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Action Video game players do not differ in the perception of contrast-based motion illusions but experience more vection and less discomfort in a virtual environment compared to Non-Action Video game players

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	Takeharu Seno seno@design.kyushu-u.ac.jp vection researcher
	Paolo Di Luzio paolo.diluzio@unibo.it Di Luzio and his colleagues have recently published a study investigating the effect of action video game play on an auditory illusion and the relationship to migraine.
	Joseph Chisholm jchisholm@psych.ubc.ca Researches the effect of action video game play on attentional processes.
	Sandro Franceschini sandro.franceschini@unipd.it Investigated the effect of action video gaming on reading abilities

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Title: Action Video game players do not differ in the perception of contrast-based motion illusions but experience more vection and less discomfort in a virtual environment compared to Non-Action Video game players

Running Title: *The effect of video gaming on illusion strength, vection and discomfort*

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AVGPs experience more vection and less discomfort when viewing contrast illusions in VR

Abstract

Action video game players (AVGPs) show enhanced visual perceptual functions compared to their non-video game playing peers (NVGPs). Whether AVGPs are more susceptible towards static contrast motion illusions, such as Fraser Wilcox illusions has not been addressed so far. Individuals with higher contrast sensitivity have been shown to perceive stronger illusory motion in these images, suggesting that AVGPs should be more susceptible to the illusions due to their improved contrast discrimination skills. The experience of illusory self-motion (vection) is believed to be dependent on top down attentional processes; AVGPs should therefore experience stronger vection compared to NVGPs based on their improved attentional skills. Lastly, due to their extensive prior experience with virtual environments AVGPs should experience less discomfort in VR compared to NVGPs. We presented motion illusions in a virtual environment and asked 22 AVGPs and 21 NVGPs to indicate the strength of illusory motion, as well as the level of discomfort and vection experienced when exposed to these motion illusions. Results indicated that AVGPs and NVGPs perceived the same amount of motion when viewing these illusions. However, AVGPs perceived more vection and less discomfort compared to NVGPs, possibly due to factors such as enhanced top-down attentional control and adaptation. Discomfort experienced by AVGPs was related to illusion strength suggesting that contrast illusions might evoke the perceived discomfort rather than the virtual environment. Further studies are required to investigate the relationship between contrast sensitivity, migraine and the perception of illusion in AVGPs which should include illusory motion onset and duration measures.

Introduction

Improving perceptual skills via action video game training has been discussed in relation to a wide range of therapeutic treatments. Individuals diagnosed with amblyopia, a developmental disorder which is characterized by reduced visual acuity in one eye, showed improvement in visual acuity and binocular vision after *action video game training* (Li et al., 2011; Vedamurthy et al., 2015a, 2015b). Similarly, children with dyslexia revealed increased reading skills when trained with action mini games such as *Raving Rabbids* (Franceschini et al., 2017).

Visual information processing abilities have shown improvements in habitual action-video game players (AVGPs) as well as after action video game training (Chopin et al., 2019; Hutchinson & Stocks, 2013; Riesenhuber, 2004). AVGPs outperform non-action video game players (NVGPs) in various motion perception tasks. They are better at perceiving the direction of motion in random dot kinematograms (Pavan et al., 2016), they are faster at choosing the perceived motion direction (left or right) (Green et al., 2010) and outperform NVGPs in motion object tracking tasks (Green & Bavelier, 2006). Better performance in motion tracking tasks has been observed for habitual AVGPs and after training and is believed to be related to improvements in attentional control functions, such as the ability to filter irrelevant information while focusing on task-relevant information (Bavelier & Green, 2019). Finding positive implications not only for habitual video game players but also after video game training would suggest that video game players are not predisposed to have a better motion perception which would contribute to them becoming habitual players, but rather that the game play itself causes these improvements in visual skills.

These studies mainly discussed motion perception elicited by *physically* moving patterns when comparing gamers with non-gamers. In the current study however, we are interested whether AVGPs differ from NVGPs in the perception of motion illusions by showing a stronger illusion percept than NVGPs and perceiving the stationary patterns as moving more. The illusions used in this study are so-called optimised Fraser Wilcox illusions (Fraser & Wilcox, 1979).

