MODULATION OF ATTENTION BY MOTOR INTERACTION:
A STUDY IN A VISUAL DISCRIMINATION TASK

By

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DEDICATORIA

A mis padres, por su amor incondicional e incentivarme a buscar, conocer y ser una mejor persona.

A mi familia, por su apoyo y soporte constante durante este proceso.

A mis hijos, Camila y Alonso quienes son mi luz en el camino.
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RESUMEN

La mayor parte de la investigación tradicional en neurociencias ha considerado a la “atención” como una función cognitiva superior orientada a los procesos perceptivos y alejada de las funciones sensorio motoras. Alternativamente, el marco de "Atención para la acción" plantea una estrecha relación entre los procesos cognitivos y sensoriomotores, donde la atención actuaría como un mecanismo integrador. Hay evidencias empíricas que sugieren que los procesos de preparación y ejecución motora tienen un impacto positivo sobre los procesos atencionales y perceptivos, a pesar de esto, no existe consenso si la interacción de estos procesos produce interferencia o mejoría en ellos. El objetivo de esta tesis es contribuir a un mejor entendimiento de las interacciones entre los procesos atencionales y motores. Proponemos que el acoplamiento funcional entre los procesos atencionales y motores modula positivamente los procesos de atención. Para evaluar esta proposición diseñamos una tarea dual de seguimiento ocular que requiere atención sostenida y discriminación de un estímulo visual (condición visual). Este diseño permite agregar un acto motor relevante a la tarea (condición motora) para evaluar su efecto modulador en la atención y explorar diferencias entre ambas condiciones experimentales. El rendimiento en la tarea se midió utilizando parámetros conductuales, electrofisiológicos (ERPs) y variación del diámetro pupilar en un grupo de niños sanos (grupo Control) y otro grupo de niños con déficit atencional (grupo ADHD). Los resultados conductuales mostraron que el grupo Control tuvo un mejor desempeño general en la tarea que el grupo ADHD siendo mejor el rendimiento en la condición visual, pero que este efecto diferenciador entre grupos desaparecía al compararlos en la condición motora, es decir el efecto motor favoreció el rendimiento conductual del grupo ADHD. La electrofisiología mostró que en la condición motora se produjo un efecto modulador en la CNV, P1 y N1 comparado con la condición visual para ambos grupos, siendo más amplia en el grupo Control. Finalmente, el diámetro pupilar mostró en el grupo Control un aumento progresivo en la condición motora durante todo el trial mientras que en la condición visual este aumento se estabilizó estabilizó 400 ms. previo a la aparición del estímulo a discriminar y se mantuvo así hasta el final del trial. El grupo ADHD en cambio mostró un aumento progresivo del diámetro pupilar hasta el final del trial para ambas
condiciones lo que podría reflejar que la tarea presenta una mayor demanda atencional para estos sujetos. Estos resultados sugieren que en la tarea analizada sí existiría un efecto modulador positivo del componente motor sobre los procesos atencionales el cual a pesar de no ser notorio en la conducta es consistente a nivel electrofisiológico y en la variación del diámetro pupilar lo que reflejaría la interacción positiva de estos procesos sobre la atención.
ABSTRACT

Most of the traditional neuroscience research has considered attention as a superior cognitive function mainly oriented to perceptual processes and away from sensorimotor functions. Alternatively, the “Attention for Action” framework proposes a close relationship between cognitive and sensorimotor processes, where attention would act as an integrative mechanism. There is empirical evidence suggesting that the processes of preparation and motor execution have a positive impact on the attentional and perceptual processes, but there is no consensus if the interaction of these processes produces interference or improvement in them. The aim of this thesis is to contribute to a better understanding of the interactions between attentional and motor processes. In this thesis we propose that the functional coupling between attentional and motor processes positively modulates attention processes. To evaluate this proposition we designed an ocular pursuit dual task that required sustained attention and discrimination of a visual stimulus (visual condition). By adding a motor relevant act to the task (motor condition) we were able to evaluate if this produced a modulating effect on the attention and if differences were observed between both experimental conditions. Task performance was measured using behavioral, electrophysiological (ERPs) and pupil diameter variation parameters in both, a group of healthy children (Control group) and another group of children with attentional deficit (ADHD group). Behavioral results showed that the Control group had a better overall performance in the task than the ADHD group, with better performance in visual condition than in motor condition, but that differentiating effect between groups disappeared when comparing them within motor condition, that means the motor effect favored the performance of the ADHD group. Electrophysiology showed that in motor condition a modulating effect was produced on CNV, P1 and N1 compared with the visual condition for both groups, it being larger in the Control group. Finally, Control group showed a progressive increase in pupillary diameter along the trial in the motor condition, while in the visual condition this increase was stabilized 400 ms. prior to the appearance of visual stimulus and remained so until the end of the trial. ADHD group, however, showed a progressive increase in pupillary diameter along the trial for both conditions, which could reflect a greater attentional load of these
subjects in the task. These results suggest that in the analyzed task there would be a positive modulatory effect of the motor component on the attentional processes, which despite not being clear in behavioral performance, is consistent at electrophysiological level and in the pupil diameter variation, which would reflect positive interaction between these processes.
1. INTRODUCTION

1.1 Perception and Action coupling

Traditionally, the study of brain functions has been approached in a segregated manner, allowing a better understanding of several specific functions but however providing an incomplete view of the overall function of the brain (Schneider et al., 2013). Sensorimotor coupling is essential for correct behavior execution in animals, and perception and action are interdependent process that occur in a tightly integrated way (Hommel et al., 2001). Thus, motor behavior is improved when more information from our senses is provided and it becomes worse with impaired sensory afferences, for example in a dim light room or when pathology affects it. Likewise our perception is better when we move, whether in an open environment or when crossing a room, when we move our head and eyes to behold a scene or when exploring an object moving the fingers across its surface. Sensorimotor integration occurs at different levels in the SNC organization, from lower levels such as neural circuits in the Spinal Cord to the highest hierarchical level in the cerebral cortex (Kandel et al., 2000). In primates, large cortical brain areas are involved in movement perception and action preparation. In that sense, the brain can be considered as a sensory-motor interface that transforms, for example, visuo-spatial information from the environment in motor commands for correct execution of the goal-directed movements (Baldauf, Cui & Andersen, 2008). Many cognitive researchers consider the sensorimotor processes as “lower” functions, and away from higher cognitive functions such as learning, reasoning, decision making or attention. I will show that, there is a closer relationship between motor and cognitive process than is normally accepted and that attentional mechanisms play a major role in the integration of these processes. This is especially important for behaviors that require intention and control, as for example goal directed behaviors where attention
plays a critical role. In this same sense, Schneider claims that “goal-directed behavior of an organism requires the joint and coordinated functioning of perception, memory and sensorimotor control. A prime candidate for achieving integration across these functional domains are attentional processes” (Schneider, et al., 2013, p. 1).

1.2 Attention for perception (Traditional view)

Attention is an important neurobiological function that allows to select in a continuous and dynamic way, behaviorally relevant stimuli from the environment and ignore irrelevant stimuli (Smith & Schenk, 2012). Thus attentional processes would be considered like a selective mechanism that manages and allocates limited cognitive resources, due to our poor ability to process information (Itti et al., 2005). This "scarce" conception about attention has had great influence on many of the most important models and theories proposed about attention (Hommel, 2010). In this sense a relevant model was proposed by Broadbent (1958), who using a dichotic listening task presented a theoretical model in which attentional mechanisms were thought as filters (bottleneck) selecting relevant information and discarding other that is not, thereby processing just one stimulus each time, to prevent cognitive capacity from being overloaded. Later in 1969 Treisman proposed that people have an attenuator filter that receives attended messages, perceiving not just the attended stimulus but unattended messages too can be perceived -although with less intensity-, again to avoid overloading the central processing system. Here, the initial identification of the message is based on its physical properties and then, after the filter, by its higher level characteristics, like meaning. This parallel processing does not happen in the rigid filter of Broadbent (Itti et al., 2005). Finally, capacity theories of attention (Kahneman, 1973), using dual or multiple task performances, propose attention as a limited resource
that can be used by the subject in a flexible manner, allowing to manage and allocate the attentional resources in an efficient way. In all of these influential models of attention the central concept is the same, to prevent overloading brain limited capacity to process cognitive information (Hommel, 2010).

At the brain network level, it is important to note that cortical and subcortical networks work together in generating the attentional process. Thus, subcortical areas exert a critical modulatory influence over cortical areas, as for example the fronto–striato–thalamo–cortical loops (Kandel et al., 2000). An influential attentional model was proposed by Michael Posner at the end of the 80’s (Posner & Petersen, 1990), where they propose a modular attentional system comprising three segregated but related networks, each of which has different functions and a discrete anatomical basis. These three networks are the Posterior attentional network or orienting network, implicated in locating and orienting attention to stimuli in space. The alerting network maintains a preparatory state or general 'arousal' needs it for rapid detection of the expected stimulus. Finally, the anterior or executive network is responsible for target selection and inhibition of responses to irrelevant stimuli, voluntary control in situations that require planning, strategy development, conflict resolution and working memory (Posner & Petersen, 2012). This model, that was mainly developed using visual attention, was very innovative by proposing that the attentional function is not a unitary entity but rather a modular system based on neural interconnected anatomical networks with specific functions (Posner & Petersen, 2012). More recently, Corbetta & Schulman (2002) proposed a brain network based model, in which visual attention is controlled by two partially segregated neural networks systems. The Dorsal system is implicated in voluntary selection of sensory information or responses and is furthermore modulated by stimuli detection. This is a bilateral dorsal fronto parietal network which includes parts of the intraparietal cortex and superior frontal cortex. The
Ventral system is activated in the detection of behaviorally relevant sensory events mainly with salient or unexpected stimulus, “this ventral frontoparietal network works as a 'circuit breaker' for the dorsal system, directing attention to salient events” (Corbetta & Schulman, 2002, p.1). This network is biased to the right hemisphere and is located on ventral frontal cortex and temporal parietal regions.

