who receive a diagnosis of autism spectrum disorder have significant impairments in social communication and interaction, which may include differences in behaviour and relation with others. The principal aim of this study was to determine the emotional behaviour that auditory and visual sensitivity can cause in a quotidian situation to an ASD individual. For this reason, auditory and visual distractors were studied and applied to typical development individuals simulating an ASD sensory overload situation.

An immersive scenario takes place; participants were involved in a virtual reality exposure, giving them the sensation of reality, while at the same time we were extracting physiological data for posterior evaluation about the immersion suffered.

Afterward, perform the same situation, but some changes in the stimulus presented in order to give them the same experience that ASD individuals

have felt. In fact, could changes in light and pitch intensity, being disconcerted affect physiological parameters of individuals, having these physiological parameters changed as ASD individuals had?

An increase in heart rate and electrodermal activity are expected. While the fixation on some stimulus will be increased, on others will be decreased [19] [20] [21].

Another questionable part will be if the activation of distractors could change the ability to acquire knowledge. A multiple-tests will be provided after the virtual exposure to verify the acquired knowledge about the lesson done during the virtual reality exposure.

Participants without distractors on the virtual reality exposure are expected to have more acquired knowledge than participants with distractors. On the other hand, inside participants with distractors, there is an expectation that will be more acquired knowledge when the distractors are not present than when they are present in the virtual reality exposure.

Chapter 2
Methods

2. 1 Participants

20 healthy adults (10 male, 10 female) between 18 and 25 years old have participated in the study. They were told that during the experiment, a head-mounted device and five electrodes were placed. After these instructions, the participants can decide to continue or not with the experiment.

All participants had normal or corrected-to-normal vision. They were evaluated at the Institute for Bioengineering of Catalonia, Universitat Politècnica de Catalunya.

Two groups of participants did the experiment. One group did the virtual reality exposure without conditioned stimuli, whereas the other group did the virtual reality exposure with conditioned stimuli, obtaining those physiological measures changed by this external factor. This between-subject design was applied to avoid the possibility of retaining facts from one experience to another.

2. 2 Experimental Task

The participants were seated on a chair in front of the table. A head-mounted device was adjusted to the eyes and the head of the participant to allow the possibility of having a virtual reality exposure. The eye tracker, heart rate, and EDA sensors were collocated. After the application of physiological sensors, participants were asked to reach a relaxed seat, avoiding abrupt movements. First of all, a resting period of five minutes to obtain steady-state measures of physiological data (heart rate and EDA) was needed.

During the experiment, the participants were alone and the experimenter was recording physiological data. The experience duration was about five minutes. Three types of physiological data were recorded during the administration of the virtual reality experience: heart rate, EDA, and eye tracking.

External factors as air temperature, body position, body size, use of medicaments and daily emotions were controlled by the experimenter so that the recorded data was not affected by them.

Air temperature and body position were forced to be the same for all the participants along with all the experience. The use of medicines was asked to the participants for not being altering the experience. Body size is preselected for participants in order to avoid interferences on affect data. Participants were asked about stress, pressure or happiness situations during the previous week; these participants are invalidated for the study, the fact that avoids extreme emotions.

2. 3 Virtual Reality Exposure

The participant had been setting like in a classroom, seated in the second row of pupils. Having in front of him/her the first row of students, the teacher, blackboard, blackboard lights and a clock on top of the blackboard. During the 5 minutes that the experiments took place, the teacher says good morning to the students and starts the class. A history lesson about the discovery of America takes place during the virtual reality exposure.

During the lesson the teacher provides the students with basic information about America discovery, giving them detailed information about this historical event. Finally, the teacher said goodbye to their pupils and 15 seconds later the experience finishes.

2. 4 Conditioned Exposure

The conditioned exposure started to like the normal one. The same situation was presented, participants have been set like in a classroom, in the second row of pupils. The participant had seen the same factors in the conditioned experience that in the normal experience. Students, teacher, blackboard, and lights were presented in front of the classroom. The class started in the same way, the teacher says good morning to the students and starts the class about America discovery.

There were auditory and visual distractors during the virtual reality exposure. Placed at the same time a question had been asked after or neutral position. These distractors were quotidian sounds, like chewing gum, a horn and clock sound for auditory sensitivity and too much light, colors, patterns and spinning objects for visual sensitivity. See Appendix A for timeline connection.

Finally, the teacher said off to their pupils, then 15 seconds later the experience expires.

2. 5 Equipment and Data Acquisition

Sensors are devices able to detect physical and chemical energies and convert it into the electrical form of energy. This electrical measurement gave information regarding the physical or chemical ones [29]. Different physiological sensors were utilized. Heart rate and EDA needs biological sensors able to convert these signals into measured data.

2. 5 .1 The Head-Mounted Device

The head-mounted device, in this case, was the HTC Vive VR Integration (see Figure 1). It has two base stations that set up the head on the centre of the virtual reality exposure. Headphones giving the participant an immersive auditory perception. It needs to be calibrated at 75cm from the floor.

Figure 1. HTC Vive for virtual reality exposure device.
Image obtained from Tobii's website.

2. 5. 2 Heart Rate Sensors

The heart rate data was recorded by placing the BITalino biomedical equipment (see Figure 2), a three-electrode sensor based on the Einthoven technique.

Figure 2. BITalino Kit for heart rate measures.
Battery, MCU, Bluetooth 4.0, sensors, and electrodes. Figure obtained from BITalino website.

The electrical activity of the heart acts as a dipole, which may be placed at the centre of the measure. One electrode is placed on the right palm, the second on left palm and the last one under the right elbow, near a bone surface. The

waveform displayed is an amplified and filtered measurement by the tissue over time [26] [31].

