[The Effect of Cognitive Load on Vection and Cybersickness in VR]

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[Virtual Reality (VR) experience through head mounted displays is becoming more and more popular both in the video gaming community (Dani, 2019) and for treatment and training programs (Laver et al., 2018). These headsets can cause adverse symptoms in the user often referred to as cybersickness (e.g. Rebenitsch and Owen, 2016). Symptoms can vary from motion sickness like symptoms (e.g. nausea, dizziness) to visual stress symptoms (e.g. headache, eye strain). Cybersickness is often linked to a phenomenon called vection (e.g. Nakamura, 2013). Vection is the illusion of self-motion in a stationary observer. The moving visual input that is presented to the observer in the virtual environment makes the individual feel as though they are moving through that environment (e.g. Palmisano et al., 2004, 2015). The relationship between vection and cybersickness is rather complex (Weech et al., 2019), however vection itself can improve a user's experience in VR (Riecke, 2011). Various stimulus attributes have been shown to affect both vection and cybersickness, such as speed (Seya et al., 2014), size (Lin et al., 2002; Palmisano et al., 2004), eccentricity (e.g. Pöhlmann et al., 2021) and motion direction (Bubka et al., 2008; Pöhlmann et al., 2021). However, not only stimulus attributes but also cognitive processes have been shown to affect the two, with more cognitive demanding tasks resulting in a weaker sensation of vection (Seno et al., 2011). Theta, beta and particularly alpha oscillations have been shown to reflect the experience of vection, with increases in alpha during ongoing vection reflecting the deactivation of vestibular cortex areas and visual areas responsible for object motion (Harquel et al., 2020). Cybersickness is also linked to cognitive processes. Using mental distraction has been shown to reduce adverse symptoms (Bos, 2015) and has been shown to facilitate habituation to cybersickness (Zhou et al., 2019). This study aimed to investigate the effect of cognitive load and eccentricity on the experience of vection and cybersickness.

Data of 21 observers were analysed (age range: 18-58 years, M = 23.24 years, SD = 9.47), 12 identified as female, eight as male and one as gender non-binary. A Valve Index headset was used to present optic motion patterns to the observer. A mask was used in the restricted conditions to limit the view of the motion stimulus to either the centre or periphery. A rapid serial visual presentation task was presented in place of the fixation cross 5s after motion onset. Ten colourful monsters were presented one after the other at 2 Hz for 30 seconds. In the control condition observers passively viewed the monsters, in the low cognitive load condition one of the monsters was the target with observers responding by button press and in the high cognitive load condition observers reacted to two of the monsters.

For each trial, observers verbally rated vection and cybersickness on an 11-point Likert scale. Vection onset and vection duration times were recorded by button press. Statistical analysis was conducted using R 1.2.5019 (R Core Team, 2019) using the 'lmer' function of the *lme4* package (Bates *et al*., 2014) to perform linear mixed-effects analyses. EEG signal was recorded using a 64-channel Biosemi Active-Two system (BIOSEMI, https://www.biosemi.com/). Based on Harquel's (2020) work cluster-based permutation analyses were conducted to investigate whether differences in the experience of vection found for the low and high cognitive load conditions in the behavioural data were reflected in differences in alpha, beta and theta activity. Increases in alpha activity were expected for ongoing vection and decreases in alpha and beta activity for vection onset and offset.

In line with predictions and the cognitive load theory (Lavie et al., 2004), vection magnitude decreased with an increase in cognitive load when the moving stimuli were presented in the *full FOV*. However, vection onset and duration times were not affected by cognitive load (see D'Amour et al., 2021 for similar results) suggesting that different mechanisms might affect vection magnitude, onset and duration times. The opposite effect was found in the *restricted FOV* conditions, here vection slightly increased with increasing cognitive load, see Figure 1a and b. Contrary to our expectation, cybersickness increased with cognitive load in both the *full FOV* and the *restricted FOV* conditions.

In the *full FOV* display lower theta and alpha activity were found over frontal areas and lower beta was observed over posterior areas for the high cognitive load (reduced vection magnitude) compared to the low cognitive load conditions (enhanced vection magnitude) during ongoing vection. Especially theta power decreased with an increase in cognitive load (see Figure 1c). No differences during vection onset were found for *full FOV* stimulation. Again, the opposite effect was found in the *restricted FOV* conditions with *higher* theta for vection onset and ongoing vection and *higher* alpha for ongoing vection over frontal areas for the condition eliciting less vection (high cognitive load, see Figure 1d).

