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Neural Dynamics Predict Visuomotor Decisions

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List of Acronyms

AD	Alzheimer's Disease
BCI	Brain-Computer Interfaces
BP	Bereitschaftspotential / Readiness-Potential
DM	Decision Making
EEG	Electroencephalography
EMG	Electromyography
ERD	Event-Related Desynchronization
ERS	Event-Related Synchronization
GM	Global Motion paradigm
GMD	Global Motion direction Detection task
GME	Global Motion direction detection task with Early responses
GMHS	Global Motion with Hand Switching task
ICA	Independent Component Analysis
MC	Motor Cortex
MEG	Magnetoencephalography
ONI	Observtion with No Instructions task
PD	Parkinson's Disease
QSE	Questionnaire for Subjective Experience
RDM	Random Dot Motion task
RT	Response Time
SLRMT	Simple Left/Right Motor Task
SMD	Simple Motion Detection task

Outline

The thesis is organized in the following structure: the first chapter provides the necessary theoretical background related to the work performed. An introduction to decision making is followed by some basics related to electrophysiology, the main research focus, and the study goals. Chapter 2 describes the methodology of the experiments that were conducted. Chapter 3 provides the behavioral, neuroscientific, and experiential results. Finally, in chapter 4, results are discussed -apart from the framework of the present study- from a broader perspective that leads to suggestions for practical applications.

Chapter 1: Introduction

1.1 Motivation.

“What is going on in our brain when we are going to act or make a decision? I mean the foreperiod during which the readiness potential occurs: Standing immediately prior to a decision, already driven by will, but reflecting and perhaps inner struggles and then insight; after the planning and the decision there is —despite the delegation of many details to subprograms which were overlearned and then became unconscious again—purposeful vigilance, care, thoroughness, corrections, will of completion and new plans: all this belongs to will. The crucial final hurdle is the decision. Power of decision above all belongs to will, but stamina is also important. Prior to all this there is already openness to the world, active searching, perceiving, considering and thinking, the manifold mental interests which already begin in infants when collecting leaves or shells.”

Deecke, 2012, p.407

1.2 The concept of decision making.

Decision making (DM) is one of the most complex expressions of human behavior. A commonly accepted definition refers to DM as “the process of choosing a preferred option or course of action from among a set of alternatives” (Wilson & Keil, 1999, p.220; Zhu, 2004, p.307). From relatively simple, fast, and even non-conscious decisions like which hand to move to scratch our forehead while being absorbed by a book, to more complicated ones like what career path to follow, at almost every moment of our lives we encounter situations where we are inevitably embedded in this process - either we like it or not, either we are aware of it or not. Taking into account the usually present factors in DM, uncertainty (about our environment) and conflict (over personal preferences), the process often begins at the information-gathering stage[1] and, following intermediate decision phases according to the nature of the decision, most of the times concludes with the final act of choosing[2] (Wilson & Keil, 1999). For instance, Shall I take an umbrella on a cloudy day? Or, Shall I choose this potential mate over the other? Or even, Is the color of this towel pink or purple?

DM has been studied by various arts and sciences, including Philosophy, Psychology, Economics, Sociology, Mathematics and more, and the topics of study depend on the spotlights of each discipline. Only that since recently, new players joined the game: the evolution of cross-disciplinary sciences concerned with the study of cognition, like Cognitive Neuroscience, allows us to examine the mind and brain bases of DM processes and associated acts. Approaches, methods and topics in Neuroscience vary from research on basic physiological processes (e.g., decision making for finger flexion), to more complex aspects of decisions, like the ones studied in the sub-fields of neurolinguistics, social and affective neuroscience, and neuroeconomics, to name some. Despite this diversity of applications, most decisions share common elements including deliberation and commitment (Gold & Shadlen, 2007).

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1 Or else, evidence accumulation stage.

2 The terms choice and decision will be used interchangably in this work.

From a medical-neurological perspective, "the study of the process of decision making in healthy and 'normal' *[sic]* brain is very important for understanding the underlying mechanisms in healthy people as well as for understanding and treatment of neurological disorders with affected decision making i.e. Parkinson's disease" as Pirtosek (2009, p.42) notes. In addition, better understanding of DM in the brain can offer tools for the improvement of neuropsychological assessment and diagnosis, which can lead to life-quality improvement, like, for example, in patients with disorders of consciousness or with locked-in syndrom. It can also lead to technological advancements in Brain-Computer Interfaces (BCI) that provide applications in a wide range of life settings[3].

Further, and in order to set a working framework, Pirtosek et al. (2009) suggests that neuroscience needs an "operational definition of decision making (as a process) and decision (as an action)" and proposes that "one of the possible definitions of decision making determines three conditions: 1. at least two different options should be available, 2. each possible choice offers certain outcome expectation, 3. possible outcomes can be evaluated" (p.42). This proposal is warmly welcomed and adopted in the present experimental work.

With an eye towards human Cognitive Sciences, this thesis focuses on the empirical study of two-alternative decision making at the individual level, mainly using cognitive neuroscientific methods and tools. We focus on simple decisions that can be studied in the laboratory, but are generally likely to extend to other settings as well.

3 For a review on BCI see Nicolas-Alonso & Gomez-Gil (2012).

1.3 Background and context.

1.3.1 Cognitive neuroscientific approaches in decision making and the prediction of behavior.

According to Smith and Ratcliff (2004), “the question of how decisions between two alternatives are made in the brain is an important one for neuroscience and psychology alike because of the pivotal role played by decision making in translating perception and cognition into action. This translation brings encoded stimulus information into contact with the behavioral intention of the decision maker to produce a goal-directed act” (p.161). But is it possible to identify neural correlates of these (motor) acts, that may even be present before the acts occur? In cognitive neuroscience, research on the topic was initiated by the discovery of electroencephalographic (EEG) activity present prior to volitional movement by Kornhuber and Deecke (1965), and studies that have dealt with the relation of brain activity to specific decisions for motor acts started taking place three decades ago. As a representative example to mention, the highly influential and controversial experiment Benjamin Libet and colleagues (1983) conducted, which advanced neural science -and empirical sciences in general- not only to new frontiers in understanding the brain, but to also participate in debates in which, back then, mainly philosophers were present.

Libet's measurements were focused on the 'Bereitschaftspotential' (BP) of the EEG or otherwise Readiness-Potential, a motor-related cortical potential commonly thought to reflect movement preparation and found over the motor cortex (MC) (Shibasaki & Hallett, 2006). His experiment had two main requirements for the participants. They were instructed to perform 'spontaneous' *[sic]* self-initiated flexions of their fingers and/or wrist of their right hand; moreover, they had to pay attention to a revolving dot of a clock and report its position at the time that they consciously decided to perform the above movement. Results showed that the cortical activity was present on average up to 1000 ms before movement and 350 ms before individuals were even aware of their intention to perform a movement (Libet et al., 1983).

Since then, a great body of empirical and theoretical work has risen across domains, with arguments and results either approving or disapproving Libet's initial research design, results, and implications. Apart from works that criticize Libet's methods and conclusions indirectly (Banks & Isham, 2009; Gomes, 1998; Gomes, 2010; Haggard, 2005; Klemm, 2010; Zhu J., 2003), similar ones that were based on Libet's experimental design found different results or inconsistencies (Miller, Shepherdson, & Trevena, 2011; Trevena & Miller, 2010).

However, other studies, using the same or different neuroimaging methods, reached the same conclusions that Libet's study implied: that neural events can predict subjects' choices prior to the behavioral manifestation of their decision, and that these events may even occur before the decision awareness, thus addressing the issues of causality, freedom of will, and the nature of consciousness (Desmurget et al., 2009; Haggard, 2011; Soon, Brass, Heinze, & Haynes, 2008). Nevertheless, there are some critical eyes on these studies as well (Klemm, 2010; Hallett, 2007).

Points of criticism that the present study tries to surpass are directed to the degree of specificity of the BP to a decision, the small number of participants that most of the studies were directed to, leading to overgeneralizations, and the sometimes complex nature of the experimental design.

1.3.2 Electrophysiology.

1.3.2.1. The electrical brain and methods of measurement.

The electrophysiological activity of the brain is produced both by the electro-chemical transmitters exchanging information between the neurons and by the ionic currents generated within the neurons themselves; this activity can be measured thanks to Electroencephalography (EEG), Electrocorticography, Magnetoencephalography (MEG) and invasive electrical measurements operated at the single neuron level (Castermans, Duvinage, Cheron, & Dutoit, 2013).

Relevant to our study, EEG is a record of the brain's electric activity caused by currents induced by neurons during synaptic excitations of the dendrites (Nicolas-Alonso & Gomez-Gil, 2012). For the generation of an EEG oscillation, thousands of cortical pyramidal neurons are thought to be involved, which are assumed to be dependent on interactions between the cortex and the thalamus (Cacloppo, Tasslnary, & Berntson, 2007). EEG measurements are realized non-invasively, by placing electrodes on the scalp, offerring spatial resolution of a few millimeters and temporal resolution of a few milliseconds (Castermans et al., 2013). To understand the functional scale, “a single electrode provides estimates of synaptic action averaged over tissue masses containing between roughly 100 million and 1 billion neurons” (Nunez & Sirivasan, 2006, p.3). An overview of EEG characteristics described above is shown in figure 1.

