Assessing the Zone of Comfort in Stereoscopic Displays using EEG

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Abstract

The conflict between vergence (eye movement) and accommodation (crystalline lens deformation) occurs in every stereoscopic display. It could cause important stress outside the "zone of comfort", when stereoscopic effect is too strong. This conflict has already been studied using questionnaires, during viewing sessions of several minutes. The present pilot study describes an experimental protocol which compares two different comfort conditions using electroencephalography (EEG) over short viewing sequences. Analyses showed significant differences both in event-related potentials (ERP) and in frequency bands power. An uncomfortable stereoscopy correlates with a weaker negative component and a delayed positive component in ERP. It also induces a power decrease in the alpha band and increases in theta and beta bands. With fast responses to stimuli, EEG is likely to enable the conception of adaptive systems, which could tune the stereoscopic experience according to each viewer.

Author Keywords

Stereoscopy; Comfort; EEG; HCI evaluation

ACM Classification Keywords

H.5.2 [User Interfaces]: Evaluation/methodology; I.4.8 [Scene Analysis]: Stereo; H.1.2 [User/Machine Systems]: Human information processing
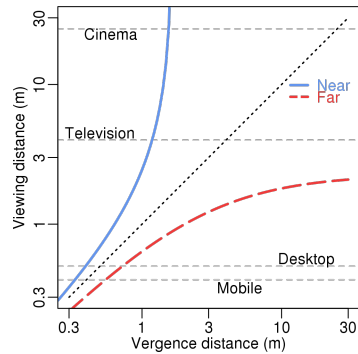
Figure 1: The acceptable zone of comfort depending on viewing distance and vergence distance (*i.e.* the apparent depth of contents). From [8].

Introduction

Stereoscopy is a technique which gives to viewers the illusion of depth by sending a different image to each eye. Stereoscopy has been studied for decades as a way to improve the perception of 3D scenes. Even so, it is only circa 2010 that the use of stereoscopic displays has been popularized among the general public, *e.g.*, in movies or video gaming industries. We investigate a new, innovative, methodology to assess comfort in stereoscopy.
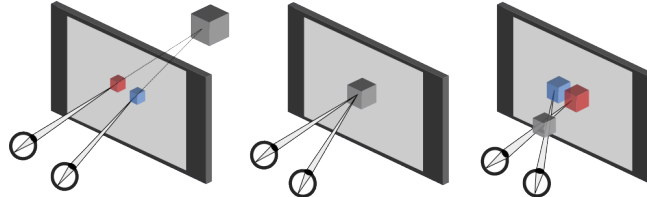

Figure 2: The vergence-accommodation conflict (VAC). **Left**: object "behind" the screen, negative VAC. **Middle**: the object appears flat, no VAC. **Right**: object "in front", positive VAC.

This study focuses on the first and foremost parameter tied to stereoscopy: apparent depth. In stereoscopic vision, the depth perception of an object is due to the discrepancy between its projection on both retinas. In order to see *one* object, the eyeballs need to rotate accordingly. This mechanism is called the "vergence". In a natural situation, as an object is moving closer or further, vergence matches another physiological phenomena: "accommodation". It enables the object's image to remain clear on the retina. It is caused by a deformation of the crystalline lens, which focuses light beams the same way camera lenses do. With stereoscopic displays however, the physical distance of the screen – thus the accommodation – remains still while apparent depth and vergence vary. This unecological situation causes a stress on viewers. It is called the "vergence-accommodation conflict" (VAC, see

figure 2). The VAC is inextricably linked to every type of stereoscopic displays and is one of the major causes of discomfort [8]; this is why we decided to manipulate this variable in our investigations.

