

EVENT-RELATED POTENTIALS IN EXTERNALLY AND INTERNALLY-DRIVEN TARGET SELECTION: A PRELIMINARY STUDY

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ABSTRACT: In this study we investigated the cue-locked (P300 and later event-related potentials components) and response-locked electroencephalography (EEG) phenomena associated to externally and internally-driven target selection. For that we designed a novel paradigm, that aimed to separate the selection of motor goals according to the respective task rules from the actual programming of the upcoming motor response. Our paradigm also made possible the estimation of the onset of a self-paced reach-and-grasp movement imagination for better capturing the associated movement-related cortical potentials (MRCPs). Our preliminary results indicate that differences between the externally and internally-driven conditions are present in the cue-locked event-related potentials, but not in the response-locked MRCPs. Our study contributes for a better understanding of the neurophysiological signature of movement-related processes, including both perception and actual motor planning, which are so extensively used in brain-computer interfaces (BCIs).

INTRODUCTION

Movement planning consists in all the movement-related processes that happen before the actual movement initiation. This broad definition of movement planning includes not only the processes that define how the movement will look like, e.g. in trajectory, but also the cognitive processes that allow us to decide on motor goals [1]. Wolpert and Landy defended that movement planning is a decision-making process, where both sensory and motor decisions are integrated [2]. In a narrower perspective, Wong et al. proposed to limit motor planning to the processes that allow the translation of the abstract definition of a motor goal to the concrete movement specifications [1]. Perception/cognition and motor planning are then linked at the moment when the motor goal is defined. For example, if we want to grasp a glass, we first observe the environment and rely on attention to locate the glass (target). Only then we decide on how we will reach it. The selection of the target is usually dependent on task rules, which are encoded in the prefrontal cortex [3]. These rules can be externally or internally-driven (e.g. *I will pick the wine glass because I intend to drink wine.*) and their application is critical to the def-

inition of the motor goal. Undoubtedly, understanding the processes that lead to the final course of action, including the definition of motor goals, is of great interest not only for basic neuroscience but also for research fields which rely on the neurophysiological signature of movement-related processes, like in brain-computer interfaces (BCIs) research [4]. Studies on event-related potentials (ERPs) show that there is a modulation of ERPs later components, like the P300, as a function of complexity of cognitive control prior to motor tasks [5]. The explanation that only attention is modulating these ERP components started to be questioned. To elucidate the P300's role in information processing, Nieuwenhuis et al. integrated evidence to suggest that the P300 reflects the response of the locus coeruleus-norepinephrine system to the outcome of decision-making responses [6]. Another interesting component of the ERP is the positive slow wave, which emerges after the P300, and has been associated to decision-making prior to the preparation of a response [7]. Recently, our group showed that the presence of motor goals is modulated in the EEG time-domain signals in the delta band around movement onset [8]. These slow EEG fluctuations, when associated with motor tasks (e.g. movement execution or imagination) are known as movement-related cortical potentials (MRCPs) [9]. We now aim to investigate goal-directed movements when several targets are presented simultaneously and in two main conditions: in the internally-driven conditions the subjects decide which of the five or two possible targets will be their motor goal and in the externally-driven condition the subjects just have one option. After selecting their target according to the task rule, the participants imagined a single reach-and-grasp movement. In a novel paradigm, we aim to separate the target selection from actual motor planning. Further, we decided on a self-paced motor imagery task since we will later investigate new methods for movement detection for BCI control. In this paper we present and discuss the results obtained, in respect to the cue-locked (P300 and later ERP components) and response-locked (MRCPs) potentials. We study these two phenomena since the first are thought to mainly reflect stimulus processing, while the second reflect the upcoming motor response.