This type of illusion consists of repeated luminance gradients (black → dark grey → light grey → white; see figure 1 and 2) with illusory motion being perceived from dark to light shading and appearing in a constant direction guided by these patterns (Fraser & Wilcox, 1979; Kitaoka, 2006; Kitaoka & Ashida, 2003; Shapiro & Todorovic, 2016). The motion is perceived due to differences in contrast and luminance which are associated with differences in neural processing speed which can lead to motion detectors in the brain producing sequential neuronal responses similar to those of physically moving stimuli (Backus & Oruç, 2005; Conway et al., 2005; Otero-Millan et al., 2012). These types of illusions are strongest when presented in the periphery and are often referred to as peripheral drift illusion (Faubert & Herbert, 1999; Fraser & Wilcox, 1979; Kitaoka & Ashida, 2003; Naor-Raz & Sekuler, 2000).

Eye movements have also been related to the perception of the motion illusions. It was believed that the illusion involved retinal shifts caused by small involuntary eye movements (microsaccades) that observers make while trying to maintain fixation (Murakami et al., 2006; Otero-Millan et al., 2012; Seno et al., 2013) suggesting that individuals with greater fixation instability are also more likely to experience a stronger perception of the illusion (Murakami et al., 2006). However, an eye tracking study conducted by Hermens and Zanker (2012) found that microsaccade patterns were unaffected by the strength of the Riley's Fall illusion, with their data suggesting that rather than microsaccades slow oculomotor drifts might be contributing towards these contrast illusions (Hermens & Zanker., 2012). The Riley's Fall illusion is characterised by black and white undulating lines that can induce a strong percept of 'shimmering' motion so similarly to the illusions used in this study is contrast dependent; therefore, rather than eye movements contrast sensitivity of the viewer might explain how the illusion occurs and could predict individual differences in perception of the illusory motion. For instance, individuals with better contrast discrimination perceive stronger illusions (He et al., 2020). Enhanced contrast sensitivity has also been observed as a result of video game training with AVGPs outperforming non-gamers in identifying Gabor patches with varying contrast (Li et al., 2009). Based on the improved perceptual skills, enhanced contrast sensitivity and discrimination reported in video game players (Bejjanki et al., 2014; Li et al., 2009, Li et al., 2010; see Chopin et al., 2019 for a review) and even after action video game training (Bejjanki et al., 2014; Li et al., 2009, 2010), we hypothesise that AVGPs will perceive the illusions presented in the current study (figure 2) as moving more compared to NVGPs.

Motion stimuli, including illusions of motion, can induce a sensation of illusory self-motion in a stationary observer, known as vection (Dichgans & Brandt, 1978; Fischer & Kornmüller, 1930). Experiencing vection while exploring a virtual environment can enhance the feeling of presence in the user by eliciting a more realistic sensation of self-motion through the virtual environment and thereby improving the user's experience of VR (Riecke, 2010). The visual stimuli inducing the illusory self-motion can be explicit (physically moving) or implicit (illusory) in nature. Traditionally, physically moving visual stimuli such as optic flow patterns (random dot stereograms) have been used to study vection, but research suggests that in order to experience vection the visual stimulus does not necessarily require explicit motion (Seno et al., 2013). According to that theory the perceived motion, rather than the physical stimulus motion causes vection (Nakamura, 2013; Seno et al., 2012; Seno et al., 2013; Seno & Sato, 2011). Vection can be elicited by motion aftereffects (Seno et al., 2010) as well as by illusory motion (Seno et al., 2013). In their study a colourful expanding optimised Fraser Wilcox illusion was able to elicit the illusion of self-motion in the observers. Contradictory findings showed that a rotating motion illusion did not induce self-motion in observers (Rosenblatt & Crane, 2015). The motion illusions used in their experiment consisted of static, repeated asymmetric patterns mapped onto a torus, giving the illusion of the inside of the torus either rotating clockwise or counterclockwise. Even though both studies used optimised Fraser Wilcox illusions as stimuli they differed in some aspects; Seno and colleagues illusions were simple expanding illusions eliciting motion-in depth whereas the illusions used by Rosenblatt and Crane's gave the illusion of the observer being in the inside of a torus which rotated around them either to the left or the right. It is possible that this type of motion is less suitable to induce self-motion in an observer. These contradictory results motivated the choice of both rotating and expanding motion illusions in this study to ensure that illusory motion either in the lateral direction or moving in depth could elicit vection.