The physiological data is the result of an interaction between the cardiovascular, respiratory, and autonomic systems. The BITalino software extracts a bipolar differential measurement and saves the heart rate measurements in a file.

The software uses a transfer function (See Formula 1) to interpolate the data obtained from the evaluated data. There are 3.3 volts operating voltage and an 1100 sensor gain.

$$ECG(V) = \frac{\left(\frac{ADC}{2^n} - \frac{1}{2}\right).VCC}{G_{ECG}}$$

Formula 1. The transfer function for heart rate.

2.5.3 EDA Sensors

An e-Health Sensor Shield V2.0 for Arduino, Raspberry, and Intel Galileo is used to measure electrodermal activity. This device gathers information to after it uses USB connection to save it in a computer file (see Figure 3).

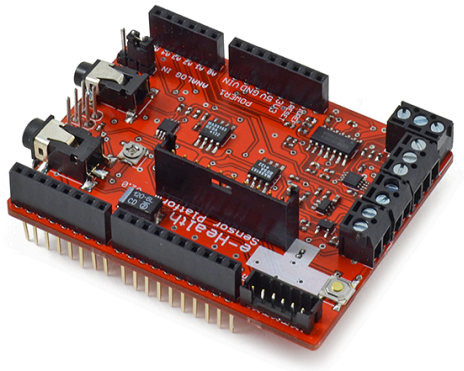


Figure 3. e-Health Sensor Shield V2.0 for Arduino, Raspberry, and Intel Galileo. Figure obtained from cooking-hacks website.

Using a two placing electrodes in two following fingers of one hand extracts the EDA data from the participant (2nd and 3rd); this place known as one of the most with higher electrodermal conductivity part is resulting from the sympathetic nervous system activity, allowing the sensor to collect electrodermal activity data.

This sensor extracts skin conductance measurements by setting two electrodes on the skin, near each other and passing a little charge between this two points. The electrical activity produced by the sweat on the fingers facilitate better the conduction of the charge between the two electrodes, providing higher measurements of skin conductance response.

At the same time that participant arousal increases, meaning that sweat production also increases, the skin of the participant becomes a better conductor of electricity. This response was measured and extracted.

The software uses a transfer function (See Formula 2) to interpolate the data obtained from the evaluated data. There are 3.3 volts operating voltage and a 1E6 sensor gain.

$$EDA(\mu S) = \frac{\frac{ADC}{2^n}.VCC}{0.132}$$

Formula 2. The transfer function for EDA.

2.5.4 EMG Disposable electrodes

The connection between the skins of the participant and the sensor device is produced by EMG disposable electrodes, which are adhesive and pre-gelled. The snap-on connector of the sensor can easily be pushed on or removed from the electrode lead.

The eye movement and position and the dilation or contraction of the pupil, which allows knowing the attention and emotions of the participants, is based in a near-infrared technology using a high-resolution camera to track the gaze direction. The concept behind the process is simple, the camera tracks the pupil centre and where light reflects from the cornea.

The eye tracker device, provided by Pupils Lab, is integrated into the HTC Vive, the virtual reality glass. This equipment has a tracking frequency of 120Hz, gaze accuracy of 1.0 degrees and a gaze precision of 0.08 degrees. The result from the equipment is an image resolution of 640x480 with a USB 2.0 connection, providing the pupil position and diameter. The calibration needs a 5 points detection, recognizing the pupil and its diameter in 5 points, the four corners, and the centre. And the connectivity for data extraction is based through a network message based on API.

Additionally, when the participant paid attention to some point on the experience the eye tracker, extracted that information data and allows us to determine where the participant was looking at and also relates that attention to some emotion to the stimulus presented at the moment.

All these sensors were connected to a computer, obtaining data and saving it. Matlab software programming is utilized to analyse data from all physiological measurements, since it is able to filter data from heart rate and EDA and also to recognize when the participant is reaching an arousal on emotion, by detecting peaks in physiological measurements.

2. 6 Signal Processing

Signal processing allows us to detect components of interest of our physiological measurements. As mentioned before, heartbeat cycle is basically based on the QRS complex waves, which are the most emphasized. Specifically the R wave or peak, the highest peak on the measurements.

Having a complex signal, such as heart cycle, can cause problems to detect the waves. Fortunately, Matlab tool for programming has helping functions. First of all, if we have complex data with artefacts and undesired frequencies, Wavelet decomposition will filter our signal and will let us have a clearer signal for peak detection.

Before Wavelet decomposition is applied, it is needed to define the sampling frequency (Fs) and the scales on the Wavelet, defined as 2 powered the chose index multiplied by time sampling (Ts), which is 1 over Fs.
The wavelet function, in our case, takes the form of the first derivative of Gaussian, composed by the Gaussian function and its derivative (Formulas 3 and 4).

$$h(t) = e^{-0.5t^2}$$

Formula 3. Gaussian function

$$h(t) = \delta^{(1)}(t)$$

Formula 4. Derivative function

The Gaussian is a low-pass filter giving us as a smooth signal, while the derivative is a high-pass filter and can extract from it the maxima and minima of the signal, collecting the zeros of the derivative we can extract the peaks of the original signal.

The commutative property allows us to apply first the Gaussian and after the derivate or vice versa because it is a multiplication of two systems, which result are two equivalent systems. Since they are connected in a cascade way the global result is a convolution of the two systems applied individually.

Convolving the derivative of the Gaussian with the original signal is not the only part needed to detect the peaks; there is a function in Matlab, “findpeaks”, which allows detecting local peaks of a signal by using a threshold or a minimum peak distance. It returns the locations of the peaks

expressed as an index into the array and the peak values, these two parameters, gave us the relation between a peak and time it occurs.