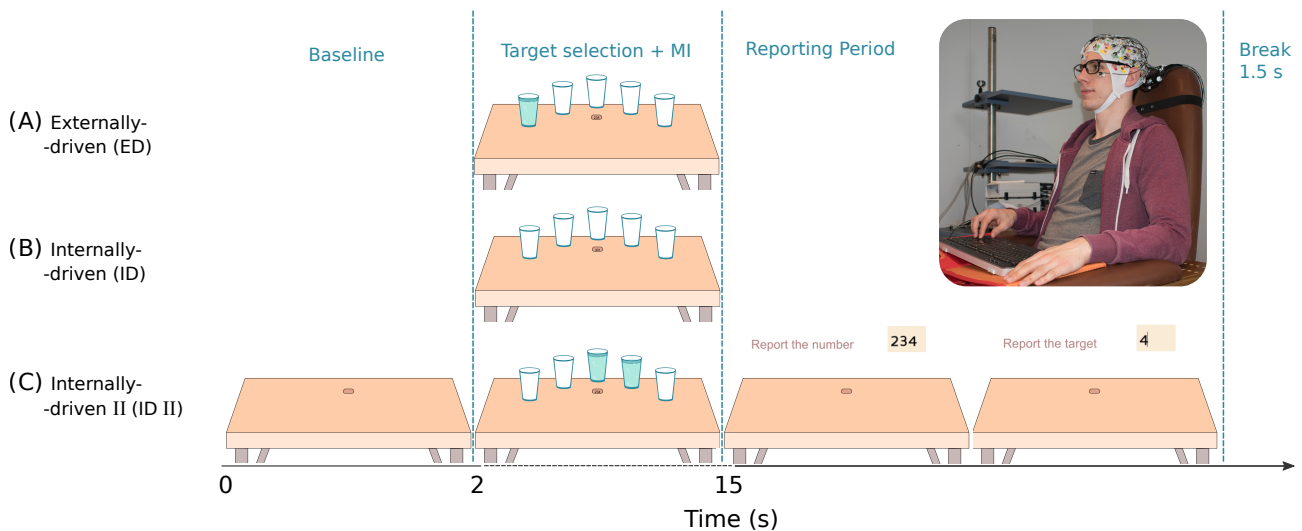


Figure 1: Trial representation. Each trial consisted of a baseline period, followed by one of the three conditions: (A) externally-driven, (B) internally-driven or (C) internally-driven II. This was followed by a reporting period, where subjects were asked to report (1) the number that was shown in the scroller (center of the virtual table) when they started the reach-and-grasp movement imagination (MI) and (2) the target of the MI.

MATERIALS AND METHODS

Participants: Six healthy participants (age 24 ± 3.3 years, 1 male) took part in this study. Participants gave their informed consent and the study was conducted in accordance with the protocol approved by the ethics committee of the Medical University of Graz. Subjects had normal or corrected-to-normal vision and no history of neurological or psychiatric disorders. All subjects were right-handed. Subjects sat in a comfortable chair, in a shielded room, facing the computer monitor that was placed at a distance of 130 cm in front of them. Their arms were supported in both armrests. Additionally, a wireless keyboard was placed in front of them, at the same level as their arms.

Conditions and Paradigm: Participants were instructed to perform a reach-and-grasp movement imagination task. After the end of each trial, there was a reporting period in which they used the keyboard. Participants performed three different conditions that were shown in a randomly alternated order, but with the same frequency. An average of 68 trials per condition were recorded, separated into runs. The trials had a variable duration dependent on the subject, due to the presence of a reporting period, and were followed by breaks of 1.5 seconds. All cues were presented on the monitor. Fig. 1 represents one trial in the three experimental conditions. Each trial began with a two-second baseline, followed by a cue that indicated one of the three conditions. In all conditions, five glasses showed up at second 2 in addition to a scroller that showed consecutive numbers every 750 ms. This scroller was positioned in the center of the screen. In the externally-driven (ED) condition, represented in Fig. 1.A, one glass was filled with water. In this condition, the subjects knew that the target of their reach-and-grasp movement imagination (MI) was the glass filled with water. In