AVGPs experience more vection and less discomfort when viewing contrast illusions in VR

Different stimulus properties can affect the experience and strength of vection, such as the *size* (e.g. Berthoz et al., 1975; Brandt et al., 1973; Nakamura, 2006; Telford & Frost, 1993) and *speed* (e.g. Allison et al., 1999; Nakamura & Shimojo, 1999; Seya et al., 2015; Seya et al., 2014) of presented stimuli. As vection increases with increasing speed of the visual stimulus, we expect stronger motion illusions, images that are perceived as moving more, to also elicit stronger vection. AVGPs are expected to perceive the illusions as moving more therefore, we also expected them to experience more vection while looking at them compared to NVGPs.

More recent research suggests that vection is not only a bottom up process that is influenced by stimulus properties but is also affected by cognitive factors (Riecke et al., 2006). Participants' experience of vection could be affected by biased instructions of the researcher prior to the experiment either priming them for self-motion or object motion (Palmisano & Chan, 2004) suggesting some form of top-down processing involved in the experience of vection. Studies investigating the effect of cognitive/attentional load on the experience of vection found that performing tasks requiring high attentional load resulted in a weaker experience of vection compared to control conditions even if the moving stimulus eliciting the vection was identical for both tasks (Seno et al., 2011).

Playing action video games has been related to improvements in attentional control functions as well as cognitive control (Anguera et al., 2013; Bavelier et al., 2012; Bavelier & Green, 2019; Boot et al., 2008; Chisholm et al., 2010;Chisholm et al., 2012; Föcker et al., 2018) which would suggest that if vection is a cognitive top-down process AVGPs should perceive a stronger percept of vection.

Discomfort experienced in virtual environments has been linked to vection and is particularly prevalent in Head Mounted Displays (HMD) (Keshavarz et al., 2015). The term discomfort used in this paper describes adverse physiological effects experienced in VR, such as motion sickness like symptoms (e.g. nausea, disorientation, dizziness) and visual stress symptoms (e.g. headache, eye strain, difficulty focusing). Traditionally vection was believed to cause or at least precede discomfort (Hettinger et al., 1990). Multiple studies have found a positive relationship between vection and discomfort (e.g. Diels et al., 2007; Moss, & Muth, 2011; Palmisano et al., 2007) whereas other studies have found contradictory results suggesting that vection does not necessarily cause discomfort or is even related to it at all (e.g. Bonato et al., 2008; Keshavarz et al., 2015; Palmisano et al., 2017; Webb, & Griffin, 2003).

Two main causes of discomfort in VR are the "accommodation-vergence conflict" (e.g. Hoffman et al., 2008; Kramida, 2015), which is a conflict within the visual focusing system, and the conflict between the visual and the vestibular system (e.g. Akiduki et al., 2003). VR sickness caused by the latter is often accompanied by postural instability and "sway" (Akiduki et al., 2003; Arcioni et al., 2019; Smart et al., 2002).

Studying these two causes separately is important in understanding how to mitigate their effects; however, finding stimuli which enable this is not as straightforward. In this study we take a novel approach by using optimised Fraser Wilcox illusions to study sickness caused by perceived motion. These illusions are 2D stationary images that, due to their patterns, are perceived as moving, and may therefore be used to stimulate feelings of discomfort associated with motion. However, they do not actually move through the virtual environment coordinate system, and so minimise discomfort caused by constant change in discrepancy between accommodation and vergence.