Another important fact is to calculate the maxima and minima of the derivative, corresponding to the inflection points of the signal. These parameters help us to find the onsets (beginning) and offsets (end) of the waves.

Once peaks, onsets, and offsets were detected, a cardiac cycle can be determined, basically, we can determine a heartbeat cycle by having a QRS onset complex, R peak and a QRS offset complex. This detection defines ventricles contraction, as it can be related to a heartbeat cycle.

Processing electrodermal activity signals were tricky because it had two components. Changes in EDA are associated with changes in sympathetic arousal, specifically the phasic component.

Tonic component of EDA can be determined as the low-frequency component of the signal and phasic component as the high-frequency part of the signal. This high-frequency component as mentioned, its related to peaks of arousal in phasic EDA.

Performing a low-pass filter allows us to smooth the signal and better determine the tonic component of EDA, while a high-pass filter provides a derivative of the original signal, there we can select the zeros and define the peaks of the signal, which are related to the phasic component.

A copy of the original signal is done, once that the low-pass filter is applied to one of the originals signals, and then a smoothed signal is obtained, on the other way, with the other original signal a high-pass filter is applied to obtain the peaks of arousal in the EDA.

Eye tracker processing data starts by dividing the experiment into different segments, allowing us to determine time alignment. The choice of segment

borders and the evaluation of eye-tracking data during these segments were selected to best fit with the stimuli presented along with the experience.

A counter of times the participant had visualized a point and the time alignment determining the exact time where it happens, define the attention a participant give to some stimulus or part of the experience. Also another counter process the time the participant spent each time he/she visualizes a point in the experience.

2. 7 Statistical Analysis

Once the extraction of the heart rate data is done during the conditioned experience, we were interested in the rhythm of heart rate measurement. Analyse the data, by counting in the interesting periods, the changes in the heart rate rhythm. A simple calculation was done, the number of beats during 15 seconds multiplied by 4. This multiplication gave us the how the heart rate (beats per minute) varies when the particular stimulus was presented.

However, during the resting state heart rate data were collected to perform an average of changes in heart rate in a short period of time (5 minutes). The heart rate rhythm is also compared with the average obtained during the control of virtual reality exposure.

When the extraction of data is performed during the conditioned exposure, skin conductance was our measurement of interest, first of all, we need to quantify a basal tone before the experience occurs, this will provide us a relaxed steady-state of the participant of skin conductance. Then, the average sweat production or skin conductance that the participant had during all the experience is quantified, this will allow us to determine if any change is significant.

In addition, the area under the curve method is applied. We calculated the total skin conductance increased between the mean during the experience

and during the mean of the pre-experience. These two parameters told us if the stimuli presented to the participants produce significant changes or not.

Furthermore, the habituation phenomenon was to take into consideration. When several stimuli were presented one next to another quickly, the participant of the experiment tends to react strongly to the first stimulus; he/she also will continue to respond to next stimuli, but with less intensity, allowing the habituation phenomenon [30].

At the time the extraction of data along the conditioned experience is done, the gaze direction and time of fixation in a determined point of the participant were data of interest. In the pre-experience minute, eye tracking was executed, since there was no stimulus to fixate the attention an average of pupil dilation/contraction can be extracted to determine if any posterior changes are significant.

An average of fixations on each point, specifically each stimulus presented were done, this static proportionate a result indicating which stimulus is higher or if the attention to the stimulus while experience is running decaying or increasing. Habituation phenomenon takes action here again.

Finally, since there is no stimulus presented during the normal experience, along with it the attention to different points of the experience is done, while the average time of fixation to different parts of the experience can be related to the fixation of the participant to the different stimulus presented along with the conditioned experience of the experiment.

The acquired knowledge was quantified by computing the corrected and not corrected answers from the posterior test. Comparing the total right answers from participants without stimulus on the virtual reality exposure to the total right answers from participants with stimulus on the virtual reality exposure.

Another analysis performed, was done inside the participants with stimulus in the virtual reality exposure, computing the right and wrong answers

depending on if the information was presented during the experiment at the same time of a stimulus or not.

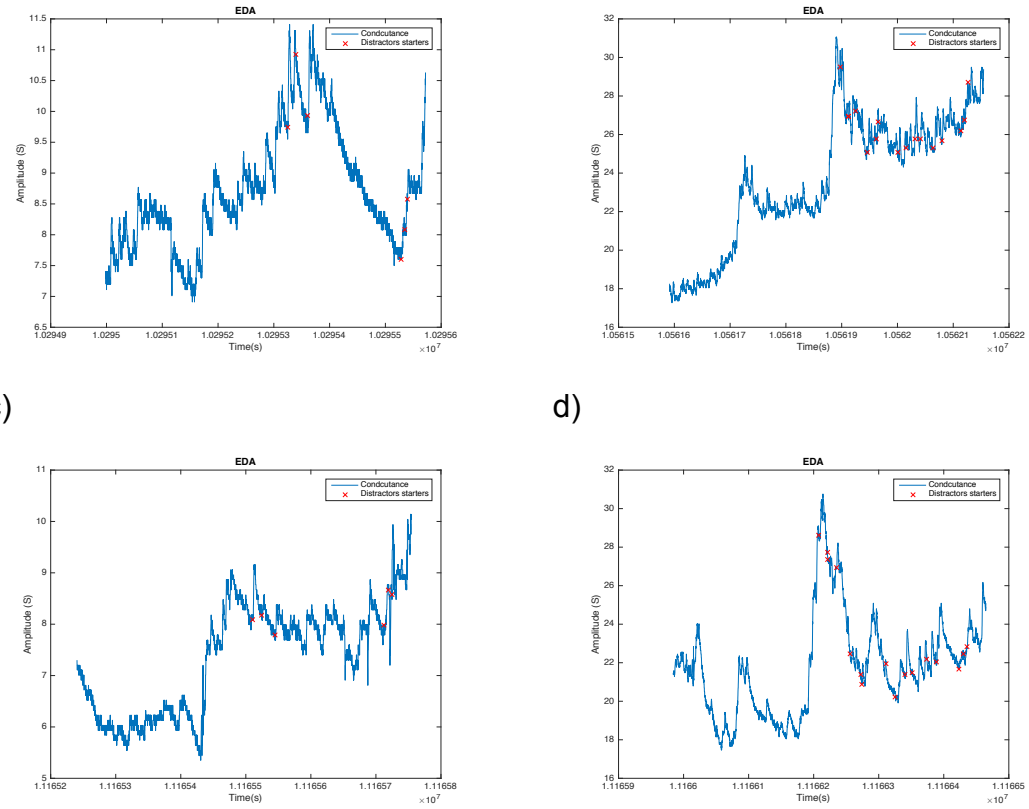
Finally, quantifying the arousal of different stimuli needs to divide these data into two components depending on valence. Evaluating if the stimuli are negative or positive for the participant, how the arousal was in each case. It the arousal is higher when valence is positive or when its negative.