On the one hand the VAC has already been studied using questionnaires; in [8] a "zone of comfort" has been established (figure 1). The apparent depth of objects should remain within this zone for the viewers not to feel discomfort. On the other hand electroencephalography (EEG) has been used to study fatigue induced by stereoscopic displays [6, 4, 3]. While results related to the VAC are great insights on how to present content to viewers, these are general rules based on controlled experimental setups. The match cannot be perfect with every user and in every viewing conditions (*e.g.*, viewing distance, ambient light). It may then be interesting to back up the VAC with another type of measure than sporadic and disruptive questionnaires: EEG. EEG can be measured in real-time without interrupting the viewing. EEG studies from the literature do not take into account the VAC. Overall they compare the state of the subjects before and after a long session of stereoscopic watching [6, 3]; or they compare "2D" versus stereoscopy, without further control of what is displayed in stereoscopy [6, 4, 3].

Therefore we decided to combine those two kinds of investigations to see if the VAC could be supported with EEG recordings. Moreover, thanks to precise stereoscopic parameters and real-time measures, one purpose of this work is to build a protocol which compares short sequences of several seconds instead of viewing sessions of several minutes (between 2min and 40min in [8, 6, 3]). If we are to succeed, detecting comfort and no-comfort situations would allow in the future to tune quickly stereoscopic display parameters for one particular viewer.
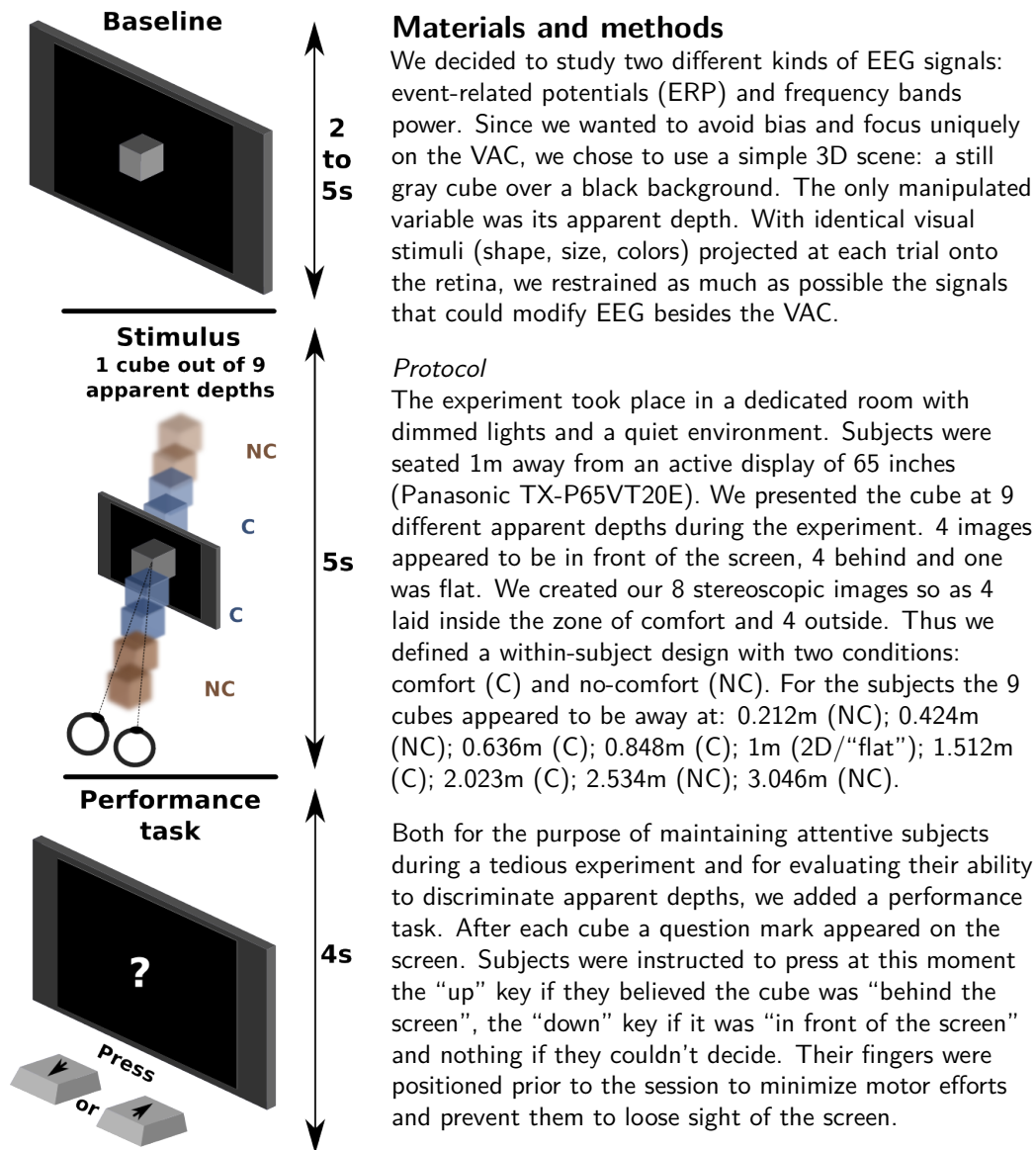
Baseline