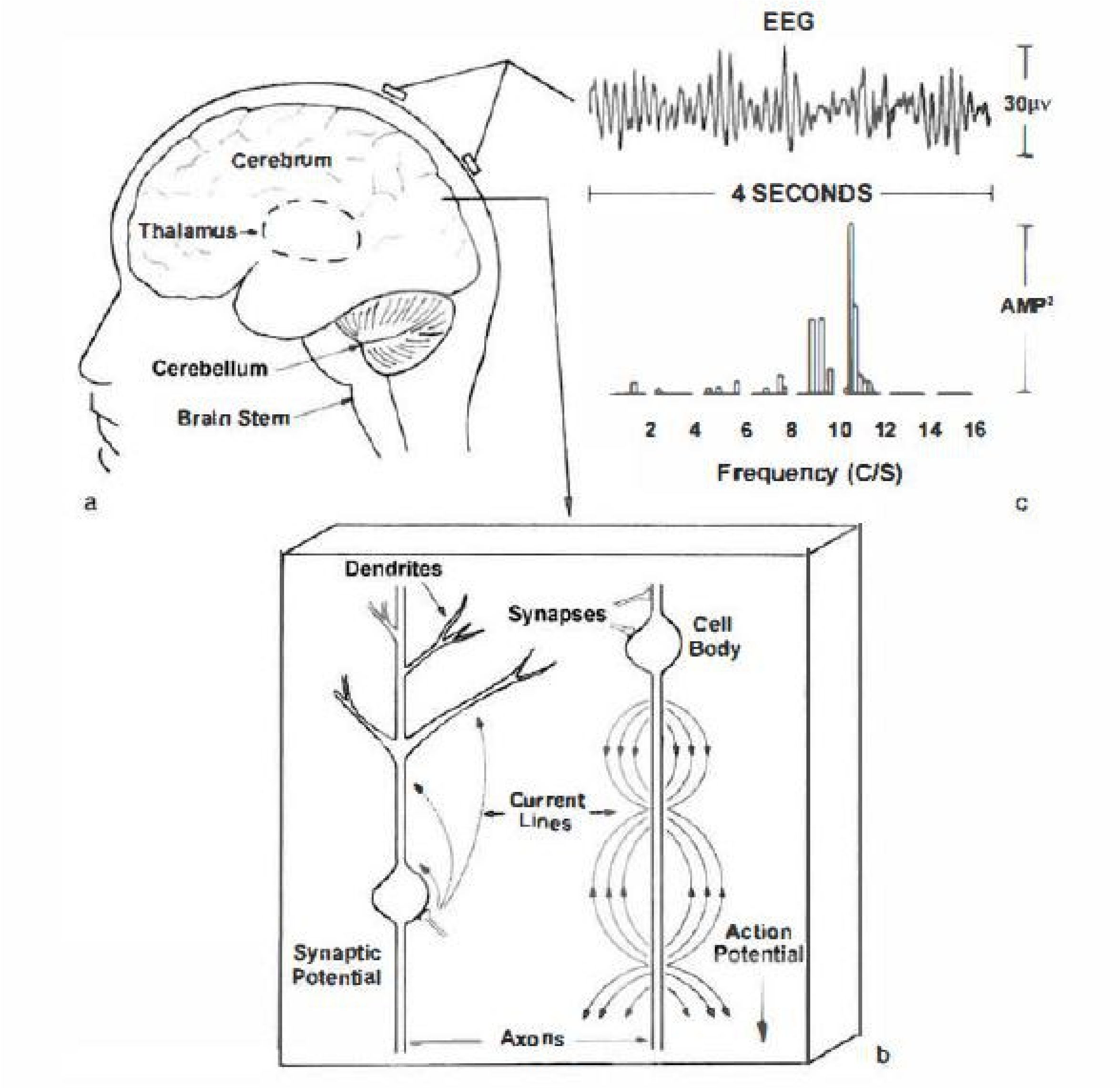

Figure 1. (a) The human brain. (b) Section of cerebral cortex showing microcurrent sources due to synaptic and action potentials. Neurons are actually much more closely packed than shown, about 10^5 neurons per mm^2 of surface. (c) Each scalp EEG electrode records space averages over many square centimeters of cortical sources. A four-second epoch of 8-12 Hz (or alpha) rhythm and its corresponding power spectrum are shown. Reprinted from Nunez & Sirivasan, 2006 © .

1.3.2.2 Neural oscillations and Event-Related Desynchronisation/Event-Related Synchronization

EEG comprises a set of oscillatory signals which may be classified according to their frequency. These frequency bands are conventionally referred to as delta (δ), theta (θ), alpha (α), beta (β), and gamma (γ) from low (1 Hz) to high (>30 Hz) respectively, defined according to distribution over the scalp or biological significance (Nicolas-Alonso & Gomez-Gil, 2012). The question of how oscillatory activity in the brain codes information for human cognition remains unanswered, with evidence suggesting that neuronal oscillations play an important functional role in cortical information processing (Siegel, Engel, & Donner, 2011), connecting the above classification to a number of cognitive functions.

In the neuronal network scale, coherent oscillations within and between cortical regions may flexibly regulate the interactions among distributed neuronal populations, and synchrony may serve as flexible mechanism to control the gain of local and long-range neuronal communication (Siegel et al., 2011). Further, "neuronal oscillations at different frequencies may provide valuable mechanistic information about the interactions between groups of neurons" (Donner & Siegel, 2011, p.2). The study of oscillatory EEG signals in the sensorimotor and related cortical areas provides a window into how the information processing in multiple neuronal networks may be realized (Neuper, Wörtz, & Pfurtscheller, 2006). In addition, certain events can cause frequency-specific changes in the ongoing EEG activity and may consist either of decreases or of increases of power in given frequency bands, fact that is thought to be due to a decrease or an increase in synchrony of the underlying neural polpulations, respectively (Pfurtscheller & Lopes da Silva, 1999). The former case is called Event-Related Desynchronization (ERD), while the latter Event-Related Synchronization (ERS).

It is now known that frequency power changes are associated with the preparation, production, and imagination of human voluntary movement (Neuper et al., 2006). The story begins back in 1979, when Pfurtscheller et al. reported a decrease of frequency power (or ERD) in the alpha band (8–12 Hz) and in the central beta band (16–24 Hz) beginning about 2 seconds before self-paced button pushing (Bai et al., 2011). ERD is most prominent over the contralateral sensorimotor areas (figure 2) during motor preparation and extends bilaterally with movement initiation (Neuper et al., 2006).

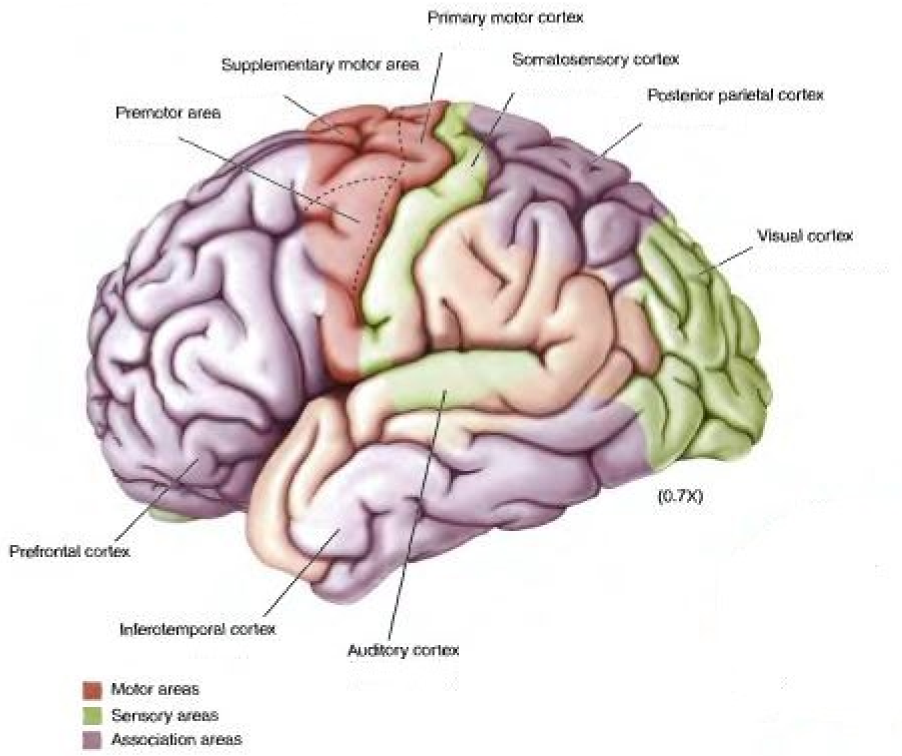

Figure 2. The gross anatomical divisions of the cerebral cortex. Adapted from Bear, Connors, & Paradiso 2007 ©.

ERD is accepted to be a reliable correlate of excited neuronal networks or activated cortical areas, whereas ERS correlates with cortex deactivation (Pineda, 2005). One of the basic features of ERD/ERS measurements is that the EEG/MEG[4] power within identified frequency bands is displayed relative (as percentage) to the power of the

4 Magnetoencephalography (MEG) detects the weak magnetic fields resulting from the intracellular electrical currents in neurons. The neurophysiological processes that produce MEG signals are the same as those that produce EEG signals, although the advantage of MEG is that magnetic fields are less distorted by the skull and scalp than electric fields (Castermans, Duvinage, Cheron, & Dutoit, 2013).

same EEG/MEG derivations recorded during the reference or baseline period a few seconds before the event occurs (Pfurtscheller & Lopes da Silva, 1999).

Pfurtscheller & Lopes da Silva (1999) descibed the steps for the computation of ERD/ERS (figure 2):

1. bandpass filtering of all event-related trials;
2. squaring of the amplitude samples to obtain power
samples;
3. averaging of power samples across all trials;
4. averaging over time samples to smooth the data and reduce the variability.

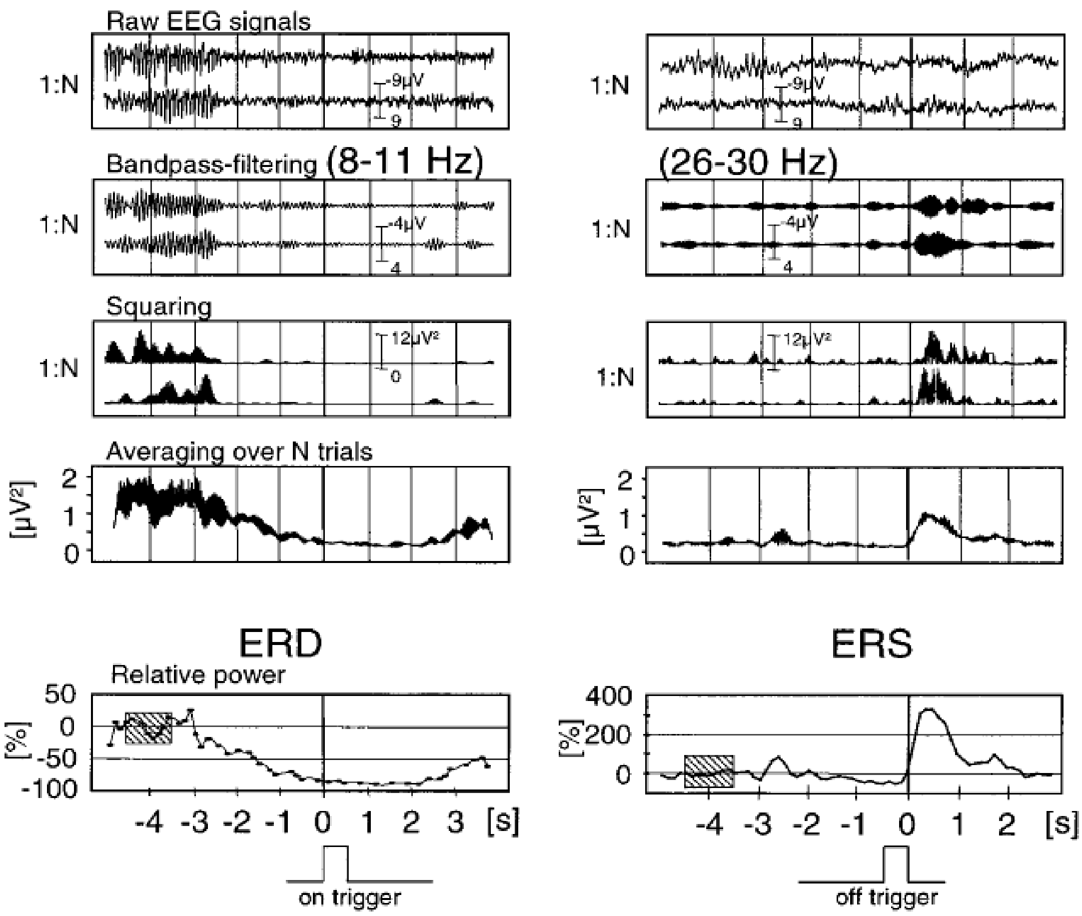

Figure 3. Principle of ERD (left panel) and ERS (right panel) processing. A decrease of band power indicates ERD and an increase of band power ERS. Note the different triggering with ERD and ERS processing. Reprinted from Pfurtscheller & Lopes da Silva, 1999 ©.