Although such theories based on neural networks are much more elaborate than their predecessors, again all of them are influenced by, and share the basic idea that we have a limited capacity to process information that must be managed, and attentional mechanism role would be select those stimuli that are considered relevant in specific circumstances and reject those that are not (Hommel, 2010).

1.3 Attention for action

Much of the traditional attentional research has considered people simply as perceivers of the world, ignoring the role of attention in action processes (Driver, 2001). Early research on visual attention was developed using purely perceptual tasks, for example how attention facilitates stimuli detection (Posner & Petersen, 1990), attention and identification of visual stimuli (Desimone & Duncan, 1995; Treisman & Gelade, 1980) or how stimuli enter into short term memory (Duncan & Humphreys, 1989). Ulric Neisser was one of the first researchers to propose a relationship between attentional processes and motor behavior. Neisser showed that a trained subject can perform a dual attentional task concurrently without much interference between both tasks (Neisser, 1976). He interpreted these experiments suggesting that if an attentional bottleneck is needed, it must be for behavioral coordination rather than for information processing capacity. It is a fact that there are bodily limitations that prevent us from, at
one time, looking in two different directions or touching your two ears with the same finger. Neisser suggests that, often, cognitive processing is selective not due to cognitive processing limitations, but because of physical constraints. Later, Allport (1987) and Neumann (1987) also posed a close relationship between attention and action. They described their approach as a 'selection for action’ theory and they argued that the cognitive capacity is not a major constraint (bottleneck), but instead the constraints are placed by the control of action (Hommel, 2001). Thus, the selection for action approach claims that the function of attention is not the management of limited processing capacity, but the management of capacity excess (Joordens & Betancourt, 2003). The system can handle much more stimuli than an ongoing task is requiring, thus a selection mechanism (attention) to get relevant information for movement control becomes necessary. Action control requirements determine the attentional selection, so that “when we detect feature conjunctions in complex visual environments this it do so in the service of particular action goals" (Hommel, 2010, p.135). For example, in goal-directed movements like grasping an object among many others, it is required to select a potential target and to extract visual spatial parameters relevant and specific for this movement, e.g. object’s position, orientation and size (Fagioli et al., 2007). Thus, in most of our interactions with the environment in the real life, attention is required for controlling actions this is its natural coupling. In summary, attention for action is a theoretical framework that proposes a different approach for the study of attention compared with more traditional approaches. This approach reject the claim that attentional process evolved as a mechanism to prevent the cognitive overload of the processing system, like computational paradigm propose. In contrast, it proposes that attentional functions evolved to deal with problems related with action control such as action planning, online control of action execution and action adjustment when is required (Hommel, 2010). My thesis proposal is in line with this theoretical framework.
1.4 Visual attention and action coupling

The close relationship between visual attention and motor actions was proposed in a radical manner by Rizzolatti and colleagues (Rizzolatti et al, 1987) in their controversial premotor theory of attention. The premotor theory of attention stated that covert shifts of attention are the results of motor system activation (oculomotor system), it which would be functionally equivalent to saccadic eye movement preparation and the difference would be given by the intensity level of the activation (Rizzolatti & Craighero, 1998). More specifically, says that “spatial attention and motor preparation use the same neural substrates” and “spatial attention is functionally equivalent to planning goal directed actions such as eye-movements” (Smith & Schenk, 2012, p. 1104). To date, we have good evidence about tightly relationship between selective visual attention and the planning of saccadic eye movements (Craigero, Fadiga, Rizzolatti & Ulmita, 1999; Corbetta et al., 1998; Deubel & Schneider, 2003; Van der Stigchel & Theeuwes, 2005), but precisely how this coupling occurs is still controversial.

Similarly to raise by the premotor theory of attention, other studies have shown that actions using other effectors, mainly hand movements, also deploys attention to the intended movement aimed to a target. For example, in overt visual attention studies where the eye-fixation behavior has been considered as an indicator of deployed attention, eye and hand movements have shown coupled behavior. In everyday and real situations such as making a sandwich, preparing a cup of tea (Land, 2006) or manipulating objects (Hayhoe, Shrivastava, Mruczek, & Pelz, 2003; Mennie, Hayhoe & Sullivan, 2007) researchers found a close and consistent relationship between actions execution and the actor’s gaze behavior. Actors usually looked at the target object of the presently motor action first, then reached or manipulated that object. Such coupling, looking at the places and objects interest first that after will be manipulated can be a
functional requirement of the system and help to collect spatial information needed for a better handling of the objects (Land, 2006). By contrast, when actors do not look at the movement targets during movement execution, spatial reach errors increase (e.g., Neggers & Bekkering, 1999). The action-related attention for other effectors than hand movements in overt visual attention paradigm have been also studied with similar results (e.g., Hollands & Marple-Horvat, 2001; Patla & Vickers, 1997; 2003).

Other studies have shown that the preparation to perform a certain movement displaces covertly visual attention to intended target location during movement planning in advance to the movement execution, enhancing visual processing of events occurs at that intended places. Thus, in eye movements studies during the preparation of saccades a better processing of visual stimulus occurs in places where it will be directed the planned saccade showing that shift of covert attention are triggered during the saccade preparation period (Hoffman & Subramaniam, 1995; Deubel & Schneider, 1996). In other study Deubel and Schneider (Schneider & Deubel, 2002) comparing discrimination accuracy between different locations during planning a saccade, show that in saccades goal positions the discrimination accuracy level was higher than in adjoining positions. Similarly to studies in eye movements, using a manual reaching task and covert attention Deubel and colleagues studied spatial attention allocation and perceptual discrimination performance for motor planning of hand effector (Deubel, Schneider, & Paprotta, 1998; Paprotta, Deubel, & Schneider, 1999). They shown that in reach planning, similar that occur during saccades planning, attention is spatially allocated to the movement target in advance until the movement is executed. In an electrophysiological study, Eimer and colleagues using event-related potentials for both an eye movement saccade task and manual response task, they show that N1 components triggered by visual probe during covert response preparation were enhanced when these stimulus were presented close to position in what saccade or hand
movement will be programmed, resulting in spatially specific modulations of visual processing (Eimer et al., 2006). In a related approach, Baldauf and Deubel (2009) using an EEG evoked-potential study and covert visual attention shown that during movement preparation of reaches for multiple goals, the visual dot probe used in the task elicited larger P1/N1 ERP components if it appeared at goal location of planned movements as compared to a dot probe appearing at task-irrelevant locations.

So far I have discussed evidence indicating that perception, attention and action are functionally and anatomically tightly coupled and are strongly interactive. This coupling has its neural basis in reciprocally interconnected networks of visual, attention and motor-related brain structures. This mechanism that has been termed “visual preparation, consists of the spatially selective, action-specific extraction of motor-relevant information from the visual scene by means of attentional mechanisms” (Baldauf & Deubel, 2010, p. 999), and could be considered the functional coupling between perception, action and attention. Thus, in goal directed movements would be a close relationship between motor planning and the spatial distribution of attention, where the former would condition or determine the second.

1.5 Statement of the problem

In summary we have seen a number of empirical studies suggesting that motor planning affects attentional spatial allocation and perceptual process performance to positions that are relevant for intended actions, and we have also seen that this holds for both oculomotor and manual actions. The question I want pose in this thesis is whether motor preparation modulates attention not only in the sense that conditioning or directing spatial allocation of attentional resources to relevant places for the planned movement, as most of the studies reviewed here has showed. But, whether motor
preparation modulates attention in the sense to increase attentional load (intensity) deployed for an specific spatial position when we make attention for action vs attention for perception, I propose that this is the case. One question that guide my reasoning and would help to dilucidate this question, but that not is the aim of this thesis proposal, is to know whether hand movements and eye movement preparation using common or separate attentional Mechanisms. Now we have evidence for an anatomical overlap between eye-movement control brain areas and attention networks, as the premotor theory of attention proposes. But for hand movements, theories that regard attention and motor control as intimately linked but not obligatory concurrent, could be better fit. In this sense, Jonikaitis and Deubel (2011) showed that during the preparation of a coordinated movement requiring saccade target selection and reach goal selection, attentional resources are allocated independently suggesting that these effectors have independent attentional mechanisms. On the other hand view that a single attentional system underlies eye and hand movement goal selection have support in psychophysical studies (Neggers & Bekking, 2002; Song & McPeek, 2009) and functional imaging studies (Medendorp, Goltz, Crawford & Vilis, 2005) thereby, this is a situation that requires further clarification. Thus, if the attentional mechanisms related to these effectors were totally or partially independent, then when both effectors act together in the same task should result in a functional and synergic coupling of theirs respective networks. This would be manifested by enhanced attentional performance level compared when they act separately.

To evaluate this proposal, we have designed (adapted from Spering et al., 2006) a dual pursuit task that enables to test the oculomotor and visual discrimination performance in a sustained attentional task. This task allows visual and motor (hand preparation movement) interaction with the task in a differential way (visual vs. visuomotor condition). We will measure behavioral attentional performance using
success discrimination score reported after each trial. We will measure attentional and motor brain processes using EEG (ERPs) during task performance in both experimental conditions (CNV, P1, and N1). Furthermore, we will measure smooth pursuit eye movements behavior and pupillary diameter during task. This proposal will be evaluated in two different groups of children, one of them composed by healthy children (Control group) and the other composed by children with ADHD (ADHD group). The attentional performance results of both groups will be analyzed and compared for all variables in the study. ADHD children are an interesting group for study of attentional mechanisms because they have problems with sustained attention and response inhibition (Castellanos & Tannock, 2002). Have been used different kind of eye movements task to study oculomotor system in ADHD children, but few studies have been performed using smooth pursuit eye movement in them (Rommelse et al., 2008). I think that attentional task raised in this proposal will be demanding for these children and could be a good discriminator between normal subjects and ADHD children.
2. HYPOTHESIS

2.1 General hypothesis

The functional coupling between attentional and motor processes improve attention processes when exist a temporal or spatial coincidence on deployment of these processes.