An average of the arousal with negative valence and an average of the arousal with positive valence determine which types of stimuli represent a higher activity on the participants and are more appropriate for further studies.

Chapter 3
Results

The initial aim of this study was to determine the emotional changes and the knowledge acquisition a participant can have while auditory and visual distractors were applied in an immersive 3D virtual reality exposure, in order to compare it to ASD individuals. Physiological results show an increase in electrodermal activity. Having p-value for normality test is p=0.0481, the data is non-parametric. The average conductance of the skin across participants in Siemens (S) is 5.1875 and 5.4898 for male and female control groups and 10.7686 and 10.8467 for male and female conditioned groups. In fact, it is 5.334 for control group (median=5.305, MAD=1.577) and 10.807 for the conditioned group (median=7.525, MAD=2.933). Each one of these peaks is preceded by a visual or auditory distractor, see Figure 4.

a) b)



c) d)

Figure 4. EDA response. a) Control male, b) Conditioned male, c) Control female and d) Conditioned female. Conductance (S) and distractors markers.

Control participants show a steady state or a decrease in EDA after history lesson starts, whereas conditioned participants show the variability of EDA through the whole lesson. Conditioned participants have an increase in EDA after history lesson starts, first distractor marker (Figure 4 b) and d)), whereas on the other hand control participants do not vary the steady state measured before virtual reality exposure.

Control participants show subsequent peaks to lesson starters markers, but on the other hand, conditioned participants show subsequent peaks to distractors markers, see Figure 5.

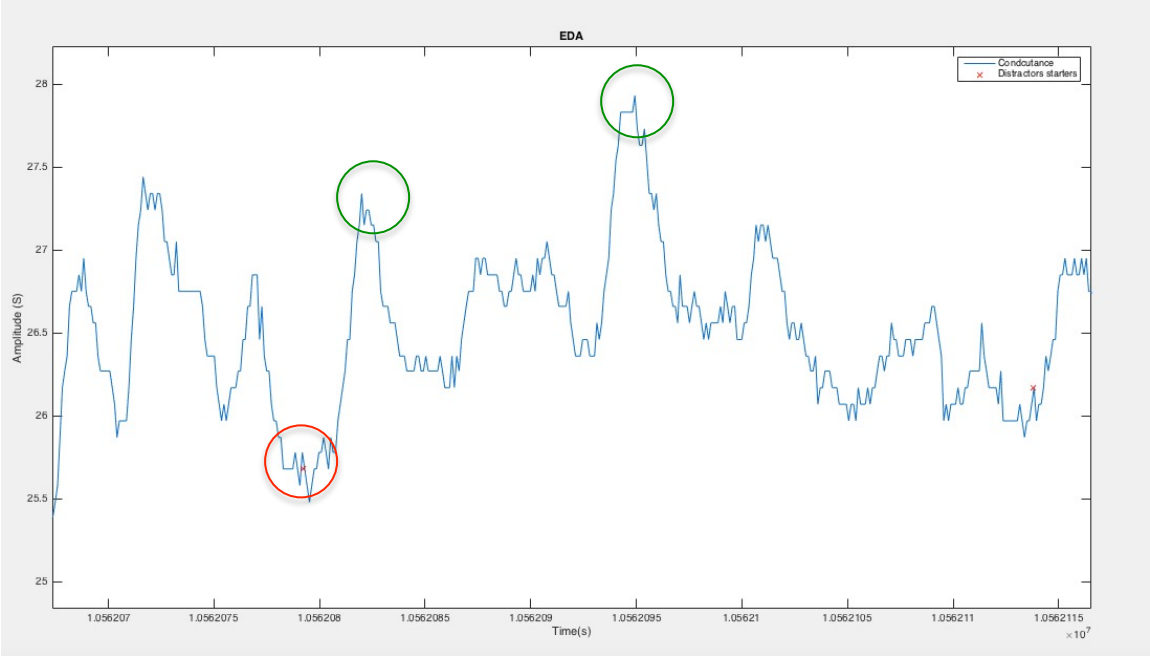


Figure 5. Five seconds of EDA from a conditioned participant. Distractor marker (red) after 1.5 seconds and two peaks (green) of arousal in the EDA subsequent to it.

Heart results exhibit higher heart rate on conditioned participants (79 beats per minute) than in control ones (73.9 beats per minute). On the other hand, conditioned participants also show an increment of heart rate and intensity of heartbeat subsequent to distractors markers, see Figure 7.