Discomfort or motion sickness in the real world as well as in virtual environments has been shown to decrease with repeated exposure. Repeatedly exposing an individual to the same sickness inducing environment (real or virtual) has been shown to reduce adverse symptoms, such as in sea travel (Li et al., 2012), driving or flight simulators (Domeyer et al., 2013; Heutink et al., 2019; Kennedy et al., 2000) or virtual environments presented using HMDs (Hill & Howarth, 2000; Howarth & Hodder, 2008; Regan, 1995). Habituation has been argued to be one of the most effective techniques to minimise discomfort experienced in virtual environments (Keshavarz, 2016) however, adaptation can be time consuming and requires motivation in the user. In this study we are interested if adaptation effects are dependent on repeated exposure to the exact same virtual environment and visual stimulus or if similar adaptation effects can occur when prior experience with virtual environments was gained using different display and set up types. We were interested whether AVGPs that played video games using computers or gaming consoles build up adaptation effects that would lead to them experiencing less discomfort in a virtual environment presented using HMD compared to NVGPs. In line with this notion previous research has found that gamers experience less motion sickness when viewing videos on large projector screens or when performing a simulated driving task (Keshavarz, 2016; Ujike et al., 2008).

In the current study we presented rotating and expanding Fraser Wilcox illusions in VR using HMDs and we asked our participants to rate the strength of the illusion and the degree of vection and discomfort they experienced. Additionally, participants indicated the onset and duration of action by button press. AVGPs are more frequently exposed to digital environments and thus can be expected to experience less discomfort in those virtual environments. According to the principles of habituation, we argue that action video game players might adapt more to virtual environments and therefore experience less discomfort when presented with visual stimuli in a 3D virtual environment.

Method

Participants

Forty-three participants ranging in age from 19 - 39 years (M= 21.00 years, SD= 4.17) with normal or corrected to normal vision took part in this study. Twenty-four identified as female, and 19 as male. Twenty-two participants were classified as AVGPs (15 males, 7 females, mean age = 20.27 years) and 21 as NVGPs (4 males, 17 females, mean age = 21.76 years). Nineteen participants had previous experience with VR whereas the other 24 had never used VR before with only one of the participants using it on a regular basis. Written informed consent was obtained from all participants prior to participating in the experiment and the study was approved by the University of Lincoln's Ethics Committee. Additionally, participants were informed that they could withdraw from the study at any point and that data would be analysed anonymously. Individuals suffering from photosensitive epilepsy as well as pregnant individuals were excluded from the study.

Apparatus

A PC with Intel i7-7700 core processor, 16GB RAM and an NVidia graphics card, running 64-bit Windows 10 was used to control the headset. A Valve Index headset was used to present the stimuli with a display resolution of 1440x1600 pixels per eye, refresh rate of 120Hz, and yields a FOV of up to 130° depending on observers' settings. Stimuli were presented using 64-bit Unity 2018.2 (Unity Technologies, San Francisco, USA), using the Steam platform.

Stimuli

The stimuli used in this study consisted of 4 circular optimized Fraser Wilcox illusions, each being made up by 8 rings containing patterns with gradient luminance profiles (black to dark grey and white to light grey), see figure 1. The 12 illusions (see figure 2) used were chosen based on pilot work trying to create rotating and expanding motion illusions that were similar in illusion strength. Illusion strength indicates how much motion is perceived in the illusion. The illusions were presented in the centre of the visual field covering around 40° of the FOV. Distance and size of stimuli were chosen (based on pilot work) to elicit the strongest motion perception in the patterns.

Subjective Measures

Gamer Group

Participants were categorised as AVGPs and NVGPs according to the criteria of the Video Game Playing Questionnaire created by the Bavelier lab (Bavelier, 2019). Participants were classified as AVGPs when they currently played at least 5 hours of action video games per week and no more than 3 hours of all other game genres. NVGPs were individuals that including all game genres spent less than 3 hrs a week playing video games throughout the last year.

Illusion Strength

For each stimulus participants were asked to verbally rate how much motion they perceive in the illusions from "0", representing no motion at all to "10". This brief verbal assessment was performed in order to obtain illusion strength ratings for each distinct stimulus and to be able to compare illusion strength ratings for rotating and expanding motion illusions.