This is manifested in that the inclusion of a relevant motor act for task, it will improve attentional processes in a visual discrimination task.

2.2 Corollaries

• This attentional improve will be evidenced in behavioral performance by an increase in success discrimination rate for experimental motor condition compared with visual condition.

• The increment in attentional networks activation will be evidenced by increased amplitudes in CNV, P1 and N1 ERPs for experimental motor condition compared with visual condition.

• The improvement in attentional level will be evidenced by a greater increase in pupil diameter for experimental motor condition compared with visual condition.

• In ADHD subjects similar adaptations will be observed as those predicted for healthy subject, but these changes will be less than those observed in control subjects.
3. OBJECTIVES

3.1 General Objective

To explore and compare attentional and behavioral performance in a group of healthy children (Control group) and ADHD children (ADHD group) during the carrying out of a visual discrimination task requiring sustained attention and motor interaction (visual & motor interaction condition).

3.2 Specifics Objectives

1. To design a visual discrimination attentional task that allows visual and motor interaction with the task in a differential way.
2. To measure behavioral attentional performance using success discrimination scores reported after each trial.
3. To measure brain attentional and motor networks activation using EEG (ERPs) during task performance in both experimental conditions (CNV, P1 and N1).
4. To measure pupilar diameter behavior in task in both experimental conditions.
5. To compare attentional behaviour performance, brain attentional activation networks and pupilar diameter between control and ADHD subjects.
4. METHODS AND EXPERIMENTAL DESIGN

4.1 Subjects

A total of 30 subjects participated in the study, fifteen healthy children and fifteen ADHD children, 10-13 years old, normal or corrected to normal vision, gender and socioeconomically matched were recruited for experiments. No significant differences were found between the groups in age, IQ, or educational level. All ADHD subjects were diagnosed as ADHD-Combined Subtype by a trained child neurologist according to the DSM-IV criteria. All participants were also screened for neurologic or psychiatric comorbid conditions using a protocol that included parents’ interview, M.I.N.I. Kid test, and general psychological and physical assessment of the children. All ADHD children were being treated with methylphenidate, but suspended medication 24 h prior to the study. The Conner’s Abbreviated Parent–Teacher Questionnaire is usually utilized to screen for symptoms of ADHD in the clinical setting. Parents granted informed consent for their children’s participation, and children signed an informed assent form. The procedures in the study were approved by the Ethics Committee of the School of Medicine of the Pontifícia Universidad Católica de Chile in accordance with the Declaration of Helsinki.

4.2 Experimental Setup

Participants sat in a dimly lit, sound-attenuated room, the participant's head was stabilized comfortably by a chin and forehead rest. The stimuli was presented on a 21” color monitor with a frame frequency of 100 Hz and providing a spatial resolution of 1024x768 pixels at viewing distance of 58 cm. Eye data was recorded at 500 Hz using an eye tracker system (EyeLink 1000, SR Research Ltd., Ontario, Canada). The electroencephalographic activity was recorded by using 40 non-polarizable Ag/AgCl
electrodes (Quick-Cap, Compumedics Neuroscan Inc.) spanning bilateral frontal, central, temporal, parietal and occipital positions. Subjects reported and interacted with the task using a keypad.

4.3 Stimuli and Procedure

Annexe 1 shows the sequence of stimuli in a typical trial of Experiment. Each trial begins with a fixation on central cross (using like drift correct) that was followed by a target circle appearing on the left side of the screen. Then, the circle began to move across the screen along the horizontal meridian until it crossed the screen completely. At a random point in time between 400-1400 ms. after starting the trial, a warning cue sound was emitted and exactly 1000 ms. after that sound a probe for discrimination was displayed for 50 ms. (It it looks like two characters, either '¡¡' incongruent, Or '¡¡' congruent) inside on the target circle. The subjects were instructed to smoothly track the horizontal displacements of the target and to inform, at the end of each trial, whether the probe of discrimination had been congruent or incongruent. To determine the level of visual attention, the objective of discrimination was balanced between congruent (50%) or incongruent (50%), each test lasted 2500 ms.

4.4 Experimental Design

Initially, each participant performed two training blocks consisting of 24 trials each one, not included in data analysis. After this initial training, the participants performed eight experimental blocks, each consisting of 24 trials, with a total of 192 trials in the experiment. Two experimental condition were evaluated, the visual condition and the motor interaction condition one in each block in alternate order. In the visual condition the task was carried out using gaze tracking to the target to then
report the discrimination probe congruency or incongruency using the response buttons. In the motor interaction condition the task was carried out using gaze tracking to the target and hand movement preparation but not execution (button press) until the moment when discrimination probe appear, when subject were instructed to rapidly press a button to report it (the report button) and then they respond again about the probe congruency or incongruency by pressing the response buttons. This make possible to compare attentional performance by adding hand movement preparation in one of the experimental conditions and evaluate if positively modulates attention. In summary each subject made eight blocks of 24 trials each one with 192 total trials and experiment duration was 30 minutes approximately (Annexe1).

4.5 Electrophysiology

The EEG was recorded from 40 non-polarizable Ag/AgCl electrodes mounted on an elastic cap (Quick-Cap, Compumedics Neuroscan Inc.) following the expanded version of the 10-20 international system. All sites were recorded respect to a CPZ reference electrode and re-referenced off-line either to the algebraic average of the left and right mastoids for ERP study, or to an average of all electrodes for time-frequency analysis. Beside the eye movement recording system, blinking, vertical and horizontal eye movements were also monitored with three electrooculogram electrodes, two below and above the left eye and one on the external canthus of the right eye. Electrodes impedance was kept under 10 kOhm and the recordings were performed in a Faraday cage that allowed to reduce electromagnetic contamination. The EEG signal was acquired at a sampling rate of 1000 Hz, amplified and band-pass filtered between 0.01–200 Hz (NuAmps, Compumedics Neuroscan Inc.). Data was corrected for eyeblink artifacts by using Independent Component Analysis (Delorme, Sejnowski, & Makeig, 2007). Trials were inspected for non eye-related artifacts and were rejected based on
amplitude (200 uV. range) and the occurrence of high amplitude high frequency spikes. ERPs were obtained for each condition and type of behavioral response by averaging over trials for each session and low-pass filtering at 30 Hz using the MATLAB (Mathworks, Natick, MA, USA) Fieldtrip Tolbox (Oostenveld, Fries, Maris, & Schoffelen, 2011). ERP components were identified on the basis of their polarity, latency and distinctive topographical properties. All ERPs were corrected respect to a 200 ms (P1, N1) or 500 ms (CNV) pre-stimulus baseline window and the amplitude of each component was calculated as the mean potential difference respect to baseline, in the latency and topography of interest. In this way we can identify event-related potentials P100/N100, P300 and CNV.

4.6 Eye movement and pupillary diameter

Eyes position and pupil size was recorded with video-based eye tracker system (EyeLink 1000, SR Research Ltd., Ontario, Canada) at 500 Hz. The apparatus was calibrated at the beginning of the experiment and recalibrated after each block of trials. Calibration error was kept below 0.5°. Stimulus display and data collection were controlled and synchronized with EEG by a host PC. Pupil diameter analysis was performed using Matlab® software (release 2016a). Periods of blinks during eye recording were detected by the Eyelink sofware and data surrounding blinks were removed and Pupil diameter during these periods was estimated using an interpolation function in Matlab. To obtain the pupil diameter average, data of each subject were baseline-adjusted and smoothed by a bandpass filter between 0.025Hz and 4Hz. A low-pass frequency filter extracted the high frequency noise, and a high-pass filter was applied to detrend the basal slow change of the pupil diameter across trials. All trials with more than 50% of missing data (due to blinks or outliers) were discarded in the analysis. Pupil diameter was measured in arbitrary units (normalization) estimated
from the maximum and minimum pupil diameter for each subject in each trial. The pupillary diameter amplitude variation was calculated respect to a 500 ms pre-stimulus baseline window. In each trial Pupillary diamter variation was time locked at time 0 sec. and stimulus probe presentation occurred one second after that.

4.7 Statistics

We used a case-control design and 2x2 mixed factorial experimental design, analyzing repeated measures ANOVAs that contrast the dependent and independent variables. In some case we used T-tests and mainly Wilcoxon non-parametric tests to attain a better fit to data distribution. For paired comparisons, we used the Wilcoxon signed-rank test. For non-paired comparisons, we used Mann–Whitney–Wilcoxon tests. We considered significant P values below 0.05 (significance level alpha=0.05) and all tests were performed using the subject as the unit of analysis. All our statistical tests were implemented in Matlab® (release 2016a).
5. RESULTS

5.1 Behavioral results

Thirty subjects (15 Control and 15 ADHD) were included for this behavioral analysis. The behavioral performance of the subjects was assessed based on the percentage (mean) of correct, incorrect and missed responses that the subjects reported by pressing a button in a joystick after discriminating the visual stimulus (probe) that was shown in each trial. Behavioral accuracy to discriminate stimulus and responses time was analyzed. For the statistical analysis non-parametric Wilcoxon Test for paired and independent samples was used.

When comparing the overall performance (mean) of discrimination between both experimental groups (not separated by experimental condition), we can observe that the control group had a better performance than the ADHD group (figure 1) showing a

Figure 1. Overall performance of discrimination between groups (mean percentage).
Blue bars represent Control group; Red bars represent ADHD group. Accuracy level in percentages (mean), error bars= Standard Error of mean. Control subjects had more correct responses and fewer incorrect responses than ADHD subjects (p<0.05 Mann–Whitney–Wilcoxon tests). There were no differences in misses responses.
higher percentage of correct responses (90.3% vs 82.3%, p=0.029), fewer incorrect responses (8.5% vs 13.5%, p=0.014) than ADHD subjects, and no differences when comparing misses responses (1.2% vs 4.2%, p=0.075) between groups (Mann–Whitney–Wilcoxon tests).