The main focus of the present research is to examine possible neural prediction of visuomotor decisions based on electrophysiological measures mentioned above (EEG ERD/ERS), by developing and using a paradigm of perceptual DM, namely a task of visual motion direction detection.

1.3.3 State of the art.

Perceptual DM refers to the process by which information accumulated from sensory systems is combined and used to influence behavior in our environment (Heekeren, Marrett, & Ungerleider, 2008). This process is often modeled as a temporal accumulation of sensory evidence to an internal decision threshold, which signs the commitment to a particular choice (Philiastides, Auksztulewicz, Heekeren, & Blankenburg, 2011). For example, say you are at a normal speed, driving in the city and you are approaching a traffic light. Suddenly, the green light turns into orange. You basically have two kinds of possible outcomes in this case: either to continue and pass it, or to break and stop. Your decision depends on the sensory evidence that you receive from the environment: orange light, speed of the car, distance from the traffic light, condition of the road, and also from the attentional/emotional states. You quickly have to make a judgment, take a decision and act. Perceptual decisions can also be influenced by other factors, such as attention, task difficulty, prior experiences and the outcome of the decision (Heekeren et al., 2008). Some models of perceptual DM usually depict the process in a serial, hierarchical manner (figure 4). Despite the fact that evidence from neuroimaging studies suggest bi-directional models of perceptual DM (figure 5), initially we had used a serial model to built the experimental design of the present research.

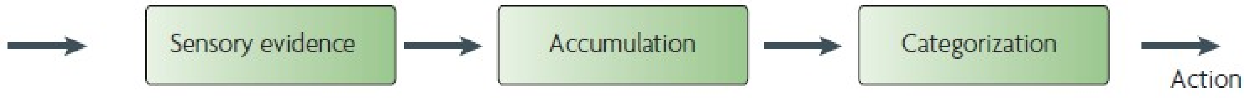

Figure 4. A model of perceptual DM, with serial progression from perception to action. Adapted from Heekeren et al., 2008 ©.

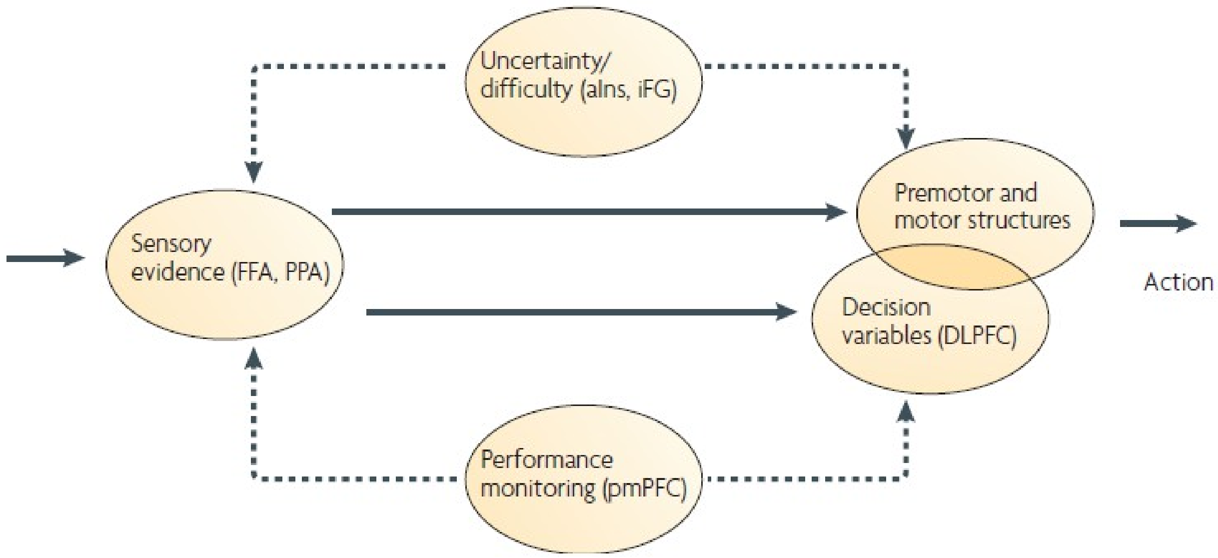

Figure 5. Cortical circuits implementing the DM process are, according to recent evidence, likely to engage in recurrent interactions mediated by bi-directional connections in the cortex (Siegel, 2011). Adapted from Heekeren, 2008 ©. For simplicity, explanation of the abbreviations in the figure is ommitted.

In laboratory settings, perceptual decisions are suited for the study of neural dynamics in the human brain, and a framework used is the mapping of those -usually binary- decisions onto motor acts. To achieve this, research groups recently started using paradigms from psychophysics, like the Random Dot Motion (RDM) direction discrimination task. This task requires a decision between two possible directions of motion of randomly moving dots. Apart from single neuron recordings in monkeys (Gold & Shadlen, 2007), the RDM task now also has applicability in combination with non-invasive techniques for the characterization of oscillatory properties and of cortical network interactions underlying perceptual decision processes in the human brain (Heekeren et al., 2008; Siegel et al., 2011).

In a recent and maybe the most relevant study conducted with MEG, Donner and colleagues (2009) coupled an intentional motor act with a perceptual decision in an RDM task, in which “yes/no” choices for coherent dot motion were given with different hands by button presses. It was found that, during stimulus viewing, the build-up of lateralized activity over the motor cortex was choice-predictive as to the hand used for responding. This gradual build up was expressed by changes in beta (12-36Hz) and gamma (64-100Hz) bands in terms of deviations from a chance level of P=0.5 after stimulus onset, and reflects, according to the authors, the temporal accumulation of evidence provided from the sensory to the association cortex.

1.4 Research Goals and Questions.

Since the evidence shows that the brain is activated before the execution of voluntary movement, we examined the possibility that ERD/ERS analysis can predict a left or right hand movement, depending on a two-alternative visual decision. The gateway to this goal was a variation of the RDM, the global dot motion direction detection paradigm (Global Motion, GM), initially tested in a preliminary study at the Laboratory for Cognitive Neuroscience with promising results[5], and further developed for the purposes of our research. We were also aiming at identifying the optimal ERD/ERS frequency band that can provide the earliest time-point of prediction. Based on the above, potential issues regarding the temporal relationship between the perceptual decision awareness and the onset of predictive activity in the brain were also explored and will be briefly discussed in the present work. To summarize, the main research goals of this thesis are the following:

- To present a paradigm and test it with a neural signal analysis method that can more reliably address the question of neural activity preceding a binary visuomotor choice.
- To investigate whether the presented framework is suitable for studying decision making in relation to perceptual awareness.
- To explore possible applications, depending on the results.

The fundamental questions of this work are the following:

- Is there ERD/ERS activity that differentiates, i.e. is specific to a binary perceptual decision that is expressed by a motor act, before the act occurs? When is the earliest point that this activity predicts the decision outcome in the brain, and which is the frequency band that better demonstrates that?
- Is it possible that the neural prediction precedes the time of perceptual awareness that leads to a visuomotor decision?

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5 For details, see Brezovar et al. (2012).

Chapter 2: Methods

2.1 Subjects.

Twenty-five healthy volunteers (14 females, 11 males) participated in the study (mean age = 25,7; SD = 4,7), during the period 12 November 2013 – 12 December 2013 at the Department of Neurology, University Medical Center Ljubljana. The study consisted of two sessions at different days for each participant, and all participants gave their written informed consent before each session. The study was approved by the National Ethics Committee. Participants were recruited through personal contacts and social media, and were invited to participate under the conditions of right-handedess and adequate English language knowledge, as the study was realized in English. Upon online registration and two days prior to their scheduled appointment, they received introductory information and preparation instructions via e-mail, for the sake of quality of EEG signal acquisition and of their behavioral performance, like for example to have a good night's sleep the night before the sessions. On site, they were screened in advance for vision, handedness, years of education and health history that could affect their involvement. All participants had normal or corrected to normal vision; most of them were university students or graduates (mean years of completed education = 16; SD = 2), interested in brain and mind research. There was no financial compensation for their participation; however, five of them received study credits, as this experiment partially fulfilled course requirements of the cognitive science master's study program. Twenty of them were right-handed and five ambidextrous, according to the Edinburgh Handedness Inventory (Oldfield, 1971). Finally, all subjects were naive as to the study aim and the tasks until they had to perform each one of them.

2.2 Experimental design.

As mentioned above, the study was realized in two separate sessions for each subject – an electrophysiological / behavioral and a behavioral only. Because of the total length and the numerous repetitions necessary to obtain the examined neurophysiological signals, the first session was devoted to electrophysiological recordings while performing the GM tasks. Subjects were asked to return for the second session after a period between three and eight days, in order to relatively maintain the same training effects across all individuals.

The sessions comprised of a brief introduction to the experiment followed by a sequence of practice runs, actual runs, and breaks inbetween. Subjects were given written and oral instructions before the beginning of each practice run and were re-instructed when necessary, as the experimenters were present at every break. They also received visual feedback on the screen after each run, in terms of percentages of correct responses and reaction times[6].

At the end of each session, participants completed a short questionnaire for subjective experience (QSE, see appendix), which consisted of four questions and an open question regarding any comments related to their answers, experience, and/or experimental procedure. Participants were not informed about the nature of this questionnaire beforehand. The QSE was inspired by studies in neurophenomenology[7] and developed in accordance to our experimental design. It served to monitor two factors: the level of sustained attention, and the level of task automatization. Although the QSE may have limitations and not be representative because of the length of the experiment leading to different experential phases along the timespan, we used it to have a rough and general documented impression of the subjects' experience.

6 Pilot subjects sugested that this improves overall task motivation and performance.

7 For example see Lutz, Lachaux, Martinerie, & Varela, 2002.

2.2.1 Stimuli: the Global Motion paradigm.

The GM paradigm (figure 6) was the basis for a variety of tasks (main and control tasks) that participants performed in each session, and was built upon three requirements

- Possibility of directly observing all possible decision outcomes (binary design in our case).
- Balanced level of difficulty for the participants to solve it, in order to temporally space out the various brain and mental processes, so they may be observed and compared.
- Production of very accurate behavioral responses (above 80%).