2 to 5s

Stimulus
1 cube out of 9
apparent depths

NC

C

5s

C

NC

Performance task

?

Press

or

4s

Figure 3: The steps of a trial: 2D baseline, gray cube at random depth, performance task.

Materials and methods

We decided to study two different kinds of EEG signals: event-related potentials (ERP) and frequency bands power. Since we wanted to avoid bias and focus uniquely on the VAC, we chose to use a simple 3D scene: a still gray cube over a black background. The only manipulated variable was its apparent depth. With identical visual stimuli (shape, size, colors) projected at each trial onto the retina, we restrained as much as possible the signals that could modify EEG besides the VAC.

Protocol
The experiment took place in a dedicated room with dimmed lights and a quiet environment. Subjects were seated 1m away from an active display of 65 inches (Panasonic TX-P65VT20E). We presented the cube at 9 different apparent depths during the experiment. 4 images appeared to be in front of the screen, 4 behind and one was flat. We created our 8 stereoscopic images so as 4 laid inside the zone of comfort and 4 outside. Thus we defined a within-subject design with two conditions: comfort (C) and no-comfort (NC). For the subjects the 9 cubes appeared to be away at: 0.212m (NC); 0.424m (NC); 0.636m (C); 0.848m (C); 1m (2D/"flat"); 1.512m (C); 2.023m (C); 2.534m (NC); 3.046m (NC).

Both for the purpose of maintaining attentive subjects during a tedious experiment and for evaluating their ability to discriminate apparent depths, we added a performance task. After each cube a question mark appeared on the screen. Subjects were instructed to press at this moment the "up" key if they believed the cube was "behind the screen", the "down" key if it was "in front of the screen" and nothing if they couldn't decide. Their fingers were positioned prior to the session to minimize motor efforts and prevent them to loose sight of the screen.

One trial consisted in 3 steps. First the 2D cube appeared on screen. It served as a reference image. It stayed on screen during 2 to 5s so subjects could not anticipate the appearance of the stereoscopic cues. Then it was randomly replaced by 1 of the 9 possible cubes. This new image remained 5s before the question mark appeared. During the 4s that followed, the first key press – if any – was recorded. Then a new trial immediately started. See figure 3. Each apparent depth was presented 30 times. The overall 270 trials were balanced across 5 sub-sessions.