When analyzing behavioral performance within groups and between experimental conditions we can see that there were no statistically significant differences in none of the comparisons made. Thus, in the control group, the performance between the visual and motor condition was very similar, being slightly better in the visual condition than in the motor one in the percentage of correct responses (91.5% vs 89.2%, p=0.298) and less in incorrect responses (6.9% vs 10.1%, p=0.112), Wilcoxon signed ranks test (Figure 2A). In the ADHD group a slight improvement in the percentage of correct responses was observed in the motor condition more than in the visual one (83.5% vs 81.1%, p=0.787) but this was not significant. Similarly, the percentage of incorrect responses (p=0.574) and missed responses (p=0.127) did not show significant differences between conditions, Wilcoxon signed ranks test (Figure 2B). When analyzing the behavioral performance within experimental condition and between groups we observed that in the visual condition, the Control group showed a better performance than the ADHD group in the percentage of correct responses (91.5% vs 81.1%, p=0.004) as well as a lower number of incorrect responses (6.9% vs. 12.8%, p=0.016) and with no differences in missed responses between groups (Mann–Whitney–Wilcoxon tests), (Figure 3A). In contrast, interestingly in the motor condition (Figure 3B) there were no differences in the behavioral performance between groups in none of the comparisons made, either in correct responses (p= 0.07), incorrect responses (p= 0.145) or misses responses (p= 0.175) (Mann–Whitney–Wilcoxon tests). That is, this could mean the existence of some kind of motor effect that would facilitate or improve the behavioural performance of the subjects in the ADHD group and equals them in performance with Control group.
Figure 2. Discrimination performance within group and between experimental conditions. A) Control group between conditions, blue bars. B) ADHD group between conditions, red bars. Accuracy level in percentages (mean). There were no differences intra groups in none of the comparisons made (Wilcoxon signed ranks test).
Figure 3. Discrimination performance within experimental condition and between groups.
A) Visual Condition between groups. B) Motor Condition between groups. Blue bars represent Control group; Red bars represent ADHD group. Accuracy level in percentages (mean), error bars= Standard Error of mean (Mann–Whitney–Wilcoxon tests).
Then we were also interested to know if there would be any difference in response times between the groups. When we compare correct responses time (ms) within group and between experimental conditions, we observed that in both groups responses in motor condition were faster than in the visual condition, this difference was significant only in control group (visual 995.5ms vs motor 837.7ms), p <0.05 Wilcoxon signed-rank test (Figure 4).

![Figure 4. Correct responses time (ms) within group and between experimental conditions.](image)

In summary, although behavioral results reflect that there are no differences when comparing the motor effect intra group and between experimental conditions, this motor effect was observed when comparing the experimental motor condition, where performance was similar between groups. In addition, response times were significantly faster in both groups in the motor condition, this could indicate again the existence a motor effect that would facilitate the execution of these responses.
5.2 Electrophysiological results.

Event Related Potential (ERPs) analysis.

One of the things that interested us was finding out if the neuronal correlate of behavior was reflected in the electroencephalographic activity. Thus, the first thing we did was studying the CNV that is an ERP that has been associated in the literature with attentional expectation.

In Figure 5, we can see the CNV component evoked in the central electrodes (Fcz, C3, Cz, C4, Cpz) during the task in both experimental conditions. CNV onset was time-locked to sound cue (first vertical arrow at time 0 sec.) and discrimination probe presentation occurred one second later (second vertical arrow at time 1 sec.), color lines corresponds to the CNV mean amplitude for each group. In Figure 5A, we can see how at the beginning of the trial the evoked activity is perfectly locked to the sound cue for both groups and conditions, after which approximately at 400 ms. begin to differentiate between the subjects and between the conditions, which increases as the trial progresses and until the appearance of the discrimination probe. Thus we can observe that CNV presents a significantly larger amplitude in the motor condition than in the visual condition for both groups, being no differences between groups (P<0,05, Montecarlo statistic test). We can also observe that in the control group there were significant differences in CNV amplitude starting early at 400 ms. after the sound key and remaining until the appearance of the stimulus (time-window between 0,4-1,0 sec., P<0,05, Montecarlo satatistic test). On the other hand, in the ADHD group, this initial difference is not observed and only appears in the late CNV stage after 800 ms. after sound key (time-window between 0,8-1,0 sec., P<0,05, Montecarlo satatistic test), Figure 5A. Thus, according to our proposal we can observe that there is a notoriously different electrophysiological correlate between the motor and the visual condition for both groups, again this would confirm that the motor condition is different from the visual condition and could be pointing out that there are mechanisms that would be different or behave differently when a motor component is present and that the presence of this motor component is capable of favoring and improving the attentional processes which is reflected in the positive modulation observed in the CNV in the motor
condition for both experimental groups (Figures 5A y 5B).

**Figure 5. Grand average CNV ERP from the central ROI FCz, C3, Cz, C4, CPz).**

**A) CNV variation during a trial for group and condition.** CNV onset was time-locked to sound cue, first vertical arrow (time 0 sec.). Probe stimulus presentation, second vertical arrow (time 1 sec.). Lines corresponds to the mean of each group, blue lines (control group), red lines (adhd group). Amplitude in microvolts (uV). Time in seconds (sec.).

**B) Scalp maps of the CNV component evoked under all conditions.** (0.4-1.0 sec., P<0.05, Montecarlo satatistic test), Mean of Color scale values in microvolts (uV) p<0.05.
Then we were interested in observing if the motor component could modulate the amplitude of the early ERPs P1 and N1 which have been related to the early attentional processes and that in our experiment were evoked by the presentation of the discrimination probe one second after sound cue. In Figure 6A, we can see early attentional components P1 and N1 evoked in the occipital electrodes (P7, P8, O1, O2) during the task. Here ERPs were time-locked to discrimination probe presentation onset indicated by vertical arrow (at time 1 sec.). In the Control group between conditions, only N1 shown differences with larger amplitude in the motor condition than in the visual condition (p<0.05 wilcoxon test). In P1 and P2 there were no significant differences between conditions (Figure 6A). On the other hand, in the ADHD group P1 and P2 showed a notorious greater amplitude in the motor condition than in the visual condition (p<0.01 wilcoxon test). N1 amplitude was larger in the visual condition than in the motor condition (p<0.05 wilcoxon test), which was the opposite of what was observed in the control group, but this difference disappears when comparing the amplitude of N1 using the peak-to-peak measurement N1-P1, due the visual ERP appears a little upwardly displaced and when adjusting it still maintains the difference in P1 and P2 previously observed but the difference in N1 disappear. When comparing between groups, ADHD group shown greater amplitude in N1 for visual condition (p<0.05 wilcoxon test), and in P1 and P2 for the motor condition (p<0.01 wilcoxon test), Figure 6A. Scalp maps of P1 and N1 are shown in Figure 6B. Thus, we can see a modulating effect by the motor component on the early attentional ERPs in the Control group in N1, and in the ADHD group in P1 and P2. When comparing between groups, a higher modulation is observed in the ADHD group in the components P1 and P2 (in motor condition) and N1 (in visual condition) than in the control group, all the above would show that there is a differentiated modulating effect when motor component is present.
Figure 6. Grand average P1, N1 ERPs from the occipital ROI (P7, P8, O1, O2).
A) P1, N1, P2 elicited by stimulus presentation (probe) in each trial, for group and condition. ERPs were time-locked to stimulus presentation onset (prove) in vertical arrow (time 1 sec.). Color lines corresponds to the mean of each group, blue lines (control group), red lines (adhd group). Amplitude in microvolts (uV). Time in seconds (sec.).
B) Scalp maps of P1, N1 (P<0,05Wilcoxon test), Mean of Color scale values in microvolts (uV) p<0.05.
Finally we were interested in observing if the **P300 component** would be affected by motor interaction. P300 is an endogenous potential that reflect cognitive processes associated with stimulus evaluation and working memory processes, furthermore P300 amplitude is modulated by attention (Donchin & Coles, 1988; Kok, 2001). In Figure 7A, we can see P300 component evoked in the central electrodes (FCz, Cz) during each trial. Here P300 were time-locked to discrimination probe presentation onset indicated by vertical arrow (at time 1 sec.). When observing P300 component amplitud we can see that both groups show a similar behavior being observed a greater amplitude in the visual condition compared with the motor condition in both groups \( p<0.05 \), there being no differences between the groups (Figure 7A). When comparing the amplitude of the P300 in the visual condition the Control group shows a slightly greater amplitude than the ADHD group but not significant with a peak of this close to 500 ms after the presentation of the stimulus. In contrast, in the ADHD group, the maximum amplitude of the P300 is closer to 600 ms after presentation of the stimulus. In the motor condition we observe for both groups that the P300 stops increasing its amplitude at approximately 450 ms after stimulus probe presentation and continues until 600 ms when this amplitude begins to decrease (Figure 7A). The scalp map shows a greater intensity of activation in the visual condition for both groups in the central and fronto medial zone which is not lateralized (Figure 7B).
Figure 7. Grand average P300 (P3) from the central electrodes (FCz, Cz).

A) **P3 variation during a trial for group and condition.** P3 was time-locked to stimulus presentation onset (discrimination prove) showed in vertical arrow (time 1 sec.). Color lines corresponds to the mean of each group, blue lines (control group), red lines (adhd group). Amplitude in microvolts (uV). Time in seconds (sec.).

