Steady state analysis for audiovisual attentional switch

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Optimal distribution of attention is a key issue in our everyday-life multitasking activities. Yet, attentional resources are of limited quantity and a tradeoff between resources allocation to different tasks exists. Efficient divided attention results in an enhancement of task relevant networks activity via cross frequency coupling in the theta and gamma band, and enhancement of secondary task networks activity at different phases to that of primary task networks. When task demand exceeds mental capacity, neural synchronization markers of primary task enhancement and non-primary task disruption appear (Todd et al., 2005). Although this shielding mechanism can prevent from mental overload and distractions, missing critical information can have devastating consequences in real-life scenarios such as operating an aircraft (e.g. missing visual/auditory alarms; Dehais et al., 2019). Even though cross-modal attention seems to be widely studied, cross-modal influences through neural oscillations synchronization remains an open question. The goal of this EEG study is to identify the EEG activity related to audiovisual and visuoauditory attentional switch and how brain areas are disrupted when switching from one modality to another. Here we propose to measure Rythmic Entrainment Source Separation (RESS; Cohen and Gulbinaite, 2017) improved activity in the frequency domain, as steady-state responses have been demonstrated as a good marker of attentional focus (Saupe et al. 2009). Future analyses will involve cluster-based permutation tests (Maris and Oostenveld, 2007) to objectively identify significantly activated brain regions, and directed connectivity measures between these regions. We expect an increased RESS activity at the steady-state frequency according to the attentional focus (visual or auditory) and decreased overall activity for audio-visual and visuo-auditory switches with peaks for both steady states activities. We also expect different connectivity patterns associated with efficient and inefficient attentional switches.

We recorded the EEG activity of 14 participants (7 females; 28.75±1.66y.o.) while they were performing an audiovisual steady-state-based attentional switch task associated with a stimulus detection task. Two participants were removed from further analysis due to line-noise contamination of data recordings. They were presented with both an auditory and a visual stream during the whole experiment (~1h) which consisted in a 500Hz sine tone modulated at 40Hz (auditory steady-state stimulation) and a white and black checkboard flickering at 48Hz (visual steady-state stimulation – see figure 1.a-top). In addition to these two constant streams, trains of 2, 3 or 4 consecutive stimuli were presented taking the shape of bips of 200% increase of the amplitude of the 40Hz sound for 50ms for the auditory modality, and of red dots (see central red dot in figure 1.a-top) for 41ms for the visual modality. Trains of two consecutive stimuli were the target to which participants had to answer by button press (the “a” key for auditory bips and the “p” key for visual points) after train presentation and corresponded to 30% of the trials. Participants performed twenty 3-minutes blocs amongst which they had to focus: i) solely on the auditory targets (five blocs); ii) solely on the visual targets (five blocs); iii) alternatively on each stream switching modality whenever a target in the current modality is detected (ten blocs – see figure 1.a-bottom for a graphical representation of switch blocs).

The EEG activity was recorded continuously during the whole experiment with a 64 active electrodes ActiCap slim headset and an actiCHamp amplifier (Brain Products, GmbH) and streamed through the LabStreaming Layer (LSL). Behavioral performances associated to button presses (hit rates – i.e. responses to 2-stimuli targets over total number of target for each condition – and reaction times) were analyzed with a two-way repeated measures ANOVA on Statistica 8, with the condition (unimodal vs. switch) and modality (visual target vs. auditory target) as within subject factors. The EEG data was analyzed with home-made scripts on MATLAB (The MathWorks, Inc.) and EEGLAB (Delorme and Makeig, 2004). After usual pre-processing (see figure 1.b), visual and auditory steady-states spectral activity were extracted with the RESS algorithm (Cohen and Gulbinaite; 2017). The signal-to-noise ratio was analyzed at 40 and 48Hz (steady-state frequencies).

Preliminary behavioral results revealed a main effect of both the condition (unimodal vs. switch – 89.31±0.02% and 75.59 ±0.01% hit rate respectively; $F(1,11)=26.58$, $p<.005$) and the modality (visual target vs. auditory target – 81.58±0.02% and 84.31±0.01% hit rate respectively; $F(1,11)=8.85$, $p<.05$) on the hit rate, but also an interaction effect with all interactions being significant ($p<0.05$) except the comparison between auditory and visual target responses in the switch condition (see fig. 1.c). Oppositely, no effect of either the condition or the modality was observed on reaction times (see fig.1.c).

Concerning the EEG data, visual inspection of RESS SNR reveal expected peaks of varying amplitude at the steady-states frequencies (40 and 48Hz), their first harmonic (80 and 96Hz respectively), but also varying amplitudes according to the condition and modality at low frequencies, in the theta (4-8Hz) and alpha (8-12Hz) frequency bands. Statistical analyses disclose a tendency of the effect of the modality on activities filtered at 40Hz ($p=0.09$; 7.59±0.48dB vs. 7.32±0.44dB for the auditory and visual target respectively) and 48Hz ($p=0.06$; 2.77±0.03dB vs. 2.93±0.04dB for the auditory and visual targets respectively). In addition, a tendency on the effect of the condition is also observed for data filtered at 48Hz ($p=0.05$; 3.00±0.10 dB vs. 2.71±0.11 dB for unimodal and switch conditions respectively).