The entire experiment comprised several sequences. Subjects entered in the room. They were given general facts about the context of the experiment and filled an informed consent form. To check their aptitude to perceive stereoscopic images they completed a TNO test [7]. If the test was successful, we proceeded to the setup of the EEG device. Then subjects responded to the pre-test questionnaire. We presented randomly the 9 images. After each image we asked them to rate the clarity of their vision and the tiredness of their eyes on a 5-point Likert scale; "1" representing no negative symptoms and "5" severe symptoms. Those questions were adapted from [8] and translated to French. They let us measure respectively how well subjects saw the stereoscopic images and how comfortable they felt. Before we started the main part of the experiment, we accustomed them to the task with a training session. Once they felt confident we began the first sub-session. On average a sub-session lasted 12min. We kept on with the 4 others, letting subjects rest a few minutes and drink water if they wanted to in-between. After the sub-sessions were over we repeated post-test the Likert scale questionnaires. Overall subjects stayed for about 2.5 hours in the room.
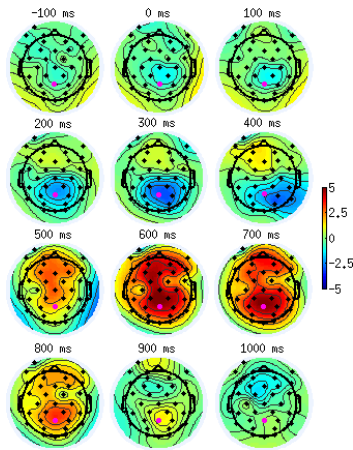
Figure 4: Scalp maps of ERP amplitudes over time (3 subjects, ≈ 240 trials over C and NC). Pz (highlighted in pink) is one of the site with the largest amplitude during stereoscopic viewing phase.

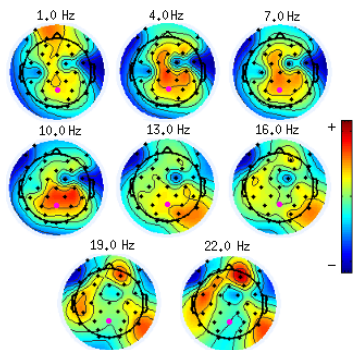**Figure 5:** Scalp map of various frequencies' signal power (3 subjects, ≈ 240 trials over C and NC). Pz (highlighted in pink) is one of the site with the largest power during stereoscopic viewing phase.

EEG processing

Three subjects took part in this pilot study (2 females, 1 male, mean age 22, normal vision). Their EEG activity was recorded at a 512Hz sampling rate with a g.tec g.USBamp system. 32 active electrodes were positioned according to the international 10-20 system (reference on the left earlobe). 4 were recording electrooculographic (EOG) activity[1] and 28 EEG activity[2]. OpenViBE [2] was used both to record signals and to manage the experiment. EEGLAB [1] 13.0.1b has been used in conjunction with Matlab R2012B for EEG processing. First we concatenated datasets from the 5 sub-sessions. We cleaned-up our signals with a 0.5-25Hz band-pass filter. Then we extracted $9 \times 30 = 270$ epochs related to the cube appearance, -1s to +4s around stimulus onset. Because of the unusual nature of the recordings – few EEG studies involve stereoscopy – we chose automated artifacts rejection methods. Epochs polluted with muscular activity were rejected with the EEGLAB function pop_autorej. Supported by [5], we removed EOG activity with the ADJUST toolbox. We ran an Infomax independent component analysis on each dataset. We rejected components detected either as eye blinks, vertical or horizontal eye movements by ADJUST. Finally we compared subjects by pairing C and NC epochs.

Hypotheses

Consequently to this protocol design, we made 4 hypotheses. **H1**: The symptoms reported in Likert-scale questionnaires would be more pronounced in the no-comfort condition than in the comfort one. **H2**: performance in the task would decrease in the NC

condition because of images more difficult to perceive. **H3**: Similarly to [6], delay in ERP would increase in the NC condition. **H4**: Frequency bands power would change between C and NC. In particular the alpha activity would increase in NC because of more disturbing stimuli.