B) **Scalp maps of P300,** (P<0.05 Wilcoxon test), Mean of Color scale values in microvolts (uV) p<0.05.
5.3 Pupillary diameter variation

To contrast the previous results we thought it would be useful to have another way of measuring the attentional processes of the subjects during the task. For that purpose, we choose an indirect physiological measure of attention (attentional load) widely used in the literature which is the variation of the pupillary diameter (Laeng, Sirois, y Gredeback, 2012; Sarter, Gehring, & Kozak, 2006), and then we compared it between the groups and the experimental conditions throughout the task (Figure 8). Pupil diameter was measured in arbitrary units (normalization) estimated from the maximum and minimum pupil diameter for each subject in each trial. The pupillary diameter amplitude variation was calculated respect to a 500 ms pre-stimulus (cue sound) baseline window. In each trial Pupillary diameter variation was time locked to a sound cue (first vertical arrow at time 0 sec.) and stimulus probe presentation occurred one second after that (second vertical arrow at time 1 sec.).

![Figure 8. Mean pupillary diameter variation during a trial, grand average for group and condition. Diameter in arbitrary units (normalization), time in seconds. Color lines corresponds to the mean of each group for condition, blue (control group), red (adhd group). Color shaded areas correspond to the estándar error of mean. Time locked to sound cue (first vertical arrow, time 0 sec.). Probe stimulus presentation (second vertical arrow, time 1 sec.). (Horizontal bars shows statistical differences between conditions and groups p<0,05, Montecarlo satatistic test).](image)
Figure 8 shows how the pupillary diameter of the subjects varies throughout the trial. We can observe that at the beginning of the trial the pupil diameter is at its basal level and as the trial progresses this diameter progressively increases until 1300 ms. (300 ms. after the appearance of the discrimination probe) when it reaches its maximum diameter, then shows a small drop. The behavior of all curves in Figure 8 is similar except for the curve of the visual condition in the Control group (dashed blue line) which shows a smaller amplitude and earlier stabilization in the progression of its amplitude. This curve in the first 400 ms behaves like the other curves, but then at 500 ms. begins to decrease and stabilize its amplitude increment (0.4 a.u.) differing from the other curves and maintaining this lower amplitude until reaching its maximum pupillary diameter at 1300 ms. (0.6 u.a.), after which it decreases progressively. On the other hand, the pupil diameter in the motor condition of the Control group (continuous blue line) and the visual and motor conditions of the ADHD group (dashed and continuous red line respectively) showed a similar behavior between them, observing a sustained increase from the beginning of the trial until 1300 ms. when it reaches its maximum amplitude (0.9 u.a.), after which they fall slightly. The ADHD group showed a greater amplitude in pupil diameter than the Control group in both experimental conditions throughout the entire trial. Significant differences in pupil diameter amplitude were observed when comparing the visual condition of the control group with the motor condition of the same group from 840 ms. to the end of the trial (p <0.05, Monte Carlo statistical test) and between the visual condition of the control group in comparison with both conditions (visual and motor) of the ADHD group from 780 ms. to the end of the trial (p <0.05, Monte Carlo statistical test). Therefore, we can observe a clear difference in the pupil diameter behavior between the visual and motor condition in the Control group, this difference is not observed in the ADHD group in which in both conditions (visual and motor) the pupil diameter shows a similar behavior between them, furthermore this behavior is also very similar to the observed in motor condition of the Control group (Figure 8). All of this would suggest that there is a different way of deploying attention among these groups during carrying out the analyzed task.
6. DISCUSSION

6.1 Behavioral performance.

To evaluate our proposal the first thing we did was to compare the behavioral performance between groups (Control vs ADHD) in the task. Here we find that when comparing the overall behavioral performance (discrimination rate) between groups without differentiating by experimental condition, we see that the Control group has a better performance than the ADHD group, which is evidenced in the fact that they have significantly higher percentage of correct responses and fewer errors while in the omitted responses there are no differences (Figure 1). This result was expected because the literature indicates that in different kinds of attentional tasks subjects with ADHD perform worse than Control subjects (Castellanos & Tannock, 2002; Nigg, 2005; Mullane & Klein, 2008, Johnson et al., 2008). Another element to consider is that the experimental task was deliberately designed as a visual tracking, which can explain the worst performance of ADHD subjects in the task because the performance of ADHD subjects in this type of task is especially impaired (Rommelse et al., 2008). Thus, we know that our experiment works well in detecting these differences between groups and is a good initial control against which to make other comparisons. When comparing the behavioral performance within groups and between the experimental conditions, we expected that in the motor condition the behavioral performance would be better than in the visual condition, this was slightly observed in the ADHD group, but there were no statistical significant differences in any of the two groups (Figure 2A, 2B). Despite the above, at least the performance between conditions intra each group was matched despite being more difficult to respond in the motor condition because it requires one more button press in the same period for responses. Then, we wanted to know if there were differences when comparing the behavioral performance within each experimental condition and between the groups. Here we find that the differences
shown when comparing the overall performance between groups (Figure 1) were maintained when comparing the groups in the visual condition (Figure 2A), but interestingly, in the motor condition these differences disappear and both groups were matched in performance (Figure 2B). Therefore, these results would indicate that the differences initially observed between the groups are due to the effect of the visual condition and that engaging the subjects in a motor situation makes this difference disappear, that is, there is a some kind of motor effect that could facilitate or improve the behavioural performance of the subjects in the ADHD group and equal them in performance with control group, situation that would support our hypothesis. In line with our results the close relationship and interaction between visual attention and motor actions has been amply demonstrated in studies of covert attention (Craigero, Fadiga, Rizzolatti & Ulmita, 1999; Corbetta et al., 1998; Deubel & Schneider, 2003; Van der Stigchel & Theeuwes, 2005) and overt attention and manipulating objects (Hayhoe, Shrivastava, Mruczek, & Pelz, 2003; Mennie, Hayhoe & Sullivan, 2007). In addition and related with our proposition there is evidence supporting the approach that perception and attention process can be enhanced by action interaction. Deubel and Schneider have shown evidence that spatial coincidence between the place where an action is made and the place where a stimulus is briefly presented enhance our ability to identify it, and this recognition capacity increase if you are pointing to the position where the stimulus appears compared to if you are pointing to a different position (Deubel, Schneider, & Paprotta, 1998; Schneider & Deubel, 2002). Other experiments performed in real situations with interaction and manipulation of objects shown that perceptual judgements (whether stimuli are inverted or not) were influenced by the type of motor interaction that the effector used to respond (Ellis & Tucker, 2000; Tucker & Ellis, 1998, 2001). These studies could help to explain the beneficial effect produced by the motor component, on the ADHD group in the motor condition, in which they
tend to equal their performance with the Control group (Figure 3B). This could also support the existence of a beneficial motor effect (facilitation) in the response time of both groups, in which the subjects respond faster in the motor condition than in the visual condition although this difference was statistically significant only for the control group (Figure 4). An interesting question is to discuss why this improvement given by the motor effect was not observed in the performance of the Control group. We believe that this could be due to the fact that for them the task was very simple (ceiling effect) which is reflected in the high percentage of correct responses observed in them (Figures 1, 2A), which would not allow this difference to be manifested between experimental conditions. Another relevant aspect is related to the design of our experimental task, and is that in most of the studies where this motor effect is reported there is a temporal and spatial coincidence between motor execution and the deployment of the attention process (Deubel, Schneider, & Paprotta, 1998; Schneider & Deubel, 2002), because this would be the factor that produces this enhancement. In contrast, in our task there is only temporal and not spatial coincidence, which could be diminishing the intensity of this effect and would be another factor to explain why this mechanism is not reflected in the control group behavior. But as we will see, this motor effect was found for the control group in the electrophysiology and in the pupillary diameter variation that we will be discussed below.

6.2 Electrophysiology (ERPs).

**CNV component.** In electrophysiology the first ERP that we studied was CNV component which presented two main findings. The first, is that a greater amplitude of the CNV was observed in the motor condition than in the visual condition for both groups, which would account for a greater attentional activation in the motor condition. The second is that this difference was manifested early in the control subjects (early
CNV) and only late in the ADHD subjects (late CNV) indicating a different attentional behavior between them (Figure 5A). Thus, and according to our proposal in the first case we can observe that there is a notoriously different electrophysiological correlate between the motor condition and the visual condition for both groups and this could indicate that there are mechanisms that would be different when a motor component is included in the task, it being able to enhance the attentional processes which is reflected in the positive modulation observed in the CNV in the motor condition for both experimental groups (Figures 5A and 5B). In this regard the CNV is an ERP that has been consistently associated in the literature with attentional expectation (Brunia & VanBoxtel, 2001; Ruchkin et al., 1986; Fan et al. 2007), and has been demonstrated that CNV amplitude is increased during attentional demand (Gontier et al., 2007), which would be consistent with our results. On the other hand, it could be argued that the effect observed in the increase of the CNV in the motor condition is a motor activity effect and not attentional effect, this is because there have been authors who have considered the late CNV as an ERP that indicates only motor preparation (Rohrbaugh and Gaillard, 1983). But at the present, the evidence has shown that it is possible to evoke CNV in the absence of a motor response (Ruchkin et al., 1986; Brunia et al., 2012) supporting the idea that CNV mainly would signal a cognitive mechanism related with attentional expectancy (Mento et al., 2013). In addition, the typical ERP that appears prior to a movement execution is the Lateralized Readiness Potential (LRP), this is a motor preparation related potential that appear lateralized on scalp and showing and showing greater activity over the motor cortex contralateral to the limb that movement was executed, mainly on central parietal electrodes C3 and C4 (Eimer, 1998). In order to rule out this alternative hypothesis, what we did was to look at the topography of the CNV scalp, which appears centralized and not lateralized as it would be if there were a motor component (Figure 5B). We also compared the amplitude of
the CNV in central contralateral electrodes (FC3, C3, CP3 vs FC4, C4, CP4) in both groups of subjects to see if there was lateralization of this, which would be an indicator of motor activity, for which there were no differences. All of the above would demonstrate that the effect observed in the amplitude of the CNV in our experiment is not a direct effect of motor activity but rather the result of attentional expectation processes enhanced by motor interaction, which is our proposal.