Before history lesson's first distractor, the average heart rate is about 72.7 beats per minute whereas after distractors the heart rate is 85.3 beats per minute, see Figure 6.

In addition, control participants do not exhibit such a huge increase in heart rate between before and after the history lesson starts (73.7 and 74.1 beats per minute respectively).

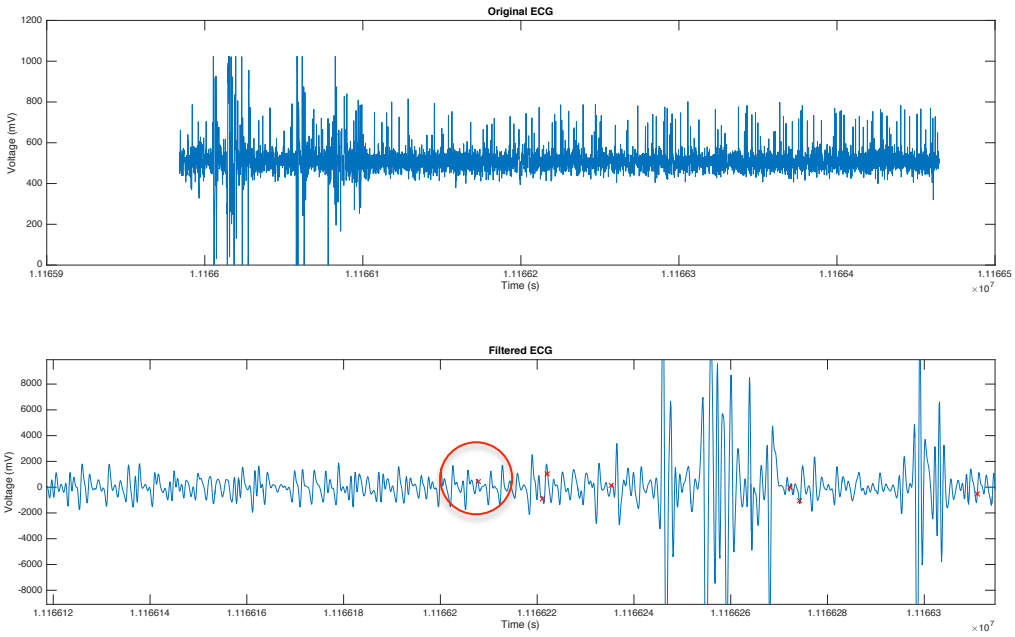


Figure 6. Original ECG, Filtered part of the ECG. First distractor marker red circle.

Figure 6. is an example of a conditioned participant, which has an increment in heart rate and heartbeat intensity subsequent to distractor markers. Before distractors markers, heartbeat intensity is lower in mV, but after history lesson starts, some distractors occur during the virtual reality exposure, then these markers were registered and after the fourth marker, the heartbeat intensity increases.

Furthermore, the same aspects occur in terms of heart rate after the fourth distractor marker in this example the beat frequency of the participant increases from 74 to 98 beats per second. After distractors markers, heart rate and beat intensity vary.

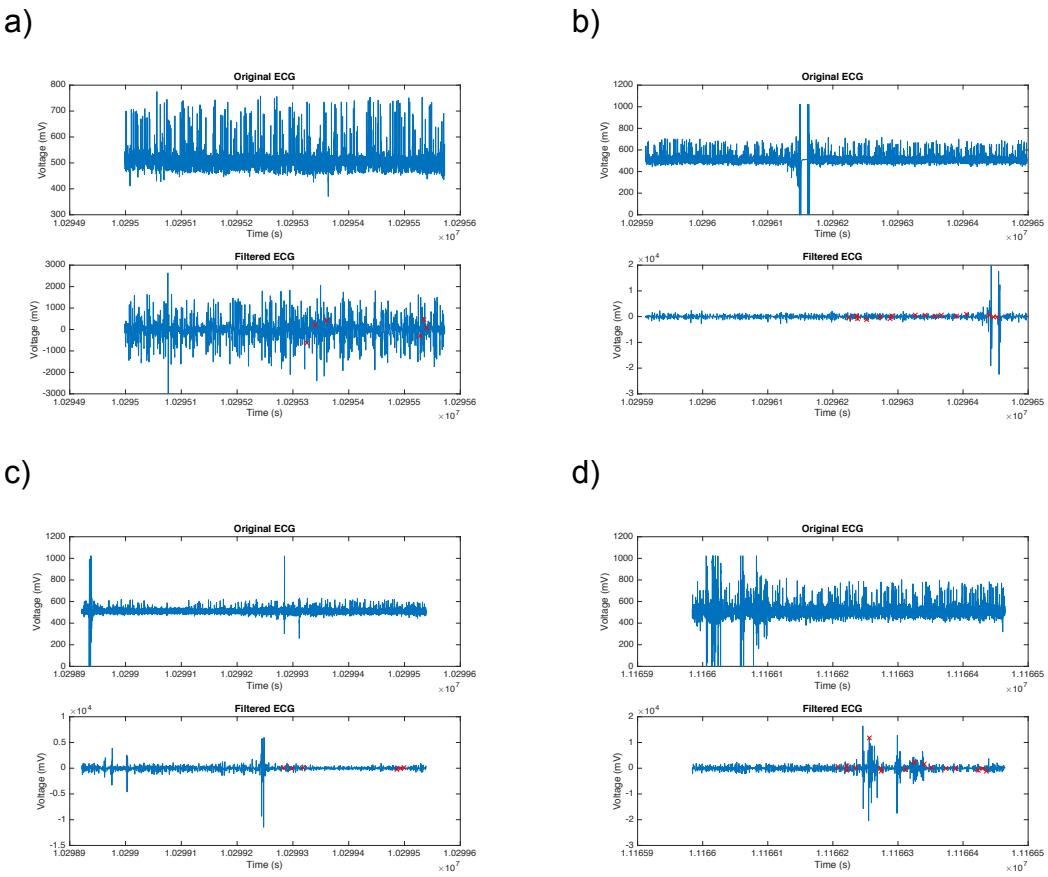


Figure 7. ECG data. a) Control male, b) Conditioned male, c) Control female and d) Conditioned female. Heart rate (mV) and distractors markers.