These findings indicate that mental task demands can affect cybersickness and vection differently. The effect of cognitive load on vection additionally seems to depend on how strong the motion perception in the stimulus is perceived and possibly where in the visual field the motion stimulus is presented. For instance, Theta power might represent a neural correlate for vection magnitude and cognitive load in the high load condition which is modulated by the visual field condition. Cognitive load in this study was expected to increase with increasing numbers of targets, however, this does not necessarily imply higher mental task demand but could potentially only relate to attentional demand. In future self-assessment measures verifying the experienced cognitive load could be applied in in conjunction with the increasing target numbers. A motor task condition in which no vection was experienced but rather observer randomly pressed a button while viewing the moving patterns could have been included in the experience to allow for a comparison between distinct vection and non-vection experiences. Identifying what sort of cognitive tasks can be performed by an individual when immersed in VR that elicits vection without causing cybersickness can guide future development for VR applications.]

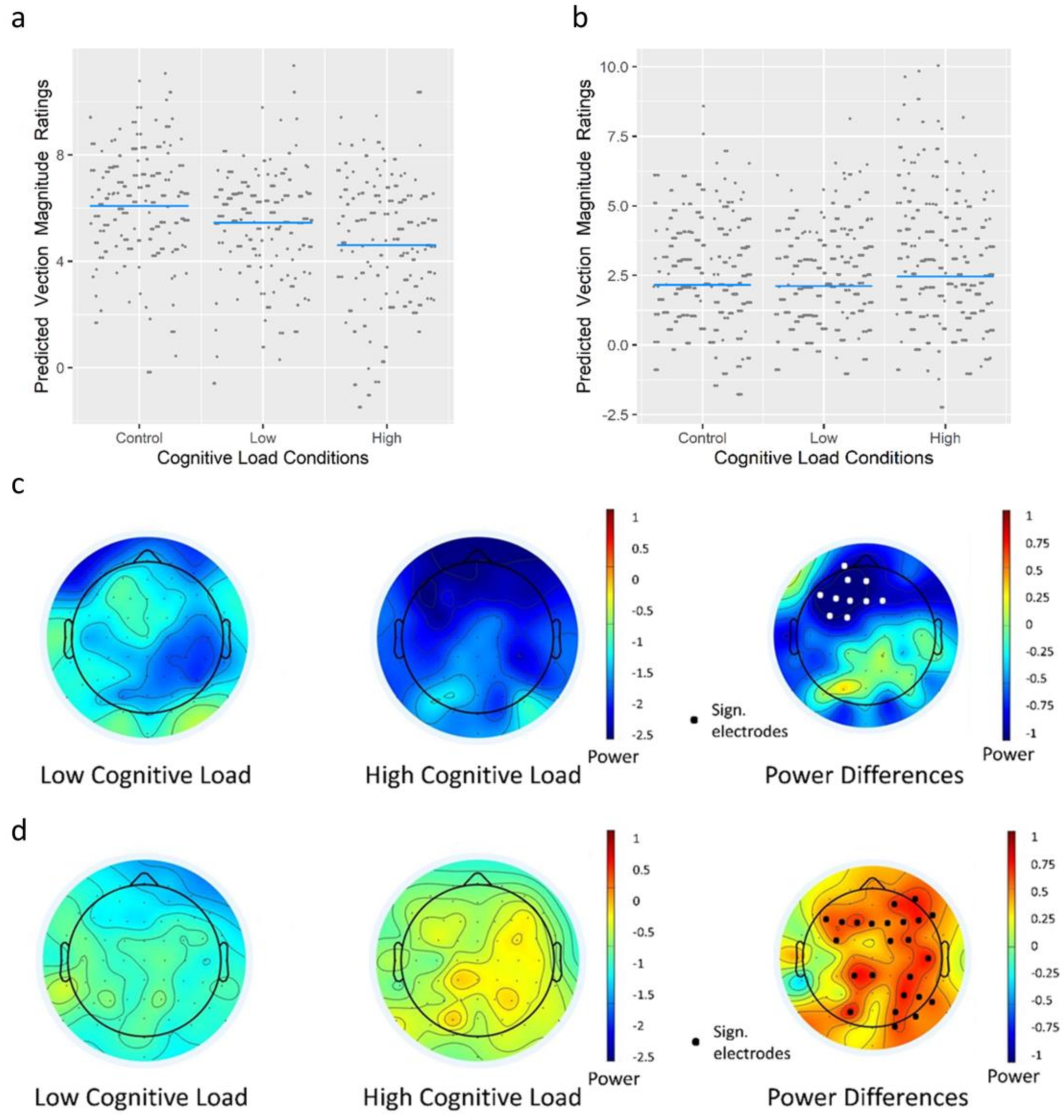

Figure 1. Predicted vection magnitude for the control, low and high cognitive load trials in the a) full FOV condition and b) restricted FOV condition. Visualisation of the Regression model with residual plots based on the lmer analysis, obtained using the visreg package. Lines representing model fits and points representing residuals. Topographies showing theta band power c) for the full FOV display and d) for the restricted FOV displays for the low and the high cognitive load condition for the entire vection period (+500ms to offset). The topography plot on the right displays the power difference between the two condition, with the power in the low cognitive load condition being subtracted from the power in the high cognitive load condition. White/Black dots indicate electrodes belonging to the significant clusters (Sign. electrodes).

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