# Review – PCI RR

The authors suggest a study which will investigate whether previous findings regarding the brain’s processing of symmetrical vs asymmetrical stimuli in different viewing conditions also hold in immersive virtual reality (VR). More precisely, the experiment shall test the hypothesis that the additional information (e.g., stereoscopic depth cues) available in such immersive settings cancel out an effect previously found for the SPN (Sustained Posterior Negativity; an ERP component). Namely, showing the stimuli with a perspective distortion (i.e., like looking at them from an angle) leads to a reduction in the (absolute) amplitude of the SPN (“perspective cost”), particularly if participants focused on other properties of the stimuli (e.g., their luminance) rather than their symmetry. The motivational argument for this new approach is that VR provides strong and intuitive depth-cues which might support the brain in forming a viewpoint independent representation of the stimulus. A truly viewpoint independent representation should (by definition) not vary as a function of the viewpoint dependent “retinal” representation of the stimulus. Therefore, if the “perspective cost” was zero in immersive (i.e., more naturalistic) conditions, this would be evidence that the SPN can reflect symmetry processing based on a viewpoint independent representation.

The authors therefore suggest a VR-based experiment which implements a design that (in similar forms) was previously used in conventional 2D-screen settings to investigate the SPN. The data gathered via this experiment shall (centrally) test the hypothesis that in such immersive conditions the amplitude of the SPN does not differ between presentations of the stimuli with or without perspective distortions. To this end, they plan to test (at least) 48 healthy participants in a combined EEG+VR setup and use equivalence testing on the resulting EEG data to test whether there is evidence to reject the null hypothesis that the SPN amplitude is different in VR conditions with and without perspective distortion.

I enjoyed reading the study proposal and learning about the field of symmetry processing and the SPN. The study appears to be based on an impressive body of research addressing similar questions. The authors demonstrate extensive experience and experimental insights into how the SPN behaves under certain conditions and how to study it effectively. Using VR to expand this knowledge base and to investigate the phenomenon of “perspective cost” under conditions that might substantially facilitate the formation of viewpoint-independent representations is a promising and informative endeavor. I look forward to reading about the results. I noticed a few aspects in the registration that could benefit from clarification, which I would like address below:

Validity of the research question(s)

Above, I attempted to articulate the underlying research question in my own words. I hope it accurately reflects the authors’ actual aims. (The only explicitly stated “research question” I found in the report was in the table at the end: “Can we achieve extraretinal representation of planar symmetrical dot patterns in virtual reality?”. However, this appears to be more of a subsidiary question related to Hypothesis 1, while Hypothesis 3 seems to be the central focus of the study.) The (assumingly) central question seems well-derived from previous findings regarding the SPN as well as assumptions and insights gathered in other studies and fields about VR as an experimental tool. I would recommend keeping the scope/formulation of the (explicitly phrased) research question narrow enough—for example, focusing on the modulation of the SPN rather than about how the brain generally processes (a)symmetry—so that the suggested experiment can provide the data to answer it. Based on the introduction and the framing of the study’s motivation, I conclude that the authors have a concrete and valid research question in mind. I recommend that a specific formulation of this (central) research question be added to the study plan (e.g., in the table at the end of the document).

Hypotheses

The authors suggest three hypotheses, all of which seem logically and plausibly derived from previous research. However, it would be helpful if the authors clarified the function of each hypothesis. H3 formulates the core claim of the study. H1 seems to describe a necessary (?) pre-condition for studying H3. H2 appears corollary and independent of H3 (i.e., H3 can be tested irrespective of the outcome for H2). This makes the role of H2 somewhat unclear. It could serve as a form of positive quality control, but this function is not explicitly mentioned.

I have a few concerns with the statements made in the columns “Interpretation given different outcomes” and “Theory that could be shown wrong by the outcomes” (in the final table):