The paradigm was built offline and presented with E-Prime software. Stimuli were presented on an LCD screen, in front of the subjects head, at a distance of 90 cm. The refresh rate of the screen was 120 Hz. Each frame consisted of an array of white dots distributed on a black background. Each dot was displaced from frame to frame according to the following rules:

For GM right, dots were programmed to move at a range of motion of 345° at each frame[8]. The restricted 15° corresponded to a completely left motion direction on the horizontal axis. This resulted to the perception of the global (net) motion of the dots as right. For a GM left, the opposite pattern was designed.

8 The angle of motion corresponded to the difficulty level, and was decided after behavioural testing on various angles (340° , 345° , 350°). As we needed the subjects to take sufficient time to realize the global direction, 345° was the most optimal.

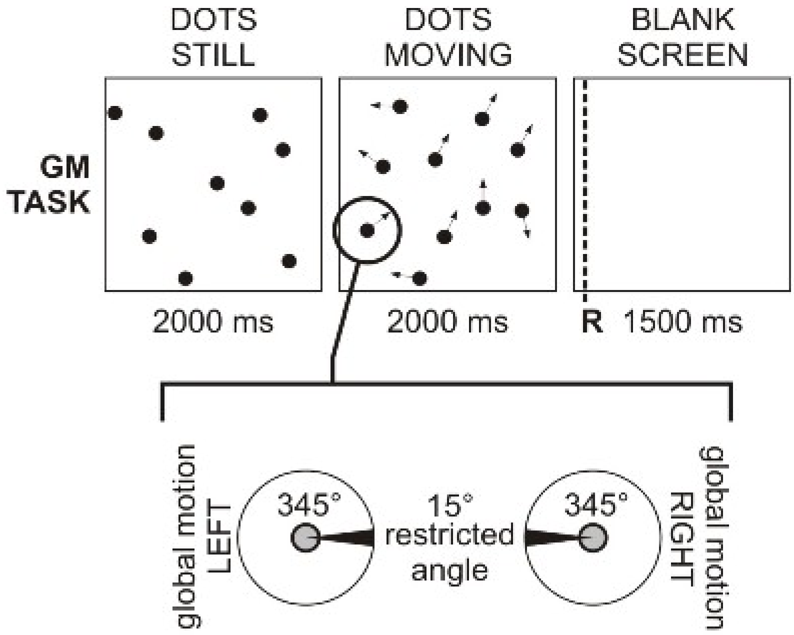

Figure 6. Principles of the GM task. Dot motion is rendered in frames. 1 frame corresponds to 1/120th of a second. The radius of the other circle represents 1 step – this is the distance each dot can travel in 1 frame. In each frame, each dot makes 1 step in a random direction. Directions within the 15^{o} restricted angle are forbidden. For aesthetic reasons, background and dot colors in the figure are reversed.

Global left and global right motion trials were programmed to occur at an equal probability level for every trial (50% left, 50% right). Trial order was randomly mixed within a run. Each trial was unique and starts with the presentation of static white dots over a blank black screen. After 2000 ms the dots start moving indicating the task to be executed, lasting for 2000 ms. At the end of this period, dots are replaced with a blank black screen giving subjects the opportunity to respond, lasting for 1500 ms. This period also allowed the transition to the next trial.

Behavioral acquisitions were exported in the form of text files, in order to be processed later on. Behavioral responses were collected with a dedicated and accurate response device (Cedrus RB-530).

2.3 Procedures.

2.3.1 First session.

2.3.1.1 Electrophysiological recordings

Subjects fitted with a 64-electrodes cap (ActiCap, Brain Products GmbH, Germany) following the standard 10-10 system, as well as with four electrodes -two for each arm- for Electromyographic (EMG) recordings, positioned on areas below the elbow, in order to record muscle contractions. EEG and EMG electrodes were connected to a Nicolet M40 amplifier, were recorded with a sampling rate of 1024 Hz, and were stored in a separate computer from the one conducting the experiment. Synchronization of the recording with the various stimuli was done by connecting the first computer to the amplifier via a parallel cable.

Total duration of preparation including time to obtain informed consent, paradigm explanation, setting up the electrodes and preparations of hardware and software took about 30 to 45 minutes.

Before the beginning of the EEG recording, subjects were briefly presented with their EEG signal on a different computer screen. In the meanwhile, experimenters were showing them movement artefacts in their EEG and instructing them respectively, in order to achieve optimal signal acquisition quality[9]. Participants were instructed to fixate at a central area on the screen, and monitor the stimulus pattern.

9 Subjects were instructed to keep their head in place, to try to be as relaxed as possible, and to avoid irrelevant movements during the stimulation. Although they were also asked to avoid strong eye blinks, they were told not to think about avoiding normal ones. For details about the sensitivity of the EEG signal acqusition, the reader can consult Nicolas-Alonso & Gomez-Gil (2012).

2.3.2.2 GM tasks.

In this session, the GM task was used in three variations, presented in the following order: observation task without instructions (ONI), global motion detection task with hand switching (GMHS), and global motion detection task (GMD). The fourth task was a simple left-right hand movement task (SLRMT).

1. ONI Task

Participants started the experiment with the ONI task, which comprised of simply observing the moving dots (figure 7). They were not informed about the underlying patterns of the task (global left or right motion of the dots). ONI task was control task that we employed to examine whether any changes in the neural signal could occur due to visual processing. Participants were not given the response box yet and were instructed to only watch at a central screen area, trial after trial. The hypothesis was that signal differentiation would not occur merely because of visual processing, i.e. differences will not involve occipital areas, which are directly associated with visual processing. This task consisted of 2 runs of 50 trials each.

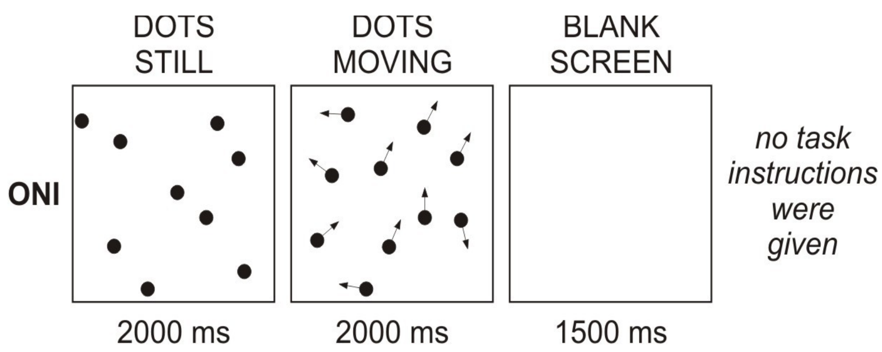

Figure 7. The ONI Task.

2. GMHS Task

The next task, GMHS, was one more control task. Participants received the response box and information regarding the GM task and the global patterns of dot motion (left/right). They were instructed to observe the dots and mentally determine the global motion direction. After the 2 seconds of stimulus display, they were presented with a symbol that instructed them as to which hand to use for reporting the global direction, which was “=” for using the same hand as the global direction, or “X” for using the hand opposite to the direction (see figure 8). For example, if they wanted to report the global motion direction as right, and after the end of dot motion they had received the “X” symbol, they would have to respond by clicking the left button with their left hand.

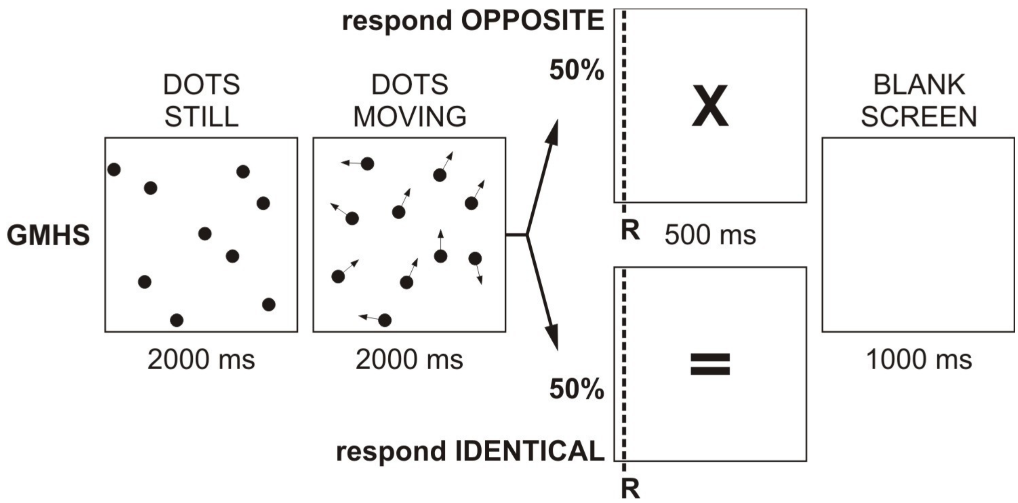

Figure 8. The GMHS Task.

We used this task in order to be more certain regarding the specificity of the signal with respect to the decision. In this case we did not expect any signal differentiation prior to the symbol presentation, as subjects could not have made a decision yet, about the hand that they were supposed to use. This task consisted of 2 practice runs of 20 sets, and 2 main runs of 50 sets each.

3. GMD Task

The GMD task was the main experimental task (figure 9). Participants observed the dots moving for 2 seconds and had to make a decision regarding the global direction, reportable after the dots stop moving, by using the hand same to the global direction. For instance, for left global movement they had to click the left button with their left hand. Further, and in order to motivate them to be as fast and as attentive as possible, we included a number of interrupted sets in each run (20% of the total sets). In the interrupted sets dots were only moving for 1 second, and participants could respond afterwards. For all sets, participants were instructed to respond as soon as the dots stop moving. The task consisted of 2 practice runs of 20 sets, and 8 main runs of 50 sets each.

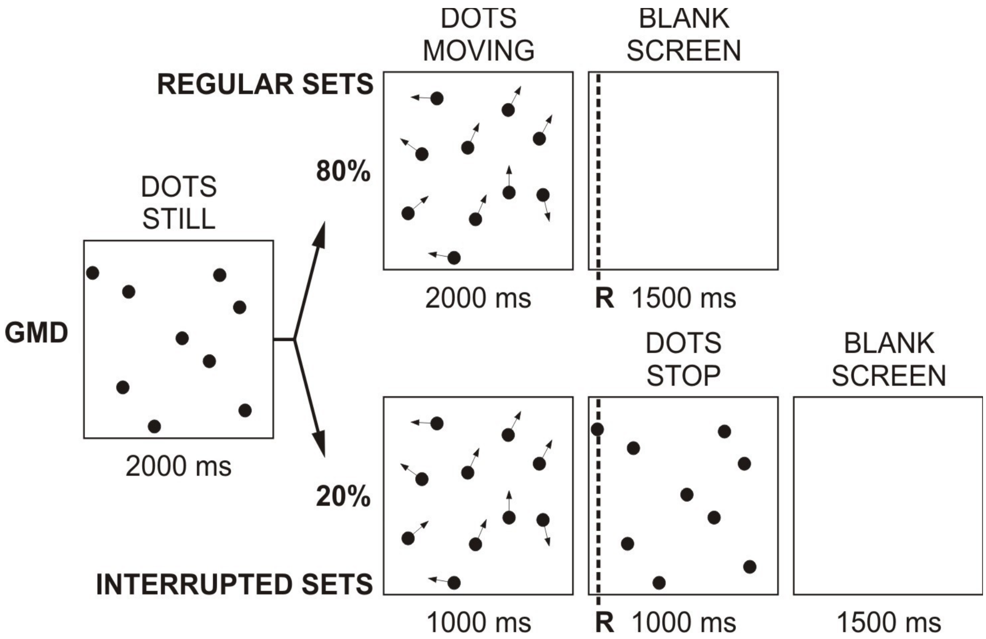

Figure 9. The GMD Task.