the internally-driven (ID) condition, Fig. 1.B, all glasses were empty and subjects were instructed to choose one of the five possible targets. In the second internally-driven (IDII) condition, Fig. 1.C, two of the five glasses had water and subjects were instructed to choose one of them. The glasses which had water in both ED and IDII conditions were pseudo-randomly positioned and all positions were covered with the same frequency. We instructed the participants to select the target as soon as they saw the glasses. After selecting their target according to the condition rule, subjects were asked to perform the imagination of a reach-and-grasp to the selected glass, as if it was positioned in front of them. At the moment they felt the urge to start the MI, they were instructed to memorize the number that was on the scroller and perform the reach-and-grasp movement imagination. Inspired by Libet's clock experiments [10], we used the reported numbers to estimate the time when the participants perceived the urge of performing the movement imagination. Later, we time-locked the data to this event. Subjects had 13 seconds to select the target and perform the self-paced movement imagination. At the end of the trial, as showed in Fig. 1, there was a reporting period in which subjects reported the number they memorized (from now on called "reported number") and the target they selected from 1 to 5. Fig. 1 also shows an example of a correct reporting for the IDII condition. After a break of 1.5 s, a new trial started. Subjects were asked to keep their gaze in the center of the monitor and specifically to avoid moving their eyes towards the selected target during the trial. Moreover, subjects were asked to minimize blinks and muscular artifacts. During the reporting period, those artifacts were allowed. All subjects performed reach-and-grasps to a real glass at the beginning of the experiment and practised the MI task.

EEG Recordings: EEG and electrooculography (EOG) signals were recorded using 64 active actiCAP electrodes (BrainProducts GmbH, Germany). Reference was placed on the right mastoid and ground on AFz. Three EOG electrodes were placed above the nasion and below the outer canthi of the eyes. Biosignals were sampled at 1kHz using two 32-channel BrainAmp amplifiers (Brain Products GmbH, Germany). For the recordings and time-synchronization we used the lab streaming layer (LSL) framework.

EEG Processing: Raw data were first inspected visually and noisy channels were removed. We excluded the trials in which participants reported an incorrect scroller number and/or target number according to the task rules. After bandpass filtering (1-70 Hz, zero-phase 4th order Butterworth), we epoched the data from 0 to 13 s in respect to the start of the trial and we used EEGLAB [11] to: (1) find values outside an interval between $-200 \mu\text{V}$ and $200 \mu\text{V}$, (2) reject trials with abnormal joint probabilities and/or (3) abnormal kurtosis. A threshold of 5 times the standard deviation was used for each statistic. On average, 25 trials were discarded per subject. After rejecting those trials, we applied principal component analysis (PCA) for dimensionality reduction and retained components that explained 99 % of the variance of the data. We then used independent component analysis (ICA) on the PCA-compressed EEG and EOG data using the extended Infomax algorithm [12]. We marked the independent components that corresponded to ocular artifacts. In the unfiltered data, after rejecting the aforementioned artefactual trials, we used the weights of the ICA to back-project the non-artefactual components into the channel-space. ERPs were locked to the cues which distinguished the three different conditions (i.e. second 2 in Fig. 1). Individual averages were collapsed to calculate the grand-average cue-locked ERPs and topographical maps of the scalp ERPs distribution were obtained. We analysed the MRCPs as response-locked EEG neural correlates of movement intention. After bandpass filtering from 0.1 to 3 Hz with a 4th order zero-phase Butterworth filter, we time-locked the trials to the correspondent reported numbers and computed the grand-averaged MRCPs, separately for the three conditions.

RESULTS

Cue-locked ERPs and their topographical maps at time windows of interest for the three different conditions are depicted in Fig. 2.A and Fig. 2.B, respectively. For all conditions, the P300 positive deflection starts around 260 ms after the cue and peaks at 340 ms. While the peak latency is the same among conditions, the amplitude is

different between the ID or IDII and the ED condition. As shown by Fig. 2.B, the differences between the internally (both ID and IDII) and externally-driven (ED) conditions are first more central distributed (200-300 ms) and then more parietal (300-400 ms). P300 amplitudes then decrease until 500 ms after the cue, followed by a slow positive component, which is stronger in the ED condition. These differences are seen in the centroparietal electrodes, according to the maps in Fig. 2.B. Fig. 3.A shows the grand-average MRCPs at electrodes FCz, C3, Cz, C4, CP3, CPz and CP4 for the three conditions and Fig. 3.B shows the respective topographical distribution around the reported number. The self-paced MI was preceded by a negativity that started at around one second before the reported number. The negative peak was higher in the midline electrodes (FCz and Cz) at 900 ms after the reported number. No differences were observed among the three conditions around this event.