For knowledge acquisition line of results, we computed the correct and incorrect answers from the post virtual reality exposure test. The p-value for normality test in these data is p=0.0487, so the hypothesis is rejected, the data is non-parametric. Participants in the control condition showed a mean performance of 75% of correct answers (median=90%, MAD=10%); in contrast to participants in the experimental condition, that showed a mean performance of 49% of correct answers (median=50%, MAD=20%) (U= 24.5, p=0.029) (see Figure 8). However, the first question of the multiple answer test, which was the only one without distractors in both conditions is always well answered.

Furthermore, conditioned participants had answers presented with distractors and without them. The average on correct answers without distractors presented while the explanation takes place is about 63% whereas the

average on correct answers with distractors presented at the same time the answer is about 42.8%.

However, distinguishing the results by participants with 20 years old or participants older, results are different. Having an average difference of 4.4 points, 20 years old or higher participants have an average of 77% whereas younger than 20 have an average of 33%. This fact could also be related to educational level, participants with more than 20 years have university level, whereas younger participants do not reach this level yet.

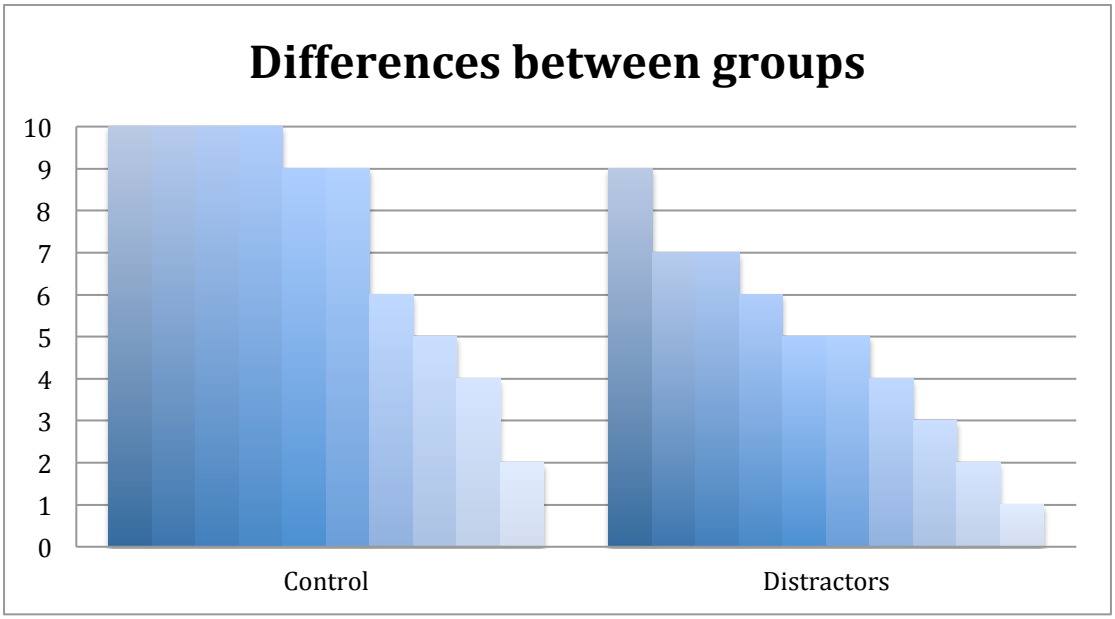


Figure 8. Differences between control a conditioned/distractors groups. Individual results, correct answers out of 10. Control groups with a median of 9 and conditioned group with a median of 5.

Finally, regarding differences between gender (see Figure 9), males have more correct answer, average of 90% in relation with females average of 60%, in control condition. Males have more differences between having distractors than females, with a 52% for males and a 46% average of correct answers with distractors in their virtual reality exposure.

This means that males have a difference of 38% between control condition and distractors condition, whereas females have a difference of 14% between control and distractors conditions. For this data, a Wilcoxon test was applied

since there are dependent variables depending on the gender (W=12.5, p=0.057).