Our hypothesis here was that, for the regular sets, significant hemispheric differences expressed by ERD signal differentiation would occure during stimuli presentation, which would be predictive to the subjects' choices for left or right hand movements.

4. SLRMT task

This task was used to identify MC activations and any atypical signal behavior related to a simple left or right hand movement. By fixating their gaze on a cross on the screen in order to minimize unnecessary eye movements, subjects were instructed to use their internal feeling of time and click at random intervals between 4 and 8 seconds, during two blocks that lasted 8 minutes each (one block for right hand, one block for left hand). With the help of SLRMT we controlled for MC activations during self initiated movements. Because of individual differences in brain anatomy, we wanted to ensure that left and right hand movements would produce typical and measurable activations over the contralateral hemispheres, as atypical ones would have unwanted effects in the analysis of the signals related to hand movements in the GM tasks.

2.3.2 Second session.

The second session was shorter and consisted of response time (RT) measurements on two variations of the GM task: the simple motion detection task (SMD) and the global motion task with early responses (GME).

1. SMD Task

In the SMD task, subjects had to report immediately after they had detected the dots' movement from an initially static frame of still dots (figure 10). Dots started moving after a random time interval between 500 and 7500 ms. There were 2 runs for each hand, with 50 trials each. We included this task in order to have an estimate of the time necessary to behaviorally respond after perceiving a movement, i.e. making a simple perceptual decision.

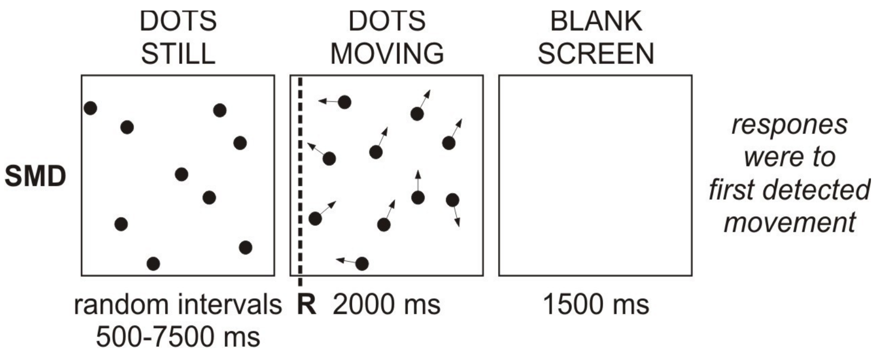

Figure 10. The SMD task.

2. GME Task

The final task of the experiment was a version of the GM task, which allowed for early left/right hand responses, i.e. participants were instructed to click with the hand same as to the global dot movement as soon as they realized the motion direction (Figure 11). There were 3 practice runs of 20 sets and 4 main runs of 50 trials each. This task was used in order to support that the GM task is an effortful procedure for the participants, and, in addition, to relate the average RT with the average onset of ERD signal differentiation that is expected to be found from the EEG analysis of the GMD task.

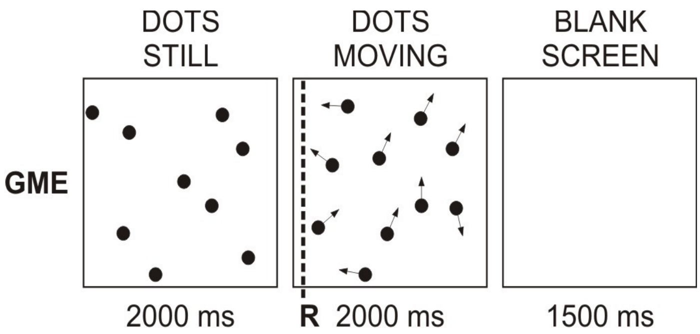

Figure 11. The GME task.

2.4 Analysis.

2.4.1. Behavioral Data.

Behavioral data were acquired with E-prime in the form of text files and were later transferred to Microsoft Excel for statistical analysis. The same software was used for the transcription of responses from the QSE.

2.4.2 EEG Data.

2.4.2.1 Acquisition.

EEG was measured from 64 surface electrodes according to the international 10–10 system. The raw data was analogue filtered between 0.016-250 Hz, sampled at 1024 Hz and later down-sampled to 500 Hz for offline analysis (BrainVision Analyzer 2.04, Brain Products GmbH, Germany). Recording reference was at FCz and ground at AFz.

2.4.2.2 Preprocessing.

The raw data were exported into a generic data format and imported to Analyzer. Each recording was first visually inspected for bad channels (electrode disconnected/poorly connected to scalp or technical malfunction) and for clear non-brain or non-eye-movement related electrical activity (muscle noise, sweating, movement, etc.). Bad channels and artifactual data portions were removed from further analysis. Ocular artifacts were corrected using a custom-devised Independent Component Analysis (ICA) procedure, which removes components based on temporal and spatial correlations with known blinking and eye-movement activity. After ICA, the previously removed channels were interpolated with spherical splines. EEG data was segmented based on each type of task (ONI, GMHS, GMD, SLRMT) and stimulus (start and end) into individual sets ranging [-500, +2500] ms with respect to the onset of dots motion. Using a custom-written artifact rejection procedure, channels within individual sets containing amplitudes further than ±3.5 standard deviations from the subject and channel-specific means, across a subset of sets in which no channel exceeded ±120 μV, were rejected from the average. Only sets with correct responses were averaged. EEG data were analyzed in three frequency domains: 9-15Hz, 9-25Hz, 13-30Hz. EMG filter was set at 50Hz.

2.4.2.3 Exclusions.

Due to large arifacts that occurred due to bad ground and reference electrodes, subject 10 was excluded from the EEG analysis. Moreover, subject 3 was excluded from further EEG analysis because his SLRMT results showed stronger activations in the ipsilateral hemishere compared to the contralateral one for both hand movements.

Chapter 3: Experimental Results

3.1 Behavior.

A summary of the behavioral results of the 4 versions of the GM task is presented in table 1.

	Accuracy (%)	SD (%)	Response time (ms)	SD (ms)	Response rate (%)
GMHS					97,6
All trials	85,2	10,4	703,7	142,5	
Identical (=)	86,2	10,8	668,9	147	
Opposite(X)	84	11,9	745,3	146,8	
GMD					99,4
Regular trials	88,8	6	396,8	169,5	
Regular, left global motion	88,9	6,1	398,3	167,4	
Regular, right global motion	88,6	7,6	394,9	172,6	
Interrupted	85,3	8	486,2	302,8	
GME					99,7
All trials	85	7,2	943,9	290,5	
Left global motion	83,9	9,6	961,4	301,8	
Right global motion	86,4	7,6	927,5	286,1	
SMD					100
All trials			253,1	23,6	
Left hand			254	26,4	
Right hand			252,1	21,4	

Table 1. Behavioral results of the 4 GM task versions.

As main reference points we can notice:

- a high percentage of accuracy (>80%) in all relevant tasks, excluding the possibility of chance responses, and allowing for ERD/ERS signal averaging in the GMD task, moreover in a significant number of correct trials (individual accuracy in the GMD task is shown in figure 12);

- consistency in accuracy and RT between left/right global motion trials.
- in the GME task, reaction times that indicate a desirable level of difficulty for it to be solved, and confirm balance between accuracy and RT.

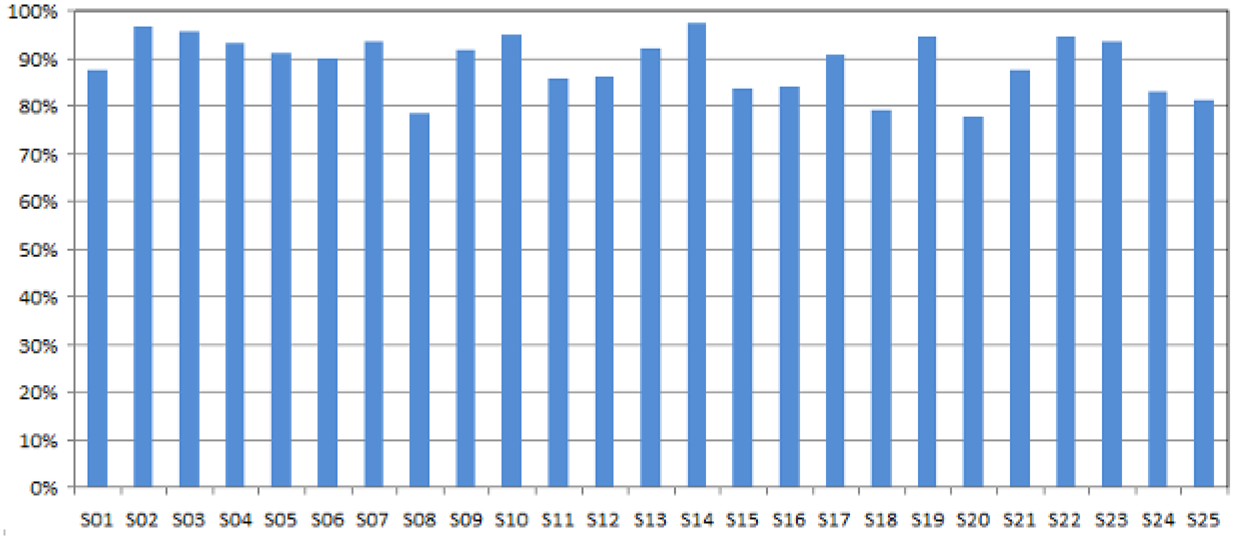

Figure 12. Individual accuracy in the GMD task.

3.2 EEG.

The figures below represent the average ERD/ERS of the left and right hemispheres of 23 subjects. Activations for each direction of dots movement are shown in terms of left MC minus right MC. P-value threshold is set at 0.05 and is depicted by the green line. Point 0 represents the onset of global dot motion.

In the ONI task, there was no significical signal differentiation between left and right hemispheres (figure 13). Results support the hypothesis that simple dot motion observation does not affect the neural signal in significant ways.