It has been described in the literature that the CNV has two components, the early and late phases of CNV (Rohrbaugh and Gaillard, 1983; Brunia and van Boxtel, 2001). The early phase of the CNV evoked by a warning stimulus reflects attention orientation and anticipatory cognitive processes and the late phase of the CNV reflects both anticipatory attention (expectancy) for the imperative stimuli and motor preparation when a response must be executed (Rohrbaugh and Gaillard, 1983; Brunia and van Boxtel, 2001; Mento et al., 2013). Furthermore, different studies have reported that CNV has a reduced amplitude in children with ADHD indicating impaired preparatory processes in them (Banaschewski et al., 2003; Banaschewski et al., 2008; Sartory et al. 2002; Benikos and Johnstone, 2009; Ortega et al., 2012). Our results showed that the greater CNV amplitude observed in the motor condition for both groups was manifested early in the Control group (early CNV) and only late in the ADHD group (late CNV) indicating a different attentional behavior between them. This behavior of the early CNV would be reflecting that the ADHD group has deficiencies in spatial attentional orientation to capture the early attentional key in this task, which has been reported by several previous studies (Perchet and Garcia-Larrea, 2000; Perchet et al., 2001; Nigg and Casey, 2005), after which an attentional build-up process occurs as a result of the motor effect induced in this experimental condition, that allows it to equal the amplitude of the late CNV observed in the control group, matching the attentional processing of both groups.
**P1, N1 and P2 components.** The early ERPs P1, N1 and P2 were modulated by the attention in a different way between the groups and between the experimental conditions (Figure 6A). The P1 and N1 components are visually evoked potentials related to early processing of visual stimuli, both ERPs are sensitive to variations in stimulus parameters (Vogel & Luck, 2000), but N1 amplitude is larger when subjects perform discrimination tasks than when they perform simple detection tasks, so this component has been related to reflects visual discrimination processes (Hopf et al., 2002; Ritter et al., 1979; Vogel & Luck, 2000). Furthermore, the P2 is an endogenous component related with higher-order perceptual processes, like feature detection, memory encoding or working memory (Luck & Hillyard, 1994; Lefebvre, Marchand, Eskes, & Connolly, 2005) that is modulated by selective attention (Hackley, Woldorff, & Hillyard, 1990; Noldy, Stelmack, & Campbell, 1990) and influenced mainly by internal variables rather than characteristics of the sensory stimulus (McDonough, Warren, & Don, 1992). Our results show that in the Control group there were significant differences only in the N1 component, which showed greater amplitude in the motor condition, which would reflect enhanced in discrimination processes for this experimental condition favored by the motor condition. In the ADHD group and between conditions showed a greater amplitude in the components P1 and N1 in the motor condition which would reflect again enhanced in early visual discrimination processes for this experimental condition by the motor component (Figure 6A).

Many studies have shown attentional modulation of the P1 and N1 components by the allocation of attention to specific locations and stimuli (Luck, 1995; Mangun & Hillyard, 1990; Hillyard, Vogel, & Luck, 1998). Our results are consistent with those found by Baldauf in 2009 in a covert attention task and motor preparation in which when the spatial location of the motor preparation coincided with the deploy of attention elicited larger P1 / N1 amplitudes than when these did not coincide indicating...
an improvement of the attention by motor preparation in these conditions (Baldauf & Deubel, 2009). In other ERP study, Eimer et al. (2005), also showed the relationship between covert shifts of attention and manual response preparation. In this study subjects had to prepare a finger movement in left or right hand after a certain delay if during delay period task-irrelevant tactile probes were delivered to the cued hand (attended), enhanced somatosensory ERP components were observed. These studies reinforce the idea that when motor and attentional processes coincide temporally and spatially, they improve the perceptual and attentional processing that is occurring. When comparing between groups, the ADHD group showed a greater amplitude than the Control group in N1 for the visual condition, and in P1 and P2 for the motor condition (Figure 6A). This could be interpreted as a greater enhancement modulation of the perceptual and attentional processes in the Adhd group by the motor component or it is a reflection of a greater attentional demand that this task demands of this group compared to the control group.

**P300 component.** As expected according to the design of the task, the P300 component was elicited around 400 ms. after the appearance of the discrimination probe, this was a reflection of the cognitive processes related to the processing of the stimulus that were occurring. The P300 is an endogenous potential which, unlike earlier P1-N1 components, its occurrence is not related to the physical attributes of a stimulus but rather reflect cognitive processes associated with stimulus evaluation and categorization as well as ongoing working memory processes, more specifically the updating of neural stimulus representation in working memory (Donchin et al., 1986; Kok, 1997; Rushby et al., 2005). Furthermore, P300 is sensitive to target probability (Duncan-Johnson & Donchin, 1977) and its amplitude is modulated by the amount of attentional resources during a dual-task performance and attentional resources allocation (Isreal et al., 1980; Kramer et al., 1985).
In our experiment P300 was clearly evoked in the visual condition in both groups of subjects, but in the motor condition the P300 was evoked with a significantly lower amplitude than in the visual condition for both groups of subjects (Figure 7A). This was contrary to we expected since we thought that the motor component would modulate this attentional component as it did with the early evoked potentials and with the CNV. We thought that this happen because, according to the design of the task, in the motor condition the subjects must press a button to report the appearance of the discrimination probe as soon as they see it appear (report button), a situation that happens between the moment when they see and discriminate the probe and the moment when they must respond about the congruence of this probe. Thus, the motor act of pressing this report button could interfere with or affect the ongoing cognitive processes of stimulus discrimination and working memory that are occurring in this period (Kok, 2001). This report button was deliberately included in the design of the task since this is the mechanism that allows to elicit the motor preparation processes that produce enhance modulation of the CNV and the early ERPs P1 and N1 as discussed above. In Figure 7A, we see that in the motor condition for both groups of subjects, the P300 increases its amplitude until 400 ms where it stops its progression. This is just the moment when the subjects begin to press the report button which could indicate that this is the factor that limits the P300 amplitude in the motor condition. Based on the paradigm of information processing theories applied to the neurosciences, attention has been considered as a selective mechanism to manage and allocate limited cognitive resources, in which the allocation of these scarce attentional resources privileges the processing of certain cognitive processes in detriment of others (Itti et al., 2005). Thus, in our experiment at the time of the press of the report button there would be a competition for the allocation of resources between the motor execution and the ongoing cognitive processes that the task requires. This could explain why the
beneficial effect of attentional modulation produced by the motor component (motor preparation) in the CNV and in early ERPs does not translate into a benefit in behavioral performance due to the interference that the pressing of the report button produces (motor execution) during the stimulus characteristics processing that must be reported. Another explanation for the smaller amplitude of the P300 observed in the motor condition would be that pressing the report button produces a direct motor effect that interferes with the P300 component, but this would not be the case since the scalp does not show lateralized activity which is what would account for this situation (Figure 7B). Furthermore, the literature indicates that the P300 component is not related to motor activity not even in early motor processes, but rather mainly in the upstream cognitive processes (Patel & Azzam, 2005). So the explanation of resource competition would give a better account to the diminished amplitude of the P300 observed in the motor condition (Kramer et al., 1985). Finally, the literature reports that children with ADHD show reduced P3 amplitudes compared to Controls in different paradigms (Banaschewski and Brandeis, 2007, Benikos and Johnstone, 2009b, Doehnert et al., 2010, Spronk et al., 2008). In our case, the ADHD group in both experimental conditions shows a P300 with a slightly smaller amplitude and a longer delay than the Control group, but these differences were not significant.

### 6.3 Pupil diameter.

Pupil diameter has been used for a long time as an indicator of cognitive states of people and has been correlated with states of arousal, emotional valence, physical effort and cognitive load (Just, Carpenter & Miyake, 2003; Bradley, Miccoli, Escrig and Lang, 2008). More specifically, the correlation between some cognitive processes and pupil diameter has also been studied, including target discrimination (Privitera, Renninger, Carney, Klein, & Aguilar, 2010), decision-making (de Gee, Knapen, &

Importantly, in all of these cognitive processes pupil dilation correlates with cognitive demands and task difficulty (Just, Carpenter, and Miyake, 2003, Kramer, 1990). During cognitive processing a phasic dilation of the pupils is evoked, this response depends of the locus coeruleus-norepinephrine system (Aston-Jones & Cohen, 2005). This system, from the locus coeruleus send projections to a different brain regions, but primarily to regions related to attentional processing such as the parietal cortex, the superior colliculus and pulvinar nucleus (Schneider & Kastner, 2009), suggesting that pupil sizes are influenced by attentional processing (Sarter, Gehring, & Kozak, 2006). In our study we used the pupillary diameter as an index to reflect cognitive demands related with the attentional load.