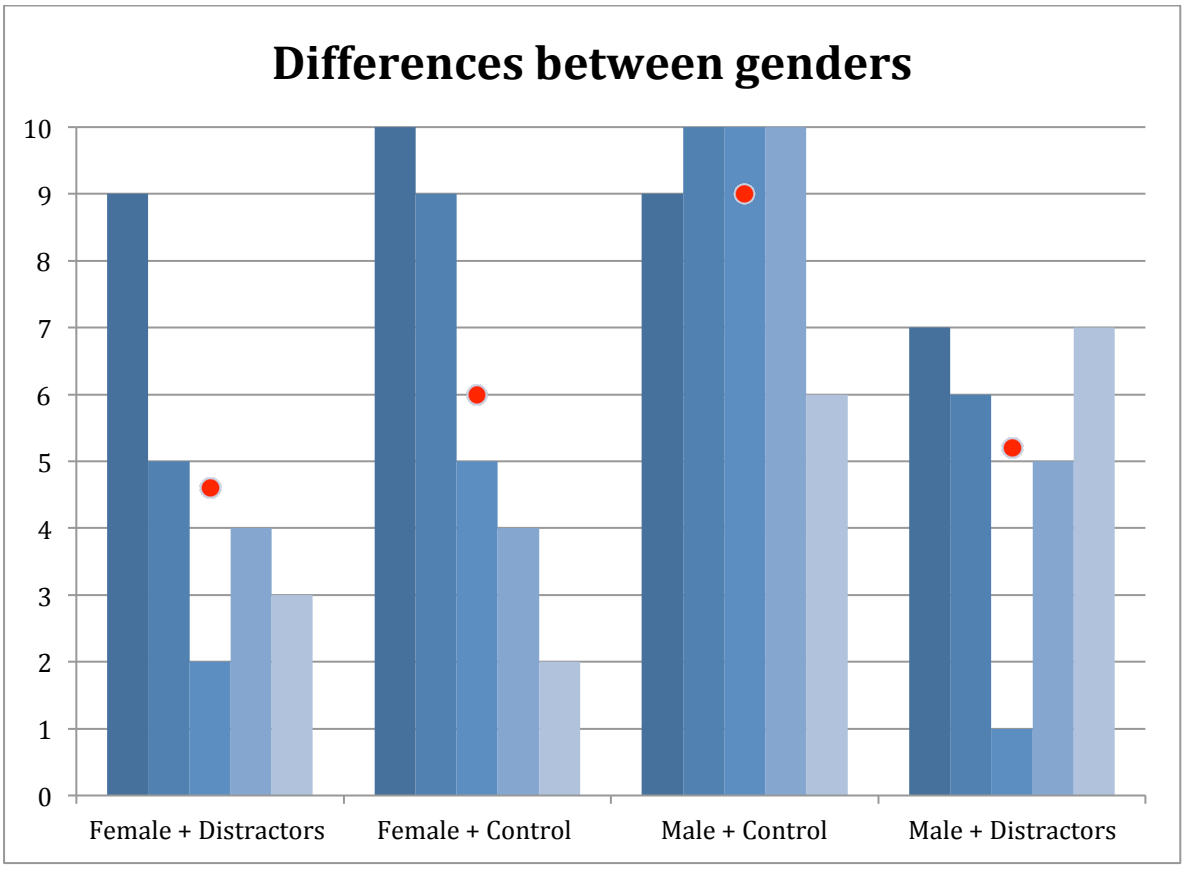


Figure 9. Differences between genders in control and distractors conditions. Average (red point).

Chapter 4
Conclusions

Going back to the hypothesis of the project, conditioned participants are expected to have an increase in heart rate and electrodermal activity, which means more conductivity.

On the other hand, another hypothesis is that control participants on the virtual reality exposure are expected to have more acquired knowledge than conditioned participants but last ones were expected to have more acquired knowledge when the distractors are not present than when they are present on the virtual reality exposure.

Regarding the results from heart rate and EDA. Heart rate increase in conditioned participants and is also more elevated when distractors were presented in virtual reality exposure than when distractors were not present. EDA has similar results as heart rate, elevated conductivity for conditioned participants, and also higher conductivity at the time distractors took part.

From these results, it can concluded that conditioned participants had higher emotional states during virtual reality exposure than control participants. Besides, conditioned participants suffer higher emotional state when distractors were presented during the virtual reality exposure. These facts can be related with [2] and [32], which results show ASD individuals having emotional states altered by auditory and visual distractors, same as It is used in this study.

In relation with multiple test results, which show higher correct responses from control participants than conditioned participants, we can conclude that conditioned participants had more difficulties to acquire knowledge than control participants, which can be associated with [15] and [35] studies with results from learning abilities, in which ASD individuals had more difficulties.

Additionally, multiple test results show differences between participants older than 20 years or younger, a fact associated with educational level, university or lower. Studies [33] and [34] gave us differences of acquired knowledge between ASD individuals with differences ages and IQ level, connecting these facts.

Finally, conditioned participants with auditory and visual distractors felt ASD virtual reality exposure, having their emotional state and their learning ability altered simulating ASD individuals, whereas control participants without distractors show typical development individual skills.

Chapter 5
Future Work

In spite of the fact that most of the objectives in section 1.6 were fulfilled, there are still many ways of working for further develop the project. One of the lines to work with it, mentioned, but not developed is eye tracking. Eye tracking technique will give the perception of attention and at the same time the valence of the different stimuli presented during the virtual reality exposure.

The more accurate analysis could have been performed on the data acquired during the virtual reality exposure. The emotional state of the user could be further analysed from the stress variables.

Appendix A

Lesson explained during the virtual reality exposure:

"¡Buenos días a todos! Hoy en clase vamos a hablar sobre las cartas anunciando el descubrimiento de las indias. Por favor, prestad atención, ya que luego os haré un pequeño examen para ver qué recordáis de ello.