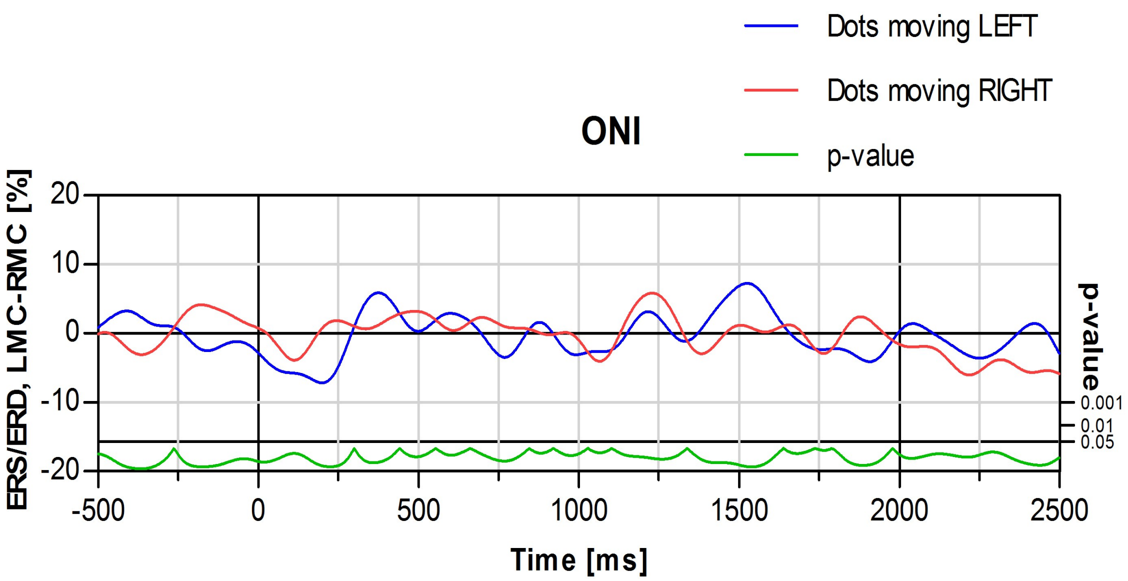

Figure 13. ERD/ERS analysis results in the ONI task.

Figure 14 shows the ERS/ERD in the GMHS. As hypothesized, despite fluctuations there was no significant differences between hemispheric activations. As response instructions (same or opposite hand) were given after the 2 s of stimulus interval, results indicate that potential signal differences that might occur in the main task, the GMD, would be strongly associated with a decision for left or right hand movement.

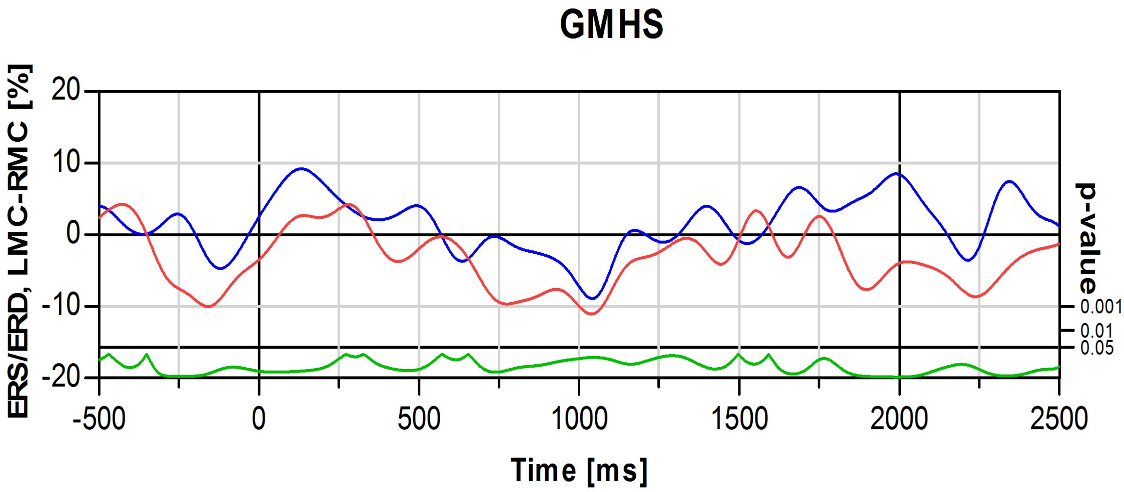

Figure 14. ERD/ERS analysis results in the GMHS task.

The following figure, figure 14, represents analysis performed at 9-15Hz for the GMD task. Whereas ERD/ERS is present across the cortex during task execution, significant power changes between left and right MC started occuring at 434ms (p-value threshold crossed) after the onset of dot movement, significance remained stable for the rest of stimulus presentation, and returned to insignificant levels at a point close to the participants overt response (396,8ms after dots stopped). Specifically, for right direction of dot motion there is a contralateral bias of motor activity reflected by desynchronization over the left MC with parallel synchronization over the right MC. The opposite pattern was observed for left direction of dot motion. The same pattern of signal differentiation was observed in other frequency bands too (9-25Hz, 13-30Hz), though later in time.

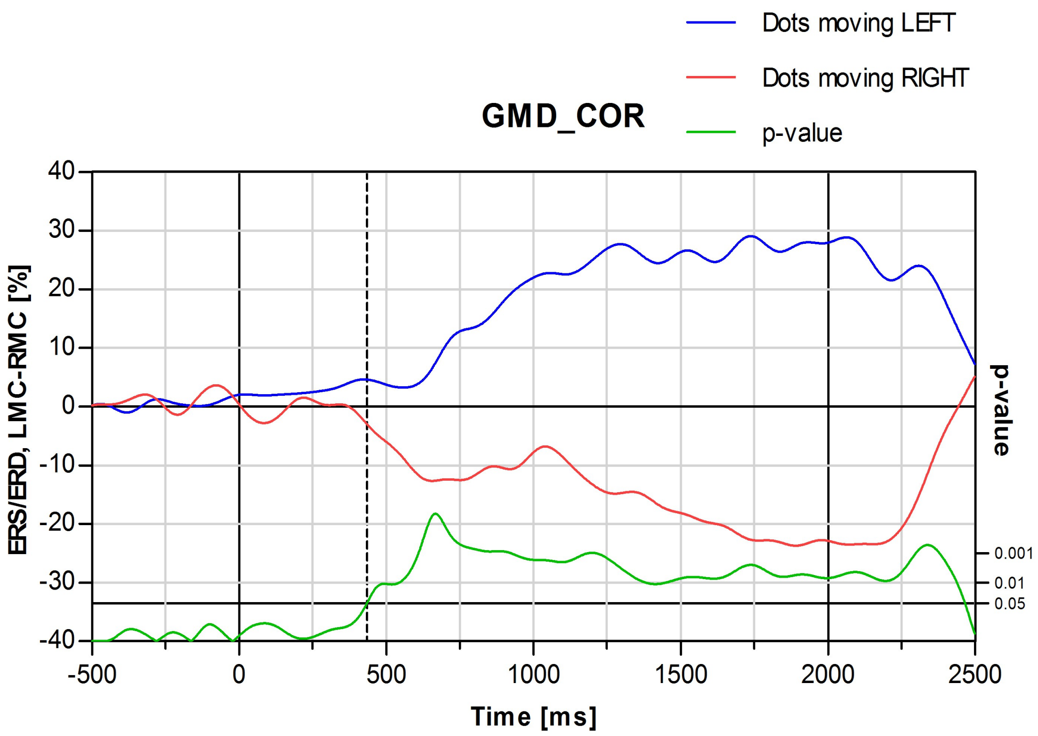

Figure 14. ERD/ERS analysis results in the GMD task. The dotted line represents the onset of significant signal differentiation (434ms).

3.3 Experiential reports.

Figure 15 represents the results from question 4 of the QSE (session 1). This question was the most relevant as it was connected to the second research question, and was the following: “On a scale from 1 to 7, how did you experience your responses in the task?”. Guidance was given by the statements “After some point my hand was automatically responding, without any conscious intervention from my part. (1)” and “It was an effortful and fully conscious process, in the sense of seeing the dots, being aware of their direction, consciously deciding to respond, and finally responding. (7)”.

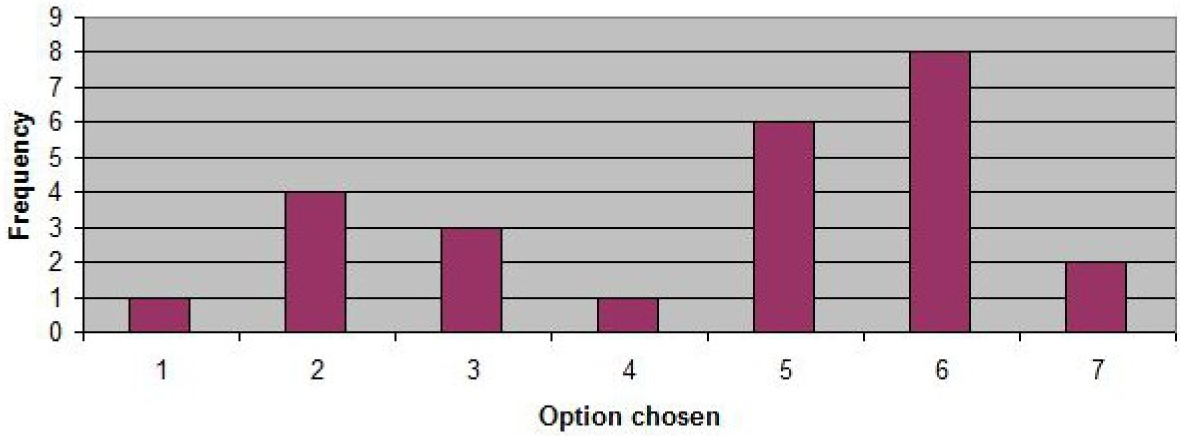

Figure 15. Answers of 25 subjects to question 4 of the QSE

Chapter 4: Discussion

4.1 Implications.

Results show that persistent EEG activity demonstrated by ERD/ERS is specific to an upcoming left or right hand movement, associated with a perceptual choice. Specifically, in the 9-15Hz (alpha and lower beta band), neural signal differences over the MC predicted the binary choices in the viuomotor task 1962,8 ms before overt behavioral responses. As to movement preparation, results are in accordance with evidence from previous studies regarding activity preceding hand movement (Bai et al., 2011; Morash, Bai, Furlani, Lin, & Hallett, 2008; Pfurtscheller & Lopes da Silva, 1999; Rektor, Sochůrková, & Bocková, 2006). Moreover, in relation to the behavioral results, the onset of signal differentiation at 434ms after stimuli presentation, indicates rapid processing and decision formation in the brain. In the framework of our cognitive task, significant ERD/ERS differences between left and right MC might not only reflect a decision for hand movement, but maybe an integrated network associated with perception-decision-action. The question of whether or not decisions in the brain preceded awareness remains to be examined.

Can perceptual decisions in the brain precede subjective direction awareness?