DISCUSSION

Using a novel paradigm, we investigated the cue-locked and response-locked EEG phenomena associated to externally and internally-driven target selection. In a preliminary analysis, our results indicate that differences between the externally and internally-driven conditions are present in the cue-locked, but not in the response-locked ERPs (MRCPs). Specifically, the P300 and the following slow ERP components are different among the conditions. The P300 is associated to stimulus processing [13], which is present in all three conditions. Furthermore, there was the need of mapping a rule to the presented stimuli, but this rule varied in complexity among the conditions. The necessity of target selection was limited to the two internally-driven conditions (ID and IDII) which indicates a higher demand in these conditions when comparing to the externally-driven condition. As suggested by Nieuwenhuis et al., later ERP components encode processes of guiding the future response in the service of task demands and rules [6]. While it could be argued that an increase in task demand is due exclusively to the different number of targets available (1 in the ED against 2 or 5 in the IDII and ID, respectively), we found no differences between the IDII and ID conditions. For that reason, our first results indicate that increased amplitudes are associated to a higher demand caused by the need of target selection in both internally-driven conditions. But an important question arises: are the observed differences strictly related to the upcoming motor response? It would be interesting to know whether the need of motor planning directly influences these components by introducing a condition where no motor task is necessary.

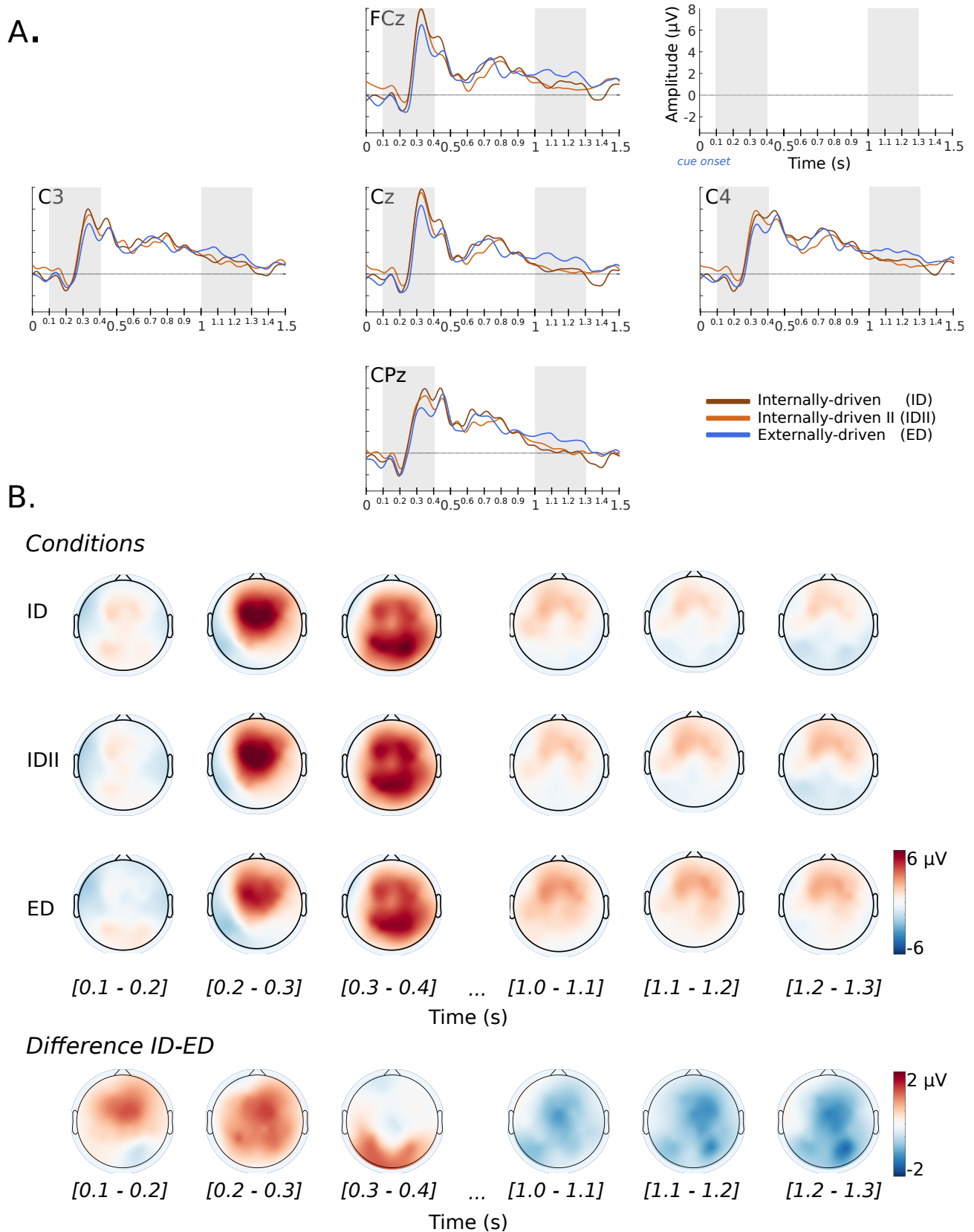


Figure 2: Results of the ERP analysis. (A) Cue-locked grand-average waveforms for electrodes FCz, C3, Cz, C4 and CPz. (B) Topographical maps in the time windows of interest. The first three rows show the topoplots for the three conditions and the last row shows the differences between the internally-driven (ID) condition and the externally-driven (ED) condition. Differences between IDII and ED are not shown since they are similar to the ID vs. ED differences here plotted.