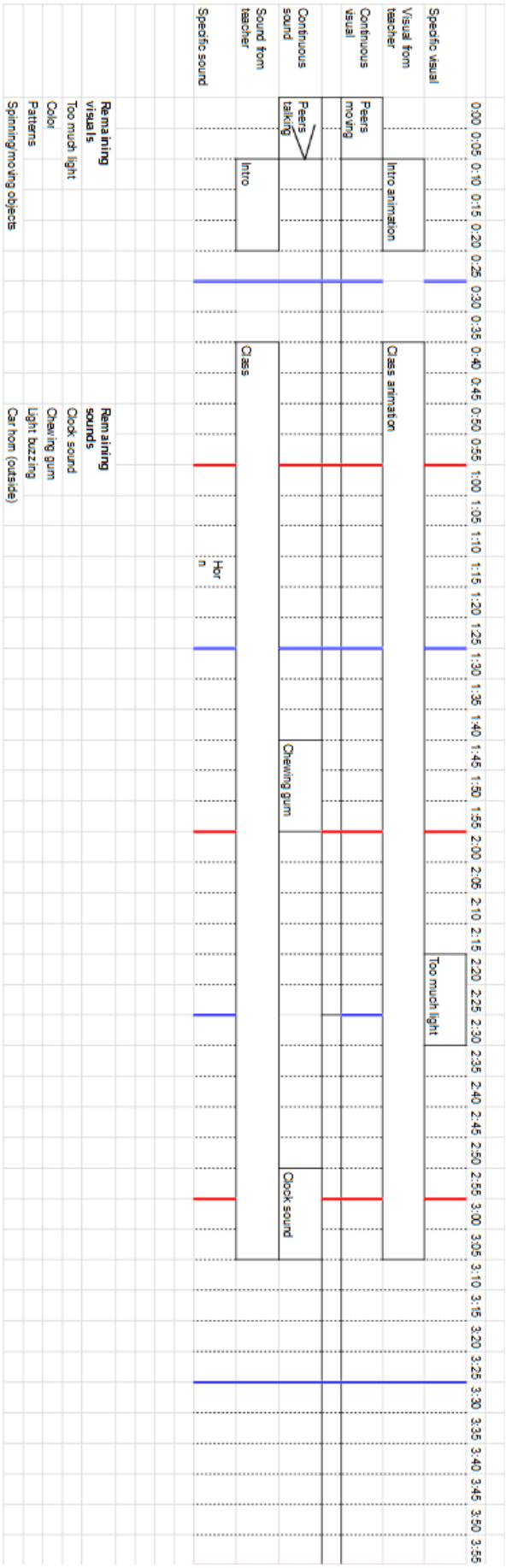
Las ***cartas anunciando el descubrimiento de las Indias*** son un conjunto de manuscritos e impresos que, a partir de 1493, hicieron públicos los hallazgos de la primera expedición capitaneada por Cristóbal Colón a lo que actualmente se denomina América. Hacia principios de abril se imprimió en Barcelona una carta en castellano dirigida al escribano de Ración de la Corona de Aragón, Luis de Santángel, funcionario de la corte de Fernando el Católico. La carta está fechada a 15 de febrero y postdatada en Lisboa a 14 de marzo. Unas semanas más tarde se publicó en Roma una traducción al latín bien de este mismo documento bien de otra carta muy similar dirigida al tesorero real Gabriel Sánchez. La versión en latín se difundió rápidamente por toda Europa, siendo reeditada varias veces y traducida a otros idiomas.[1] Posteriormente han aparecido manuscritos de contenido similar a la carta impresa en Barcelona y, en 1985, una copia quizás del siglo XVI de una carta de Colón a los Reyes fechada en marzo de 1493 y que trata del mismo tema.

Estas cartas describen las islas descubiertas, en particular Cuba y La Española, y las costumbres de sus habitantes, abundando las exageraciones sobre el tamaño de las islas, sus riquezas y la docilidad de los indios.[3][4] Sin embargo, ofrecen pocos datos concretos sobre el viaje (se omite, por ejemplo, la referencia a la pérdida de la nao capitana)e, incluso, algunos de ellos contradicen a otras fuentes, en particular al *Diario de a bordo*.[5] Sí se menciona la duración: 20 días en la versión en castellano y 33 en la latina.

La postura tradicional sobre la autoría de las cartas impresas en 1493 es adjudicar la misma al propio Colón, quien habría promovido su publicación como una forma de proteger sus intereses.[6] Otra teoría, en cambio, afirma que fueron escritas por el rey Fernando II y Luis de Santángel, inspirándose en diversos informes enviados por Colón a los Reyes a su regreso.[5] A pesar de las dudas sobre su autoría, estas cartas tienen una gran importancia histórica porque constituyeron la única fuente sobre el primer viaje de Colón que estuvo disponible públicamente durante la vida del Almirante.[7] Por lo demás, su publicación constituyó, intencionadamente o no, una extraordinaria operación de propaganda gracias a la recién inventada imprenta. En este sentido, la consecuencia más inmediata fue que la difusión de la noticia del Descubrimiento se convirtió en la más rápida y universal de todo el siglo XV y parte del XVI.

Eso es todo por hoy, gracias por vuestra atención."

Timeline of the distractors in the virtual reality exposure:



Post virtual reality exposure multiple-test:

America's Discovery Test

1. ¿A partir de qué año se hicieron públicos los hallazgos de las Américas?

    a) 1493
    b) 1492
    c) 1494
    d) 1593

2. ¿A principios de qué mes se escribió la carta al escribano?

    a) Febrero
    b) Marzo
    c) Abril
    d) Mayo

3. La carta estaba fechada a data de:

    a) 15 de Marzo
    b) 15 de Febrero
    c) 14 de Marzo
    d) 14 de Febrero

4. ¿Dónde se publicó una traducción al latín?

    a) Barcelona
    b) En Aragón
    c) Roma
    d) En Cuba

5. ¿En qué año se encontró una copia de la carta?

    a) 1493
    b) 1985
    c) 1993
    d) 1995

6. ¿Dónde se encontró dicha copia?

    a) Cuba
    b) La Española
    c) Ninguna
    d) A y B

7. ¿Cuánto duro el viaje en la carta española?

    a) 20
    b) 33
    c) 30
    d) 23

8. La postura tradicional adjudica la escritura de la carta a:

    a) Colón
    b) Rey Fernando II
    c) Luis de Santángel
    d) Todos

9. ¿Porqué Colón habría promovido la publicación de la carta?

    a) Proteger sus riquezas
    b) Proteger su familia
    c) Proteger al rey
    d) Proteger sus intereses

10. Gracias a qué su publicación fue un éxito:

    a) Manuscritos
    b) Carta
    c) Imprenta
    d) Difusión

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