The range of responses in the QSE, as well as the comments of the participants' subjective experience in the very same questionnaire, but also during the short breaks of the experimental trials are probably key factors for answering this question. Under certain assumptions, namely (i) that the process of DM from perception to action is serial (figure 16), (ii) that the GMD was and effortful and non-automatic task for all participants, and (iii) that conscious perceptual awareness (of motion direction) is an all-or-none phenomenon, one could infer a positive answer to the above question by averaging the individual behavioral results (figure 17).

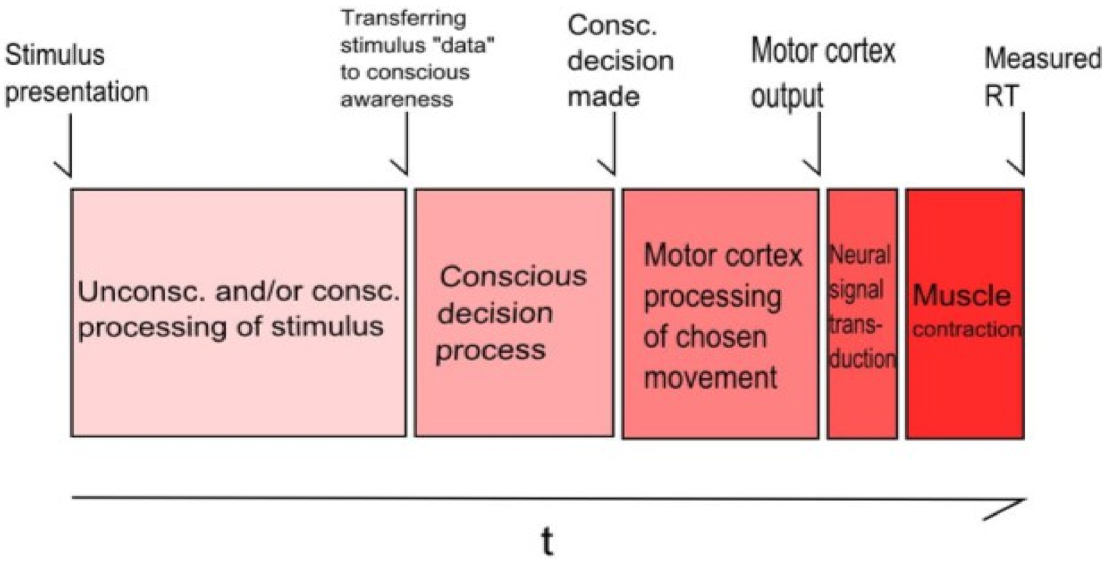

Figure 16. The linear DM model that was initially used in the study for comparing the timing of decision awareness in relation to neural events predictive to visuomotor decisions.

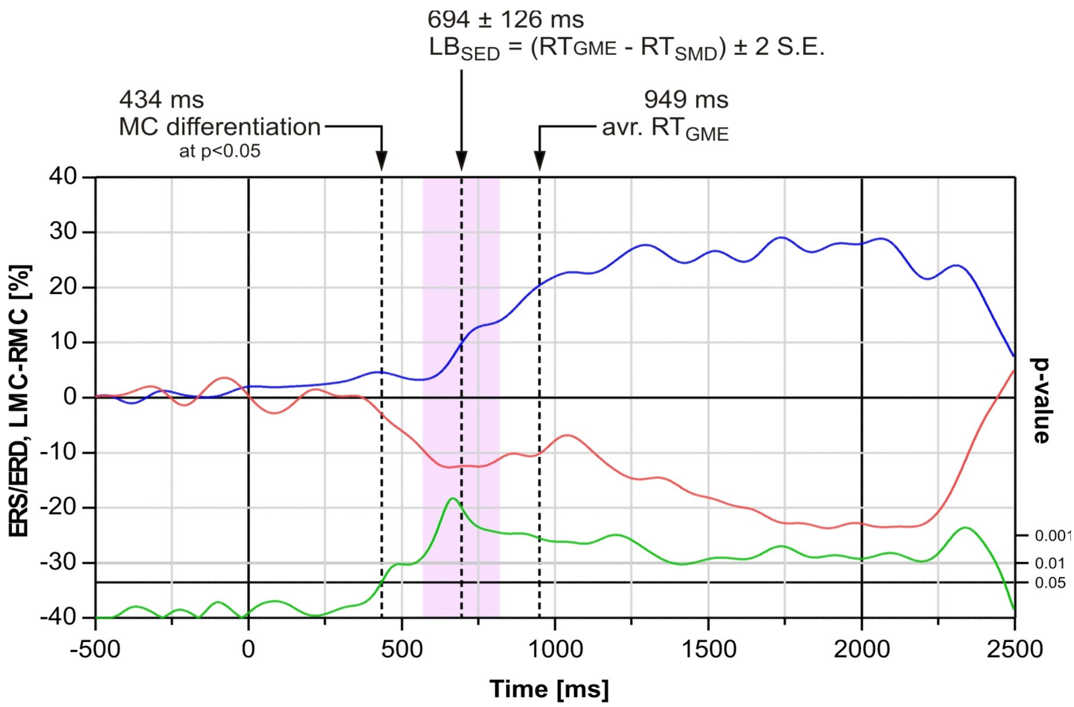

Figure 17. Synthesis of EEG and behavioral results. Based on certain assumptions, subjective decision awareness appears to have a lower boundary (LB_{SED}) significantly later than neural signal differentiation.

However, a direction in the scientific literature suggests that “conscious perception may not be an all-or-none phenomenon, but a continuum of clarity unfolding in time, so that the notion of a precise point in time at which the conscious sensation pops out may be too simplistic” (Gregori-Grgič, Balderi, & de’ Sperati, 2011, p.1). Additionally, what is missing can be represented by the question: *Did the subjects actually exhibit direction awareness throughout task and was that necessary to produce accurate responses?* In these two sub-questions the answer is, to my view, negative. For firstly, it seems that the task was, during the sessions, becoming automatic (according to replies to the 4th QSE question and to oral explainations of this preference to the experimenter), and secondly, written comments are indicative that conscious direction awareness was not a necessity for accurate responses. For example, some phrases were *“indicicive”* (S05, session 2), *“getting automatic”* (S05, session 2), *“clicked left when it seemed there was no particular direction”* (S07, session 1), *“instinctive answer”* (S13, session 1), *“intuitive”* (S23, session 1). Moreover, there were several subjects who were surprised by their accuracy, and I can recall at least two cases where they thought that the display of performance was a trick to keep them motivated, as they thought they did bad in the task.

In my opinion, due to the task length and the big number of trials, subjects naturally (due to physical limitations) could not exhibit the same attentional effort in every single trial. Based on the above, it would be interesting to group subjects of this and of similar studies according to an open post-experimental questionnaire, and examine their ERD/ERS differences. According to statements on the course of the present study, in some subjects there seemed to be a kind of agnosia for succesful task performance, exhibiting a 'blindsight'-like effect. An interesting hypothesis would be that subjects that were unaware (still very accurate) of the dots' global direction were using different networks than the ones used by subjects who performed in the expected way, according to the evidence accumulation model of DM. Those individual differences would most likely mirror on their signal analysis, as well as in haemodynamic responses. A further development and use of the QSE may appear benefial in future studies in, for example, grouping aware with unaware participants and examining signal and network differences. Thus, I can only but support and suggest a turn towards first-person neuroscience, in the sense that (Northoff & Heinzel, 2006) described: “First-Person Neuroscience uses methods for the systematic examination and evaluation of mental states by themselves and their contents as experienced in first-person perspective and links them with data about neuronal states as obtained in third-person perspective” (p. 2). This turn would be especially beneficial, not only in studies of DM or volition in general, but in every field that addresses questions related to consciousness topics.

Another interesting question that comes up, is the quickness with which the the signal differentiaton occured in the GMD task. If we also consider the appx. 60 ms that are needed for visual cortex excitation after the presentation of a stimulus, it is quite extraordinary that we are left with 374ms in which the processing took place all the way in the brain and even produces a neural response associated with a correct behavioral response in the task. So the question is how did all that processing happen in such a short time? And what happened with the people who claimed to be intuitive, unaware of the dots direction, still choosing correctly? In accordance with Custers & Aarts (2010) and Deecke (2012), my suggestion is that subjects who, through their attentional effort, managed to observe the global pattern and direction were using their conscious 'programs' to complete the task, whereas in the unware subjects, their individual consciousness, responsible for the declaration of the correct response did not exceeded the threshold, leading to the usage of other brain pathways or streams, maybe of older brain structures, in the 'need' of task completion.

Putting it in a broader perspective, after a review of studies related to the above Custers & Aarts (2010) point out “...that the unconscious nature of the will has an even more pervasive impact on our life. Goals far more complex than finger movements, can guide behavior without being consciously set first, when they themselves are activated outside conscious awareness. These unconsciously activated goals cause people to invest effort and select actions available in their repertoire to attain the goal in novel settings without them being aware of the goal or its operation. Overall, the evidence on unconscious goal pursuit indicates that the control of unconscious goals is flexible and effortful, suited to meet the dynamics of the environment”. (p. 50)

Our results in a framework of Embodiment[10].

After the experiential findings that brought the question of awareness from a first-person point of view, the hypothesis that the route from perception to action is not serial should also be considered. Thus, it is necessary to place our findings in an embodiment framework of perceptual decision-making. According to this, “the route from perception to action is not a one-way street, rather, perception and action interact continuously” (Green & Heekeren, 2009, p.207).

In this framework, it is argued that “cognitive, perceptual, and motor processes are not necessarily separate components of the functional brain architecture” (Filimon, Philiastides, Nelson, Kloosterman, & Heekeren, 2013, p.2135). Indeed, in the same review of neuroscientific (among other) evidence by the same group suggests “an immediate sharing of information between higher-level decision-making and motor systems when such sharing is possible, rather than with a serial processing model in which the decision is first completed and then passed onto the motor system” (p.2135).

This interplay may well explain the rapid signal differentiation in our study. In other words, and adapting the suggestion of Klein-Flugge & Bestmann (2012), action representations (for right or left hand movement) in the motor cortex may occur (signal differentiation) before the decision process (for global direction) is complete. In any case, the rapid occurrence of decision formation in the brain remains extraordinary.

Therefore, in the above framework and in the case of our experiment and the methods used, the initial question (*Can perceptual decisions in the brain precede subjective direction awareness?)* may not be a relevant question to pose. For, first there was no need for some participants to be aware – or otherwise there was no conscious experience - of the correct global direction, and, second, the specific point in time that the decision was made during the 2 s stimulus interval may neither be identified, nor inferred by serial models.

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10 A basic idea of Embodiment is that an organism is coupled via a sensorimotor loop with the environment (Green & Heekeren, 2009).