**H1:**

* + The authors will conclude that “something in the experiment went wrong” if H1 is not supported by data from both frontoparallel conditions. I think, this is a good but strict criterion. Does this mean, that if there is no significant SPN in one of these two conditions, the rest of the data can and will not be analyzed and interpreted in any case? What happens for the case that there is evidence for H3 in the regularity condition but no evidence for H1 in the luminance condition (or vice versa)?
	+ The authors write that “We are also confident we will observe SPNs, **albeit smaller** in the perspective conditions given the results of Karakashevska et al. (forthcoming 1,2)” which seems to contrast with H3. If the authors expect smaller SPNs in the perspective conditions (i.e., perspective cost), wouldn’t they want to test this hypothesis (and reject the H0 that there is no perspective cost) instead of the other way around?
	+ Furthermore, if H1 is not supported by data from the two “perspective” conditions, the authors will conclude that “in a virtual reality environment, the brain is blind to extraretinal symmetry”. This claim is way too strong, in my opinion. (A) If participants are behaviorally capable of performing the symmetry task in the perspective condition, this is strong evidence that “the brain” is not blind to this kind of symmetry. Any conclusions should be restricted to the SPN and the processes it reflects). (B) Additionally, the generalization to VR environments as such is not justified. The results might be specific to the design, environment, setup, hardware, or stimuli used in this study. Whether such a finding generalizes to other VR experiments needs to be tested explicitly. (C) Finally, the credo “absence of evidence does not imply evidence of absence” also applies here.
	+ As the authors write themselves, “the brain is not sensitive to symmetry presented in virtual reality environments” is not a particularly interesting or probable theory to disprove. Isn't the aim (of H1) rather to demonstrate that the SPN can also be measured and studied in immersive settings? This would refute the claim that the SPN is merely an artifact of unnaturalistic, simplified, abstract 2D lab experiments.

**H2:**

* + As with H1, I am not a fan of the (potential) conclusion that “the task modulation of SPN amplitude does not apply in virtual reality environments [if the data does not support H2]”. I would advise against generalizing such findings to all virtual reality environments/studies.

**H3:**

* + As with H1, the claim that “symmetry presentations in VR are not sufficient for achieving extraretinal symmetry representation [if there is perspective cost for both tasks]” is too strong, in my opinion. This should be more focused on the SPN and the experimental design/setup of the study.
	+ Furthermore, it would be valuable to know what the interpretation will be if there is support for H3 in only one of the two tasks.
	+ “The brain codes extraretinal symmetry in a different way that it codes frontoparallel symmetry” appears overly general. Even if there is no difference in SPN observed in this experiment, it does not justify conclusions about how “the brain” universally processes symmetry. Regarding the sentence "We will acknowledge that it is not possible to achieve equivalence in the symmetry signal for retinal and extra-retinal representations of symmetry," it seems unclear.

Experimental setup/design:

The experimental setup and design seem feasible, sound, and mostly well-thought through. Potential challenges might arise from the fact that (in comparison to the previous experiments which the authors refer to) this study will be conducted in VR. Besides the positive aspects of VR (which the authors outline), it also brings additional obstacles. Foremost, putting a VR headset on top of an EEG cap is likely to introduce additional noise into the EEG measurements, potentially leading to a lower signal to noise ratio (SNR) compared to previous data sets. Consequently, effect sizes in the data may be smaller than those observed in previous studies. It is difficult, if not impossible, to estimate the magnitude of this impact beforehand. Therefore, I believe it is reasonable to base power calculations on recent non-VR studies (as done by the authors). However, to err on the side of caution, the authors might consider adjusting power calculations to account for the potentially lower SNR and reduced power due to the VR setup. This could involve increasing the number of trials or participants to compensate for any anticipated decrease in data quality/SNR. At least, it should be discussed (at latest when interpreting the results) that the power analyses conducted may be overly optimistic as they do not reflect potentially interfering effects of a VR setup.

Another difference to the previous studies is the (more naturalistic and therefore) less controlled background against which the stimuli pattern will be presented. I understand that this is a core feature of the study and do not want to criticize it. However, this might introduce confounds in the data, as, for example, in the perspective condition not only the stimulus will be non-symmetric (in the visual field) but also the background which may lead to changes in EEG potentials which are not related to stimulus processing (e.g., the background is asymmetric also for “symmetric pattern” trials in the perspective condition).

I have some clarification questions regarding the sizing of the stimuli (i.e., the actual dot patterns). The authors write that the patters have a size of “approximately 7.5° of visual angle”, show dots with a diameter of 0.25°, and are presented at a distance of 4.13m (Fig. 6). To my understanding, this translates to an absolute width of the whole pattern of ~0.54m and 0.018m diameter for a single dot (diameter = tan(0.25°/2) \* 4.13 \* 2). This seems small for stimuli in VR (at 4m distance). Is the resolution of the Vive Pro Eye high enough to clearly see stimuli (dots) of this size (at the given distance)? The example environments which were provided by the authors seemed to hold placeholders for the stimuli patterns, but these looked substantially (by far) larger than the numbers mentioned above. Maybe these placeholders are/were not representative of the final design? To ensure a concrete understanding of the actual experimental setting it would be beneficial to see screenshots (or even blender models or Unity scenes) of the final layout of the scene containing an actual stimulus.