The motivation of this study was to identify the neural markers associated with efficient (i.e. hits) and non-efficient intermodal attentional switches. Preliminary results show varying hit rates according to both the condition (as expected from the literature) and the sensory modality (as suggested by Dehais et al., 2019). In addition, preliminary EEG results suggested that steady states activities could discriminate brain response to unimodal and switching attention at high (>30Hz) frequencies, but also at low frequency activities (around 10Hz). Further processing and state-of-the-art analyses including cross-frequency coupling in the alpha/theta frequency bands or directed connectivity measures could help to better understand the mechanisms underlying bi-modal resources management in the brain and why they can be inefficient.

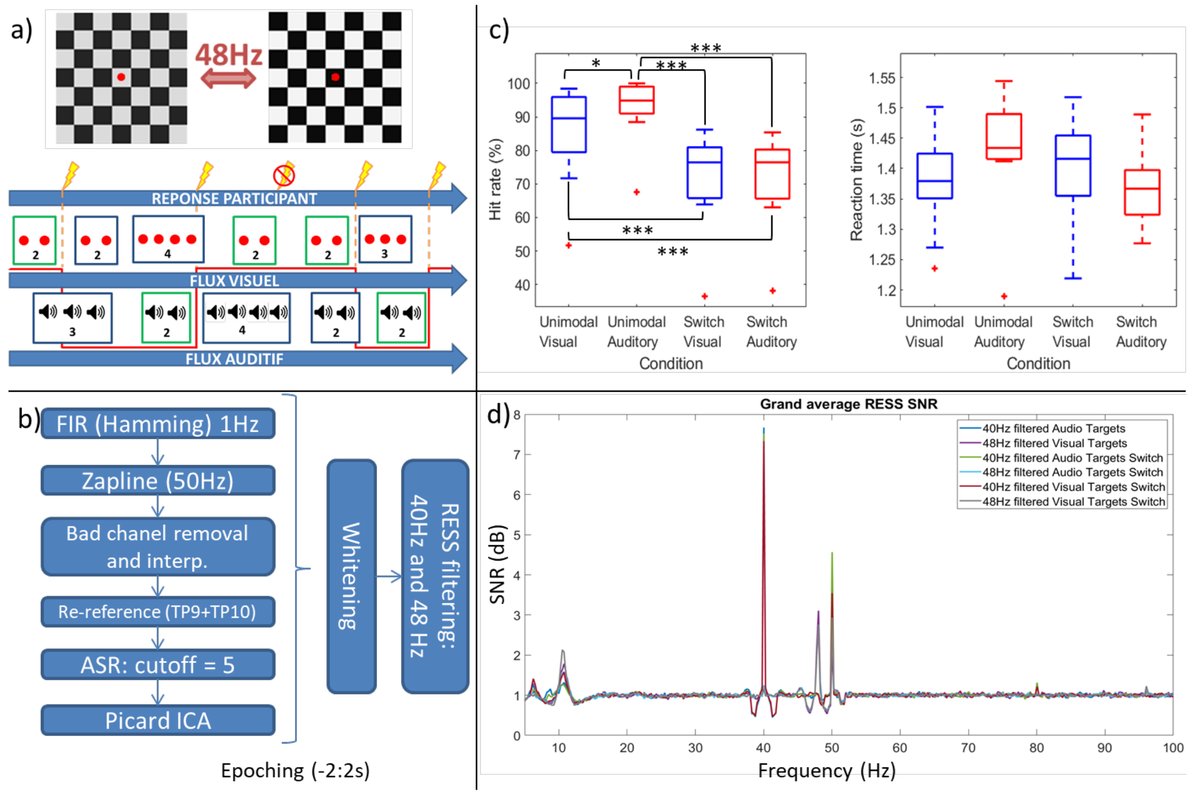

*Figure 1. a) Visual steady-state stimulation (48Hz checkboard) with stimulation point (central red dot), and attentional switching task representation showing the « attentional flow » of the participant (red line) when answering (or not – third target) to target stimuli trains going from the visual modality (« Flux visuel », middle line) to the auditory modality (« Flux auditif », bottom line) presented simultaneously ; during switch blocs, the participant has to respond to target trains of two stimuli (in green) by pressing a specific key on the keyboard (top line) and switch modality. b) Preprocessing and processing steps applied to raw EEG data to obtain power and SNR RESS grand averages. c) Average behavioral results (hit-rate – left graph – and response time – right graph) across participants in the four (unimodal vs. switch and auditory vs. visual) conditions represented as boxplots showing median (midline) and first and third quartile values (top and bottom whiskers) as well as preliminary statistical results between each condition (***: p<0.005; *: p<0.05). d) Grand average RESS signal-to-noise ratio across participants for unimodal (visual and auditory) as well as switch (visuo-auditory as well as audiovisual) with peaks appearing at 40, 48, 80 and 96Hz, as well as low frequencies (alpha and theta frequency bands)*

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