Our results show that the Control group and the ADHD group behaved differently in terms of pupil diameter variation during the task. Thus, in the ADHD group the pupil diameter shows a similar behavior in both experimental conditions (visual and motor) while in the Control group a significant difference between conditions was observed, showing here the visual condition a smaller amplitude during the whole trial (Figure 8). In all experimental conditions the pupil diameter increases in a sustained manner, reflecting a progressive attentional demand throughout the trial, except in the visual condition of the Control group (dashed blue line) that shows a stabilization of this increase at 500 ms. that is when the subjects were able to orienting attention to the target (moving circle on the screen). Then the target was followed visually without an additional attentional effort until the appearance of the discrimination probe (second vertical arrow) when the attentional level rises again to perform the discrimination of the probe, after which the pupil diameter begins to
decrease while the subjects maintain the information in working memory and execute the selected response pressing a button, a situation that the curve does not show since the pupil record is cut before this (Figure 8). On the other hand, in the motor condition (continuous blue line), the attentional requirements are higher and longer. Thus, in addition to orienting the attention to the target and performing the pursuit, prior to the appearance of the discrimination probe, there is a motor preparation to press the report button as soon as the letters appear into the probe, at the same time they must discriminate the stimulus presented and then execute the selected response by pressing the response button. As we noted earlier, there is broad agreement that increases in task demands result in increases in pupil dilation (Just, Carpenter, & Miyake, 2003; Kramer, 1990). Two interpretations have been proposed for this finding: the first is that the dilation of the pupil reflects the demands or load of the task, and the second is that the dilation of the pupil reflects the effort exerted by subjects in response to these demands (Hess & Polt, 1964; Kahneman, 1973). In the first case, the increase in pupil diameter would be a reflection of a greater and better deployment of cognitive resources that would favor a better performance in a task, here individuals with greater pupil dilation should have better performance than individuals with less pupil dilation (Rondeel et al., 2015; Van Der Meer et al., 2010). If instead the pupil diameter was an indicator of attentional cognitive effort, here greater pupil dilation would reflect a greater attentional cognitive effort to perform a given task, in this case if the task is demanding even with large pupillary diameters the performance may be poor or insufficient (Hockey, 1997; Laeng et al., 2011). Alternatively, smaller pupillary diameters and good performance in the same task could reflect that these people process information more efficiently and therefore exert less effort (Ahern & Beatty, 1979). We believe that the pupillary diameter as a reflection of the cognitive load better describes our results. Thus in the Control group we observed a similar behavioral performance between both
visual and motor conditions (Figure 2A), but a significantly lower amplitude in the pupil diameter in the visual condition, which could be reflecting a lower attentional effort in this experimental condition for these subjects (Figure 8). On the other hand, in the motor condition, despite having a behavioral performance similar to the visual condition, the pupil diameter shows a greater amplitude during the whole trial, which would account for a greater attention requirement to achieve the same behavioral result (Hockey, 1997). An alternative explanation is that this greater amplitude in the pupil diameter observed in the motor condition is a reflection of the greater attentional deployment induced by the motor preparation that occurs prior to the appearance of the discrimination probe, which is what we indicated in our hypothesis. Here the motor effect would be potentiating the attentional performance of this group, which should be reflected in a better behavioral performance, but this does not occur (it is the same in both experimental conditions). But as we discussed earlier, the electrophysiological results did show an attentional enhance in the motor condition (reflected in the increased CNV) that apparently is later interfered when they pressing the report button (reflected in diminished P300 in motor condition) which could be the cause that this improvement in behavior was not expressed, so we can not rule out this effect, although it should be better evaluated.

Another important aspect to mention is that the exact relationship between effort and behavior to be reliable must be investigated in an experimental design where floor and ceiling effects are absent (Norman & Bobrow, 1975, Hockey, 1997). Our experiment, as we mentioned earlier in the discussion, could have problems related to the ceiling effect which does not allow us to correctly discriminate the behavioral performance between conditions since it is similarly high for both groups. This is a situation that should be improved in the design of future experiments. In the ADHD group, the pupil diameter shows a greater amplitude in both experimental conditions
(visual and motor) than that observed in the Control group throughout the trial. This greater pupillary amplitude in the ADHD group, which is significant compared to the visual condition of the Control group, was only slightly greater than that observed in the motor condition of the Control group, and there were no significant differences between them (Figure 8). Thus, in the visual condition of the ADHD group (dashed red line) the pupillary diameter shows a clear increase between 400 and 600 ms. that coincides with the orienting attention towards the target, after which the pupillary diameter continues to increase and remains higher than in the other experimental conditions throughout the trial, reaching almost to its maximum possibility of amplitude when the discrimination probe appears (second vertical arrow). This group, contrary to what happens in the Control group, in the motor condition shows a slightly lower pupillary amplitude than in the visual condition during the whole trial, which together with its slight better behavioral performance could indicate some facilitating effect in the motor condition for this group, but we can not make this statement with certainty because of the slight effect observed and probably due to the same methodological reasons mentioned before, the effect of interference of the report button and the ceiling effect that has not been well isolated in our experimental design.

In summary, the greater pupil amplitude observed in the ADHD group throughout the trial in both experimental conditions could be the reflect of a higher demands or attentional effort that for this group represents the task, where to achieve a behavioral performance similar to the Control group represent for this group a high attentional effort, which is reflected in the fact that at the moment of discriminating the probe at the end of the trial, an amplitude of the pupillary diameter is observed almost at its maximum possibility (Figure 8).
The aim of this thesis was to contribute to a better understanding of the interactions between the attention and motor processes like that occur when we carry out goal directed movements or intentional actions. In this situations we propose that the functional coupling between attentional and motor processes modulates (enhance) attentional processes. To evaluate this proposal, we designed a visual pursuit dual task that enabled tested visual discrimination performance and sustained attention in two different experimental conditions, visual and motor interaction. Behavioral performance in the task, electrophysiological evoked components amplitude (CNV, P1, N1, P300) and pupillary diameter variation were measure as indirect indicators of deployed attention. This proposal was evaluated in two groups of children, healthy children (Control group) and ADHD children (ADHD group). Performance and results of both groups in the task were analyzed and compared for all variables in the study. ADHD children are an interesting group for the study of attentional mechanisms because they have problems with sustained attention and response inhibition (Castellanos & Tannock, 2002) and for that reason we thought the task would be demanding for them and a good discriminator between normal subjects and ADHD children. Taken together, the results suggest that in the analyzed task there would be a positive modulatory effect of the motor component on the attentional processes, which despite not being clearly evidenced in behavioral performance, is consistent at the electrophysiological level and in the pupil diameter variation, which would reflect a positive interaction of these processes on attention.

Thus, the main conclusions of this thesis are:

The visual discrimination dual task designed for this research allowed visual and motor interaction in a different way to evaluate and demonstrate a positive effect
of the motor component over the attentional processes in the studied groups. This motor modulation in attention was observed at electrophysiological level and in the pupil diameter variation, but not in behavior performance, we thought this was due to some deficiencies in the experimental design of the task such as the lack of spatial contingency (which is relevant in the goal directed movements) and the way in which the motor component was evoked through a report button that, despite effectively enhancing early attentional process, later during trials apparently produces an interference in the ongoing cognitive processes required to report the discrimination of the response, this was evidenced in a decreased P300 amplitude in the motor condition for both groups and in a worse behavioral performance in this experimental condition.

The behavioral performance (discrimination rate) reported after each trial showed a significantly better overall performance of the Control group compared with the ADHD group, not showing differences between experimental conditions (visual vs motor) intragroup, which is that we expected. The differences observed in the overall performance between groups were maintained when comparing the visual condition intragroup (Control or ADHD), but interestingly, in the motor condition these differences disappear and both groups were matched in performance. Therefore, these results would indicate that the differences initially observed between the groups are due to the effect of the visual condition and that engaging the subjects in a motor situation makes this difference disappear, that is, there is some kind of motor effect that could facilitate or improve the behavioral performance of the subjects in the ADHD group and equal them in performance with control group, situation that would support our hypothesis.
In electrophysiology, the ERPs evoked during the task and related with attention and discrimination process, showed enhanced modulation in motor condition. Thus we could observe that CNV presented a significantly larger amplitude in the motor condition than in the visual condition for both groups, being no differences between groups. This difference was manifested early in the Control group (early CNV) at 400 ms. after the cue sound, while in the ADHD group this initial difference is not observed and only appears in the late CNV stage at 800 ms. after cue sound. This could indicate a different attentional behavior between groups, reflecting that the ADHD group has deficiencies in spatial attentional orientation to capture the early attentional key in this task, situation which has been reported by several previous studies, but after which an attentional build-up process occurs as a result of the motor effect induced in this experimental condition, it equals the amplitude of the late CNV observed in the Control group and matching the attentional processing of both groups. That is to say, again we observe how the motor component favors the attentional enhance of the subjects.

Early attentional ERPs were modulated by the attention in a different way between the groups and between the experimental conditions. In the Control group, the N1 component showed greater amplitude in the motor condition than in visual condition which would reflect enhanced in discrimination processes favored by the motor condition but not reflected in behavioral responses. The ADHD group showed a greater amplitude in the components P1 and N1 in the motor condition, which would reflect again improves in early visualization processes but not reflected in behavioral responses. The P300 component was clearly evoked in the visual condition in both groups of subjects, but in the motor condition the P300 was evoked with a significantly lower amplitude than in the visual condition for both groups of subjects. This was
contrary to we expected and we thought that the lower P300 amplitude in the motor condition is the result of the motor act of pressing the report button that interferes with ongoing cognitive processes needed to carry out stimulus discrimination like working memory that are occurring in this period and its decay was reflected for this smaller amplitude of P300. This report button was deliberately included in the design of the task to elicit the motor preparation processes and despite it produces enhancement of the CNV and the early ERPs P1 and N1 at the same time it would also produce interference with the delayed cognitive processes necessary to report the response and it could be one of the reasons that early attention improvement is not reflected in the behavioral performance of the subjects.

Finally, pupil diameter variation behaved differently between the Control group and the ADHD group. Thus in the ADHD group, the pupil diameter shows a similar behavior in both experimental conditions (visual and motor) while in the Control group a significant difference between conditions was observed, showing the visual condition at a smaller amplitude during the whole trial. We believe that the pupillary diameter as a reflection of the cognitive load better describes our results. Thus in the Control group, we observed a similar behavioral performance between both visual and motor conditions (correct report rate in Figure 2A), but a significantly lower amplitude in the pupil diameter in the visual condition, which could be reflecting a lower attentional effort in this experimental condition for these subjects (Figure 8). Furthermore, subjects of the Control group in the motor condition despite having a behavioral performance similar to the visual condition, the pupil diameter shows a significantly greater amplitude during the whole trial, which would indicate that in this condition the subjects require a greater attention effort to achieve the same behavioral result. An alternative explanation is that this greater amplitude in the pupil diameter observed in
the motor condition is a reflection of the greater attentional deployment induced by the motor preparation, in this case this improvement should be reflected in a better behavioral performance, but this does not occur as we discussed earlier.