Furthermore, I find it challenging to reproduce the placement of the cameras with the provided written information. It's unclear around which point and axes the cameras will be rotated. Are these coordinates based on Blender rather than Unity? This issue aside, Figure 6 is very helpful and mostly self-explanatory (however, also here the numbers do not really add up: if the triangle C1-C2-Stimulus is equilateral [4.13], all inner angles should be 60 degree). What concerns me is the “tilt”: if the camera is rotated 15° downwards, the center of the stimulus pattern will be approx. 15° above the participant’s straight line of sight (i.e, the center of the field of view). That is quite a big eccentricity for VR. I know from own experience that stimuli with an eccentricity >15° (i.e., the upper half of the pattern in this setup) can become quite blurry in the Vive Pro Eye (due to the Fresnel lenses). Might this become a problem? Or am I misunderstanding the setup?

Related to the size of the stimuli is another challenge that I envision for the experiment: participants will most likely perform eye movements to explore the patterns. The larger the patterns, the larger these eye movements will be. It is possible that there could be systematic differences between conditions (e.g., perspective vs frontoparallel) in terms of eye movements, which may/will influence the EEG signals. Do the authors have a plan to address this issue? How will participants be instructed regarding fixation behavior? Will fixation and gazing behavior somehow be monitored? The Vive Pro Eye allows for measuring eye tracking. This could be an option (e.g., in order to show post hoc that there were no systematic differences between the conditions). Relying purely on ICA to clean the data from eye movement artefacts and gaze related EEG components (which do not need to be artefacts) might not be sufficient. I am not requesting the authors to add eye tracking, but I want to send a sign of warning. We see in comparable VR experiments a lot of eye movements which often are confounded with experimental manipulations and correlate with EEG findings (also in parieto-occipital sensors). This is not a bad thing per se but should be factored in when setting up a new study.

EEG preprocessing

The pipeline seems reasonable and well thought through. I only have minor comments/questions here:

* ICA rejection: I do not know the `Adjust()` function in MATLAB. I assume it has some settings or parameters which can be chosen to adjust the rejection criteria. For reproducibility, it would be good to mention/register the choice for these settings. Will the function make use of the EOG channels? Will ICA be run on continuous or epoched data?
* Channel rejection: also here, it’d be great to register which criteria (even if applied visually/manually) will guide the selection of channels which are to be rejected. Will this rejection be performed on continuous or epoched data?
* Trial rejection: the authors plan to reject every trial with an amplitude >100uV. Does this apply to all channels (i.e., will a single channel which reaches >100uV at one point of the trial lead to rejection of the entire trial)? Or only to channels in the ROI?
This might be a very strict criterion (especially when applied to all channels) in VR-EEG settings that leads to high rejection rates.

Statistics

H1: Will the significance criterion for the four t-tests be corrected for the number of tests (if so, by which procedure)?

H2: What will be the interpretation if (instead of only the factor “*Task”*—as hypothesized) also or only the interaction between the two predictors (“*Task”* and “*Angle”*) turns out significant? What if the main effect “Angle” is found significant—will this influence the interpretation of H3? Will the testing of additional participants continue even if after 48, 72, … participants a solid effect of “Angle” manifests?

H3: To provide evidence that there is no “perspective cost” the authors plan to apply an equivalence testing strategy by refusing the hypothesis that there is a meaningful difference in the SPN for the perspective as compared to the frontoparallel condition. Hereto they only specify an “upper” boundary (-0.35uV) for the equivalence test. To my knowledge, it is common to also provide and test against a lower boundary if one wants to show equivalence. It would be great if the authors provided concrete arguments why they think that testing only one side of the equivalence boundaries is sufficient.

A meta comment

Throughout the report, the authors refer to (some of their) previous works by citing “Karakashevska et al. (forthcoming …)” that have relevant explanations and method descriptions for the present study. As this previous work seems to be unpublished and not (yet) accessible, this makes it difficult/impossible to fully understand, evaluate, or reproduce the according sections.