Results

We analyzed ERP from -0.5s to +2s around stimuli onsets and frequency bands from -0.5s to +3.5s, averaging data from all subjects. Although in the future more electrodes will have to be considered, in a first approach this pilot study focuses on Pz. It is a standard site studied in the literature and it is less likely to be polluted by EOG activity than frontal sites. Moreover, for both ERP and frequency bands power, scalp maps showed that Pz is among the most active sites in our data (see figures 4 and 5). We chose to use event-related spectral perturbations (ERSP) to gather first insights of modifications in frequency bands power between C and NC. Statistical analyses not related to EEG were performed with R 2.15.2. Because of the small size of our samples we used non-parametric tests to analyze our data – permutation statistics in EEGLAB.

H1: A Wilcoxon Signed-rank test showed a significant effect of the C/NC condition for both Likert-scale questionnaires ($p < 0.01$). Subjects reported more eye comfort in C than in NC (means: 1.83 *vs* 2.67) and more vision clarity in C than in NC (means: 1.58 *vs* 2.58).

H2: There was 3 possible answers during the performance task. "Good" were mapped to "1", "bad" to "-1" and "none" to "0". A Wilcoxon Signed-rank test showed that there is a significant effect of the C/NC condition in the performance task ($p < 0.01$, 120 trials for each subject and condition). The overall mean scores are 0.44 in C and
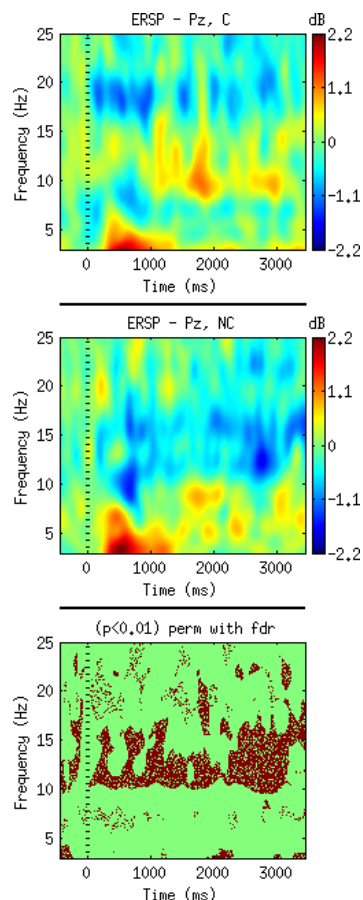
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[1]LO1, LO2, IO1 and FP1 sites
[2]AF3, AF4, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, C3, Cz, C4, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, PO3, PO4, O1, Oz and O2 sites

Figure 6: ERSP in Pz. **Top**: comfort condition; **middle**: no-comfort condition (≈ 120 trials each, 3 subjects). **Bottom**: red dots indicate significant differences in frequency powers between C and NC ($p < 0.01$, FDR correction).

0.74 in NC. We ran a post-hoc analysis on answer types. Because we couldn't match one C trial with one NC trial (they were randomly distributed), we chose a Chi-square test. It showed a significant effect between C and NC both for the "good" and "none" answers – $p < 0.01$, adjusted for multiple comparisons with false discovery rate (FDR). C/"good": 48%, NC/"good": 79%. C/"none": 48%, NC/"none": 16%.
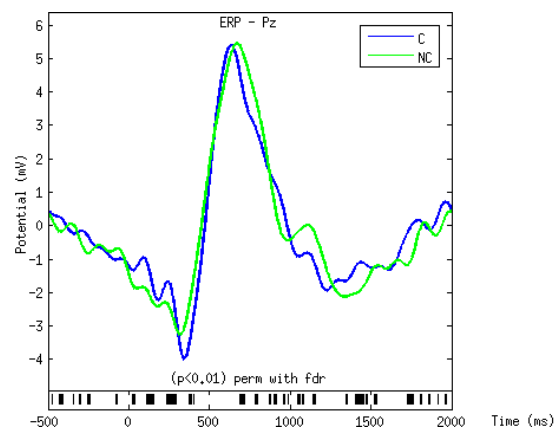

Figure 7: Average ERP in Pz of comfort (blue) and no-comfort (green) conditions (≈ 120 trials each, 3 subjects). Bottom marks indicate significant differences ($p < 0.01$, FDR correction). For easier interpretations a 8Hz low-pass filter is applied (view only).