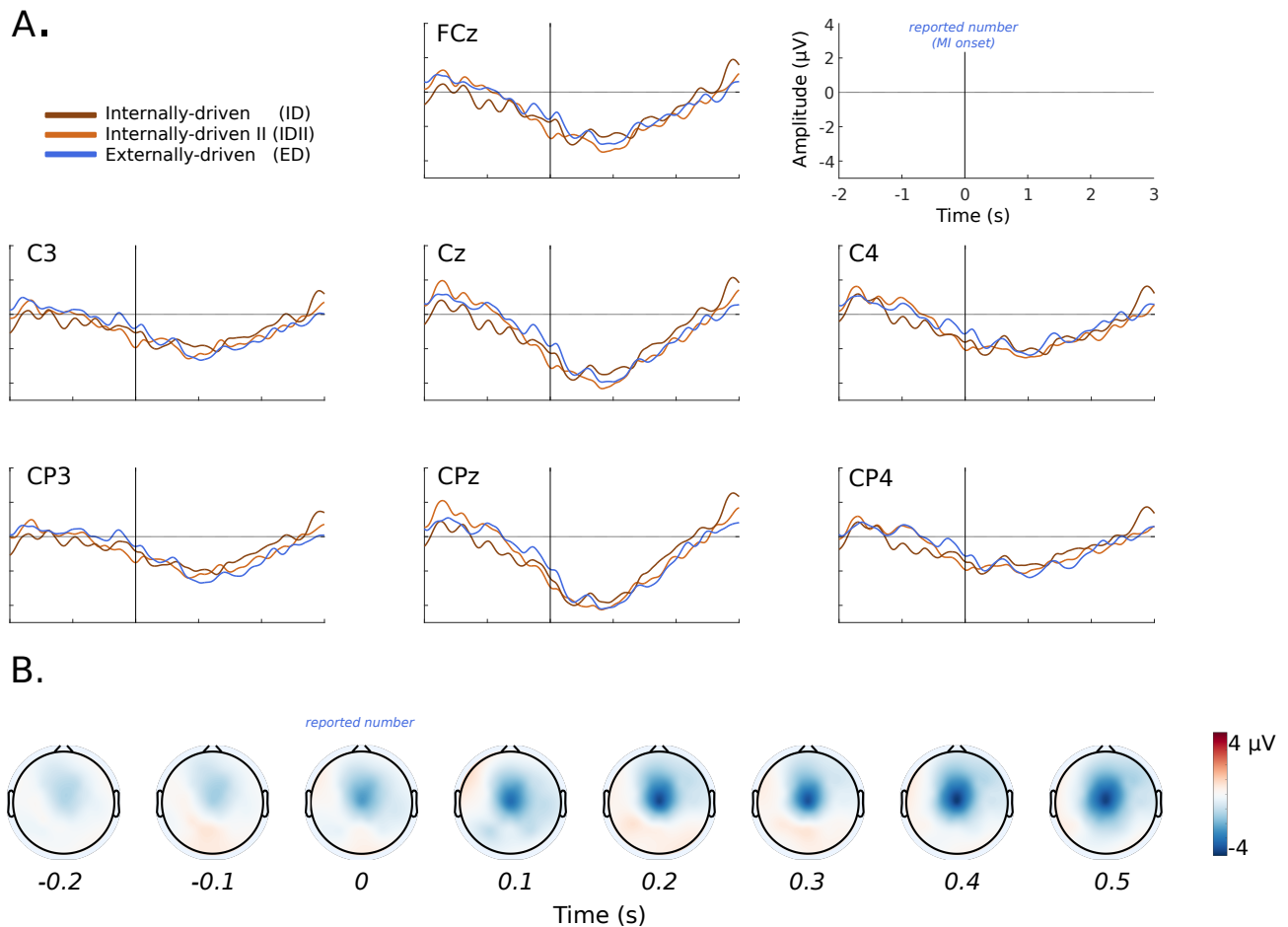


Figure 3: Grand-average movement-related cortical potentials in respect to the imagery onset (i.e. reported number). (A) Time-domain signals for electrodes FCz, C3, Cz, C4, CP3, CPz and CP4 separately for the three different conditions. (B) Topographical maps of the EEG activity around movement onset.

Internally-driven processes have been linked to the more frontal areas of the brain: fronto-striatal circuits, dorso-lateral prefrontal cortex and sensorimotor area (SMA) [14]. We found out that the differences in amplitudes between the conditions are first mainly frontally distributed (higher for the internally-driven conditions) and then located in more parietal areas. The role of parietal areas in visuomotor transformations has been extensively studied [15]. Claiming exactly which brain areas contribute to the observed differences would be premature at this early stage, but the topographical distribution of the ERP components suggest the involvement of the same brain regions. With regard to the MRCs, internally and externally-driven conditions did not differ in respect to both amplitude and latency of the negativity observed when time-locking the trials to the reported number. Participants were instructed to select their target as soon as they saw the five glasses. Since the motor goal had been previously decided according to the task rules, at the time the participants felt the urge to start the imagination, only the pure movement preparation (i.e. the abstract kinematics [1]) was necessary. These processes were the same for all the conditions but they were then dependent on the spatial location of the motor goal (i.e. position of the se-

lected glass), which will then define the trajectory of the reach. Since a motor goal was always present, no differences were expected due to the experimental conditions. Differences can be expected depending on the target location, since low-frequency time-domain signals contain information about movement direction [4]. It is also important to mention that in our paradigm the MRCs were not closely related (in time) to the cue-locked ERPs, since the minimum time between cue and reported number was 3.4 seconds out of all recorded trials. An interesting discussion point is then whether in paradigms in which cue and response are very close in time there is an accumulation of these two cue-locked and response-locked events. Given the nature of the self-paced task (movement imagination), we included the scroller and the reporting period to obtain a time-locking event for motor imagery. Data time-locked to this event can later be used to train a model for movement detection intention which is then tested in a pseudo-online manner. We preferred memorization to an actual motor task (e.g. key press at the end of the task) since there is the high chance that an additional motor task interferes with the motor imagery task, making the observed pattern questionable. Further, we could use this intermediate task to separate target selection from the ac-

tual motor task. To determine the consistency of the EEG phenomena observed we will measure more participants and conduct the appropriate statistical analysis to assess the significance of our results. Behavioural analysis still needs to be performed, specifically to investigate the interaction between the response times (i.e. time between the cue presentation and the reported number marking the MI start) and the type of condition.

CONCLUSION

In this study we analysed the event-related potentials (cue-locked and response-locked) associated to target selection in a self-paced motor imagery task. Our first results show that differences between internally and externally-driven target selection are present in cue-locked but not response-locked ERPs. In the future we will analyse more subjects and conduct a careful statistical analysis to assess the significance of the results. Further, the paradigm that we implemented allows for a more accurate determination of a time-locking event in movement imagination tasks, which can be important for single-trial movement detection of self-paced movements.

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