4.2 Applications.

As for clinical applications, it is now known that symptoms of Parkinson's disease (PD) are not limited only to motor processes. Sensory and/or cognitive deficits are also evident, with findings suggesting visual impairments using similar motion discrimination tasks (Trick, Kaskie, & Steinman, 1994). Since our task requires both sensory (motion direction) and cognitive abilites (decision making, movement planning), it would be interesting to further investigate the hypothesis of signal differentiation, also in demented PD patients, and in combination with frequency power changes during the GMD task, for which recent evidence suggests it might be abnormal (Heinrichs-Graham et al., 2013). In a similar fashion, the protocol could be used for addressing questions related to the neurophysiology of navigational or other cognitive deficits in Alzheimer's disease (AD) patients, since prior evidence suggests it does exist[11], or even in the neuropsychological assessment of AD or dementia in general[12]. Further, since Obsessive-Compulsive Disorder is suggested to be considered as a disorder of decision making (Heekeren et al., 2008), the GMD paradigm could be used to assess clinical characteristics that are associated with ERD/ERS, or with simple RT in the task. In general, it seems that abnormalities in neural synchronization are associated with neuronal dysfunctions and disorders like -apart from the above- schizophrenia, epilepsy, and autism (Uhlhaas & Singer, 2006). Therefore, and since neural oscillatory synchrony is involved in many cognitive functions, the clinical relevance of our protocol may be of high consideration.

To continue, the use of ERD/ERS in applied sciences can be found in the continuously growing domain of BCI. The core principle is that, using algorithms, the neural signal can be translated to a specific command in a computer or device. To briefly mention a few examples, ERD/ERS is used to develop a system that allows cursor control towards four directions in a 2-D computer interface (Nicolas-Alonso & Gomez-Gil, 2012). In another case, ERD/ERS was found to be elicited during motor imagery as well (Jeon,

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11 For example, see Kavcic, Fernandez, Logan, & Duffy (2006).

12 For a review on the general topic, see Salmon & Bondi (2009).

Nam, Kim, & Whang, 2011). The above imply that the use of ERD/ERS in BCI can be highly beneficial over patients with paralysis or other disorders (Neuper, Müller, Kübler, Birbaumer, & Pfurtscheller, 2003). Thus, it will be also interesting to explore the neuronal dynamics of motor imagery using the GDM task, which could, among others, prove beneficial for further development of BCI, especially for the disabled. For example it could be used for training the elicitation of ERD/ERS signals that could later be coded for the control of robotic hands, cursors[13], or even as a communication tool in disorders of consiousness[14] and/or locked-in patients. In the latter well reviewed topic by Demertzi et al. (2008), it seems that we are in an urgent need for measures assessing the levels of consiousness beyond behavioral observation[15]. For example, if we use a version of the GMD task with verbal or written instructions on a post-comatose patient, who is unable to respond behaviorally, we could, by examining the ERD/ERS, assess his neural performance in the task. I suggest that the results would be indicative of the existence of consciousness in such a patient.

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13 For example, see Huang et al. (2011).

14 Defined in this case as “a first-person experience that consists of two major components: arousal and awareness” (Demertzi et al., 2008)

15 According to the same review, 40% of Vegetative State patients are misdiagnosed.

4.3 Conclusion.

All in all, our results provide further evidence of the existence of neuronal dynamics that predict simple perceptual decisions, and it is apparent that these dynamics can be expressed by ERD/ERS in our visual motion task. Coming to a conclusion, it should be mentioned that test paradigms like the GM can be more ecollogically valid for the study of DM in the brain. Rather than performing stereotyped and simple one-hand movements, the proposed paradigm offers the possibility for active engagement in an at least binary decision task with observable behavioral outcomes, and can provide us with opportunities mentioned in the above discussion. Moreover, using the ERD/ERS signal analysis we can escape from the movement-specific potentials and all the constrains they carry, and invest on efforts that may provide a more spherical and applied study of DM in the brain, as well as volition in general. Our framework can also serve as a common ground for all sensory decisions, such as auditory DM[16]. Finally, studying simple perceptual decisions in the brain can help us re-evaluate perceptual DM models, seek for first-person methodologies, examine conscious and non-conscious decision processes, and head to investigate how more complex decisions are made in real life settings.

16 For example, see Kaiser, Lennert, & Lutzenberger (2007).

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Appendix

Questionnaire for Subjective Experience

1. How prepared were you at the point of stimuli presentation?

A. Unprepared, saw the stimuli only because they were there

B. Less sharply, less focally (despite of effort, because of distractions, tiredness, sleepiness, discursive thoughts)

C. Ready, present, well-prepared

2. How was the presentation of the stimuli experienced?

A. I felt totally surprised, stimuli interrupted thoughts (memories, plans, imaginations)

B. I had a feeling of surprise and discontinuity

C. With a feeling of continuity and confirmation of my expectation

3. How fast did you respond?

A. Not as immediately because of inattentiveness

B. Immediately and decidedly most of the times

4. On a scale from 1 to 7, how did you experience your responses in the task?

- After some point my hand was automatically responding, without any conscious intervention from my part (1)

- It was an effortful and fully conscious process, in the sense of seeing the dots, being aware of their direction, consciously deciding to respond, and finally responding. (7)

Answer: 1 2 3 4 5 6 7

-------- General Comments:

Zusammenfassung

Das Studium zugrundeliegender Hirnvorgängen von Entscheidungen in Anbetracht zweier Alternativen kann Einsichten in die komplexen Manifestationen menschlicher Entscheindungsfindungen geben. Das Thema der vorliegenden Arbeit ist es mögliche neuronale Predikatoren visuo-motorischer Entscheidungen mit Hilfe elektrophysiologischer Methoden (Event-Related Desynchronization/Sychronization des Elektroencephalograms) zu messen. Zu diesem Zweck wurde ein entsprechendes Versuchsdesign zur Erfassung visuomotorischer Richtungen entwickelt, in dem Versuchsteilnehmer in kurzer Zeit Entscheidungen über die globale Bewebungsrichtung einer Vielzahl von Punkten treffen und diese mit der linken oder rechten Hand zu berichten. Die Untersuchungen zeigen eine spezifische Hirnaktivität, welche charakteristisch für eine bevorstehende Bewegung der linken bzw. rechten Hand in Assoziation mit einer Wahrnehmungsentscheidung ist. Diese Wahrnehmungsentscheidungen können, in Form neuronaler Prozesse, bereits 1,96 Sekunden vor der Verhaltensreaktion beobachtet werden. Des weiteren wurden Themen des subjektiven Entscheidungsbewusstseins mittles Modellen perzeptueller Entscheidungsfindungen und Fragebögen behandelt. Das angewandte Versuchsdesign liefert ein vielversprechendes methodisches Konzept für Anwendungen auch im klinischen Bereich.

Abstract

Studying decisions between two alternatives in the brain can provide a window into the complex manifestation of human decision making. The objective of the present research was to examine possible neural prediction of visuomotor decisions based on electrophysiological measures (Event-Related Desynchronization/Synchronization of the Electroencephalogram). For this purpose, a paradigm of visual motion direction detection was developed, where participants had to decide and on the global direction of randomly moving dots within a short amount of time and report on it by using their left or right hand. It was found that distinct brain activations were specific to the participants' upcoming left or right hand movements, which were associated with their perceptual decisions. These decisions could be predicted 1,96 seconds before overt behavioral responses. Addtionally, issues related to subjective decision awareness were also addressed using models of perceptual decision making and experiential questionnaires. It is concluded that the proposed framework can lead to applications also in the clinical domain.

Curriculum Vitae*

Education

October 2011 – Present

Candidate, Master's degree in Cognitive Science

University of Vienna, Austria.

- Interdisciplinary studies in cognition sciences and arts.
- Joint international MSc programme, research orientation.
- Specialization focus on Cognitive Neuroscience.
- Thesis (ongoing): 'Neural dynamics predict visuomotor decisions'.

October 2001 – January 2006

'Ptychio' in Business Administration (Technological Education)

Higher Technological Educational Institute of Larissa, Greece.

- 4-year studies (240 ECTS).
- Specialization focus on Management and Operational Research.
- Internship in tourism & hospitality sector.
- Thesis: 'Tourism and its contribution to the development of Greece.'

September 1998 – July 2001

Leaving Certificate of Upper Secondary Education

'Apolytirio' of Unified Lyceum, Nea Triglia, Halkidiki, Greece.

General education with technological orientation: natural sciences, IT, and services.

Intervals between studies

June 2011 – August 2011: Employment in the food & beverage service area (Germany).

March 2007 – January 2011: Employment in the hospitality industry (Greece, various full-time placements).

February 2006 – February 2007: Fulfilment of military service duties (Greece).

Awards

October 2013 — Performance scholarship awarded by the University of Vienna.

June 2013 — Short term grant awarded by the University of Vienna, for research abroad (University Medical Center Ljubljana).

October 2001 — Entry grant awarded by the Greek State Scholarship Foundation (IKY), for being amongst the best-5 candidates admitted in the study programme of Business Administration.

International study experiences

March 2013 – February 2014 — University of Ljubljana - University Medical Centre, Slovenia. Deliberate stay abroad after invitation for thesis realization and internship in the Cognitive Neuroscience Lab (Erasmus scholarships, funded by OeAD-GmbH Austria).

September 2012 – February 2013 — University of Ljubljana, Slovenia. Academic exchange for the fulfilment of the master programme mobility requirements (Erasmus scholarship, funded by OeAD-GmbH Austria).

August 2011 – September 2011 — University of the Basque Country, Donostia-San Sebastian, Spain. Intensive Spanish language course (self-organized).

March 2011 – June 2011 — University of Tübingen, Germany. Intensive German language and guest attendance at academic lectures in Psychology and Cognitive Science (self-organised).

Personal skills

Languages*

Greek	Mother tongue
English	Proficient user
German	Independent / Proficient user
Spanish (Castellano)	Basic user
French	Basic user
Slovenian	Basic user

*Common European Framework of Reference for Languages

Computer skills — MS Office, SPSS, Python, and other science and business-related softwares.

Scientific Activities

Conferences

Talk: *'Distinct cortical activations for motor outcomes in a decision-making task:Investigating probable signs for preconscious knowledge'*. Middle European Interdisciplinary Cognitive Science Conference, Budapest (June 2013).

Poster presentation: Pantzakis, R., Martins, M., '*The influence of verbal and visual processing resources in the generation and application of recursive representations'.* Middle European Interdisciplinary Cognitive Science Conference, Bratislava (June 2012).

Organization

Assist in the organization of the neuroscience conference "SiNAPSA '13" in Ljubljana (September 2013).

Research

Assist in several studies at the Laboratory for Cognitive Neuroscience, department of Neurology, University Medical Centre, Ljubljana (October 2012 – March 2013). The studies assessed cognitive functions in clinical and healthy populations by the means of Electroencephalography.

Realization of the study "Working Memory and Visual Recursion", department of Cognitive Biology, University of Vienna (March 2012 – August 2012). The study was part of the project '*Shared neural resources for music and language: Verification and clinical exploitation*'.

Design and successful implementation of numerous hotel marketing and sales projects, Aristoteles SA, Halkidiki, Greece (2008-2010). The projects involved, among others, website creation and advertisement strategies, market research, e-bookings and e-sales systems.