H3: Average ERP at Pz in C and NC showed significant differences ($p < 0.01$, corrected with FDR). Figure 7 suggests a delayed peak for the positive component in NC. The differences appear more pronounced in the negative component which precedes: greater amplitude in C.

H4: ERSP in Pz between C and NC showed significant differences in several bands power (see figure 6). The

most notable is a *decrease* within alpha band (10-14Hz) in NC; but an *increase* within theta (4-7Hz) and beta (15-25Hz) also seems to occur in NC compared to C.

Conclusion

The main purpose of our study was to compare the EEG activity between comfortable (C) and uncomfortable (NC) vergence-accommodation conflicts in stereoscopic displays. Beside a better understanding of the repercussions of this conflict within the brain, one goal would be ultimately to build an adaptive system. Lightweight and practical EEG devices could help to calibrate the display to each viewer, avoiding uncomfortable experiences. In the literature subjects are mostly exposed to long sessions of stereoscopic viewing before measures are performed. Because an efficient adaptive system could not wait half an hour to find the right parameters, we built a pilot study which relied instead on short sequences of several seconds. We used a simple 3D scene in order to limit bias.

According to the questionnaires, we replicated two different zones of comfort as described in [8] (H1). We conceived a performance task to sense how well subjects perceived depths. Surprisingly, they performed *better* in NC (H2). They did not give a greater number of wrong answers in C though, instead they couldn't decide more often if objects appeared in front of or behind the screen. As such, the reported poorer vision clarity in NC does not seem to correlate with a poorer depth perception. We remain cautious on our interpretation though, since the cube we used lacked many cues which should change the scene comprehension (e.g., shadows, relative movements).

With EEG some results were similar to [6] and [4], even though we did not use an oddball paradigm and compared two stereoscopic conditions instead of stereoscopic and 2D

images. In NC the ERP differed in their negative component (lower amplitude) and their positive component (higher latency) (H3). Unexpectedly, the frequency power in the alpha band was greater in C than in NC (H4). Maybe our short sequences did not induce a greater fatigue in NC, but instead made our subjects more attentive to the stimuli. This result is similar to [4] and [3]. However the increase in the beta band contradicts both and supports [6] instead. We stress again that these studies compared stereoscopy to 2D. We should use more complex protocols and analyses to understand exactly how EEG bands power relates to the VAC.

We managed to build a pilot protocol which supports the study of the VAC through EEG. We presented a new method comparing different apparent depths. There is several ways to improve on our study. We did not have the material to measure pupil distance to reduce inter-subject variability. On the same note, using a device such as the Oculus Rift could give a far better accuracy in stereoscopy. We used simple stimuli; random objects and orientations would allow us to consider the "2D" condition and create more realistic scenarios. If we show at the same time objects with various depths, as in every movie, is it less comfortable for the viewer? Fatigue and comfort goes beyond the VAC. We chose one viewing distance but there is more to explore in the zone comfort of [8]. We had to make two clusters (C/NC) from our 8 stereoscopic images to gather enough EEG data. If we find a way to present more stimuli while keeping the duration of the experiment acceptable for subjects, more conditions could be studied.

When we pursued our analyses, we sensed that the ability to perceive stereoscopy well could impact brain activity. EEG may not only be used as a way to make stereoscopy comfortable, but to measure if it *works*. Moreover, when

we added a condition "in front of"/"behind" the screen, various profiles appeared. Whenever it is for physiological or cognitive reasons, we may not perceive equally both effects. Once the protocol is strengthened, more subjects will have to be involved so as to draw strong conclusions.

By extending our protocol it should be possible to study at the same time comfort and depth perception. With more data, we could build an EEG classifier and also have a better understanding of stereoscopy: guidelines for an improved technology and greater entertainments.

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