In summary, the greater pupil amplitude observed in the ADHD group during the trial in both experimental conditions could be the reflection of a higher demand or attentional effort that for this group represents the task, where to achieve a behavioral performance similar to the Control group represent for this group a high attentional effort, which is reflected in the fact that at the moment of discriminating the probe at the end of the trial, an amplitude of the pupillary diameter is observed close to its maximum possibility (Figure 8). All of this would suggest that there is a different way of deploying attention between these groups and that Adhd group requires a greater attentional effort to get similar results than Control group and that this task is effective to identify these differences.
Annexe 1. Task design
1.A) Temporal sequence of trials in the experimental task.

1.B) Stimuli and Procedure
Annexe 2. Statical design & measurements

2.A) Statical design for comparisons.

2.B) Behavioral, electrophysiological and pupillary measurements.
Annexe 3. Bioethics Committee
This appendix contains the documentation required by the bioethics committee of the medical faculty of the Pontifical Catholic University of Chile to conduct biomedical research in humans.

TÍTULO DEL PROYECTO DE INVESTIGACIÓN:

MODULACIÓN DE LA ATENCIÓN EN UNA TAREA DISCRIMINACIÓN VISUAL INFLUENCIA DE LA INTERACCIÓN MOTORA

(MODULATION OF ATTENTION IN A VISUAL DISCRIMINATION TASK INFLUENCE OF MOTOR INTERACTION)

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DOCUMENTO DE CONSENTIMIENTO INFORMADO

El objeto de esta información es ayudarlo a tomar la decisión de participar o no en este estudio. El presente Consentimiento debe ser leído en el marco de una entrevista del paciente y sus padres o familiares con uno de los investigadores del Proyecto, con el fin de aclarar cualquier duda y tomar así una decisión bien informada respecto a participar o no en la investigación propuesta. A la familia se le da la opción de llevar el consentimiento a casa para consultar con otras personas antes de tomar una decisión.

OBJETIVOS DE LA INVESTIGACIÓN:

Esta investigación tiene por objetivo el evaluar cómo los niños con Trastorno por Déficit Atencional e Hiperactividad (en adelante, TDAH) controlan los movimientos de sus ojos mientras ejecutan una tarea determinada. Los movimientos de los ojos son extremadamente importantes para explorar el mundo que nos rodea. Qué vemos y qué recordamos depende en gran medida de dónde fijamos nuestra vista, aunque sea por un tiempo muy corto. De esta manera, este estudio intenta determinar si existe alguna diferencia en los movimientos de los ojos entre los niños sin ningún diagnóstico neurológico y los pacientes con TDAH, y en la actividad cerebral que tiene lugar mientras ellos realizan estos movimientos. De obtenerse resultados positivos, pensamos que dichos hallazgos podrían apuntar a estrategias terapéuticas para estos niños en el futuro.

Los niños participarán un experimento que se realiza sentado frente a una pantalla de computador. En la pantalla del computador se mostrarán una serie de esferas de distinto color que se mueven y rebotan continuamente en los 4 costados de la pantalla, se le pedirá al niño que siga continuamente con la mirada una de las esferas (por ejemplo, la esfera azul). Esta esfera azul durante su trayectoria chocará con otras esferas y el niño deberá intentar seguirla con la mirada lo mejor posible mientras dure su desplazamiento por la pantalla además deberá intentar discriminar un blanco visual que aparecerá momentáneamente en el interior de la bola que está siguiendo y deberá discriminar si este estímulo es congruente (2 letras iguales) o incongruente (2 letras diferentes). En la segunda parte del experimento el niño deberá realizar la misma tarea de seguimiento ocular de la esfera, pero ahora además, presionará una botonera cuando el estímulo a discriminar sea congruente.

Durante el experimento, monitorearemos los movimientos oculares del niño por medio de un aparato llamado eyelink 1000®, el cual es usado en forma rutinaria en este tipo de trabajos. Además, mediremos la actividad eléctrica cerebral por medio de un sistema de electroencefalografía Neuroscan®. Amos sistemas están totalmente avalados para su uso en
personas normales y en pacientes, son totalmente inocuos para el sujeto, y no causan ningún tipo de molestia aparte de tener que lavarse el pelo después de los experimentos.

Se admitirán niños con diagnóstico certero de TDAH, de 8 a 13 años de edad, con inteligencia normal, y sus familiares directos. Pruebas neuropsicológicas se efectuarán en cada niño. Se estudiara además a un grupo de niños de igual rango de edad, sin TDAH, que servirá como grupo de comparación o control.

**DETALLE DE PROCEDIMIENTOS:**
1° Explicación del Proyecto (paciente y apoderado responsable) 2° Entrevista y examen clínico con Neuróloga Pediátrica
3° Entrevista con Psicóloga Clínica Infanto-Juvenil
4° Evaluación de Inteligencia (test de Wechsler, aplicado por Psicóloga Clínica. 5° Sesiones de pruebas neurocognitivas y electroencefalográficas.

Estas son las pruebas ya descritas, durante las cuales a los sujetos se les toma un registro electroencefalográfico. Este registro es no invasivo e indoloro, y se coloca al paciente una gorra provista de electrodos destinados a captar la actividad eléctrica de la corteza cerebral. Los movimientos oculares se miden por una pantalla que monitorea los desplazamientos de los ojos en los sujetos. Cada uno de los tests se administrará en una o dos sesiones y tendrá una duración de entre una y tres horas. El horario será convenido con la familia.

**BENEFICIOS DEL ESTUDIO:** No hay beneficios por participar. Como participante usted estará contribuyendo para que la ciencia médica amplíe sus conocimientos sobre el TDA y mejorar así su enfrentamiento clínico. Los beneficios son más bien a largo plazo y en un sentido global más que personal; no implica un tratamiento. Si bien lo anterior, cada familia recibirá un informe sobre los resultados de todos los exámenes, de libre disponibilidad (si los padres lo desean, pueden mostrar estos exámenes a otros profesionales involucrados en el tratamiento del niño).

**RIESGOS:** No hay riesgos asociados a este proyecto.
**COSTOS Y COMPENSACIONES:** Gastos de transporte del paciente y sus familiares serán financiados con dineros del Proyecto. Todos los exámenes y procedimientos antes descritos son gratuitos para el paciente y su familia.

**CONFIDENCIALIDAD:** Si bien los resultados que se obtengan pretenden servir para publicaciones de carácter científico, se garantiza confidencialidad, es decir, la identidad de los participantes permanecerá en secreto; cualquier persona ajena a esta investigación carece
de acceso a la información que se pueda obtener con ella.

**PARTICIPACIÓN EN EL ESTUDIO:** La participación en este estudio es enteramente libre, gratuita y el otorgamiento del consentimiento por parte de los participantes no tiene ningún tipo de repercusión de orden económico, legal, ni obligatorio a futuro. Asimismo, los participantes pueden abandonar el estudio en cualquier fase de éste si esta fuera su voluntad. La no participación en el estudio no tendrá ninguna consecuencia en el manejo médico futuro o la relación con los médicos tratantes.

**COMUNICACIÓN CON EL INVESTIGADOR PRINCIPAL:**
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**COMUNICACIÓN CON EL COMITÉ DE ÉTICA:**
Comité de Ética de Investigación de la Escuela de Medicina, Pontificia Universidad Católica de Chile, Av. Marcoleta 301, Santiago de Chile. Para cualquier consulta, se ruega contactar:
Presidente de Comité de Investigación Dr. Eduardo Guarda, Fono: 354 8173.
DECLARACION DEL PACIENTE Y DEL APODERADO RESPONSABLE
Consentimiento informado

El presente estudio se me ha explicado por __________________________ (nombre de la persona informante), en forma verbal y escrita. He podido aclarar todas mis dudas respecto del proyecto y entiendo que si surgen dudas adicionales me serán oportunamente aclaradas. Por lo tanto, consiento voluntariamente que mi hijo / hija / pupilo ______________
___________________________________________________________ participe en esta actividad. El investigador ha expresado estar disponible para atenderme.

Entiendo que mi hijo o hija será citado(a) a una o dos pruebas para medir sus capacidades de control de los movimientos oculares; cada una de estas pruebas toma entre una y dos horas; mi hijo(a) será citado(a) no más de dos veces, en días distintos. Si él o ella se siente incómodo y desea abandonar el estudio, es libre de hacerlo en cualquier momento y sin ningún tipo de consecuencias.
______________

Nombre, firma ____________________________________________

___________________________________________________________

Nombre, firma del padre / madre / apoderado ________________

___________________________________________________________

Firma Investigador Responsable: ____________

___________________________________________________________

Cristián Arellano Roco

Fecha y hora: ______________________________

Firma Director de la Institución o su delgado: ________________________________

___________________________________________________________

Dr. Francisco Aboitiz (delegado)

ASENTIMIENTO
Me han explicado en qué consiste este estudio y las actividades en las que debo participar. Sé que seré citado a realizar varias pruebas en el computador, donde me van a poner una gorra con electrodos para medir la actividad del cerebro en un electroencefalograma. Cada prueba dura entre una y dos horas, y me van a citar hasta dos veces.

Me han explicado que mi participación en este estudio es voluntaria. Entiendo que puedo dejar voluntariamente el estudio si así lo deseo, o sea puedo retirarme en el momento que me sienta incómodo sin que esto produzca ningún problema. Si me llegara a ocurrir algo malo, seré tratado a tiempo y sin ningún tipo de costo.

La persona que me ha informado es: ____________________________________________

_________________________________________

Nombre y firma del participante: ________________________________________________

_________________________________________

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