Vection

Vection magnitude, onset and duration were recorded as measures of vection in this study. Participants verbally rated the vector magnitude for each stimulus on a 11-point Likert scale with 0 meaning no vection at all and 10 meaning strong vection after the presentation of each stimulus. This measure reflects the magnitude of the experienced vection. In addition, vection onset and duration were recorded by button press.

Discomfort

For each stimulus participants were asked to verbally rate their level of general discomfort, headache, blurred vision, dizziness and eye strain on a 11-point Likert scale. This brief verbal assessment was performed in order to obtain discomfort ratings for each distinct stimulus. These 5 ratings were aggregated in one overall discomfort measure.

Procedure

Participants filled out the gamer questionnaire online and if they qualified as either an AVGP or NVGP they were invited to take part in the lab-based VR study.

In the lab, participants were provided with an information sheet outlining the objectives and the procedure of the study. They were then asked to complete a consent form. Following they started the VR part of the study, with participants standing in the centre of the experimental area wearing the headset and holding the controllers. To adjust to the virtual environment and to get used to controllers and headset participants were allowed to play a VR-game prior to completing the experimental task. They played the *Spiderman: Homecoming-VR Experience* (Create VR, Sony Pictures VR, 2017). The game play lasted for around 5-10 min, none of the participants reported any symptoms of discomfort and consequently withdrew at this point of the study hence were happy to progress on to the experiment.

Participants were shown examples of the type of motion illusions they were going to view in the VR (see figure 2). They were instructed that it is a free viewing condition and to perceive most movement in the illusion they should not focus on any specific point on the image but rather “wander with their eyes over the image”. They were also informed that the motion illusion will most likely be strongest in their periphery.

The environment within the experiment consisted of a completely black surround, which prevented any distraction from task irrelevant visual input. The experiment consisted of two parts: a training and the experimental trial. Both the training and experimental trial started with the presentation of text informing the participant that pressing the “A” button will allow them to move on. At this point participants were instructed to try out the different settings of the headset to get the text as focused as possible. When participants were satisfied with the focus of the headset, they could initiate the training by pressing the “A” button on the controller. In the training trial the 12 the illusions were presented one after the other in random order for 5 seconds after which they disappeared, and the text screen came up again prompting the participant to press the “A” button to move on to the next illusion. In this short training participants were able to practise pressing the trigger button when they experienced vection in the trials, got familiar with the type of stimuli that were going to be presented in the experimental trial and they familiarised themselves with the procedures. In the experimental trial illusions were presented in random order for 90 seconds after which they disappeared, and the text screen came up again prompting the participant to press the “A” button to move on to the next illusion. Participants were instructed to indicate when they started experiencing vection (vection onset) by pressing a button and to hold it in for as long as the experience of vection lasted (vection duration). They were able to press the button multiple times per trial. After each stimulus presentation, participants verbally rated the strength of the illusion as well as their experience of vection magnitude and discomfort on a 11-point Likert scale. After rating each stimulus, the researcher prompted the participant to initiate the next trial.

Analysis

Statistical analysis was conducted using R 1.2.5019 (R Core Team, 2019) using the *glm*, and *lmer* function of the lme4 package (Bates et al., 2014) to perform generalised linear and linear mixed effect analyses on the effect gamer type on illusion strength, vection magnitude and discomfort ratings as well as on vection onset and duration times.

Illusion strength, vection magnitude and discomfort ratings were predicted using generalised linear models with gamma distribution as data were positively skewed. Prior analysis using a generalised mixed effect model including participant variation as a random effect showed low participant-level variance resulting in the random effect being omitted from the final analysis.

Linear mixed effect models were used to analyse vection onset and duration, as these data consist of time-series for each participant and for each stimulus, which are not independent observations. Linear mixed effect models have advantages in their ability to model non-linear, individual characteristics (Krueger & Tian, 2004). Additionally, they allow for multiple observations from the same participant and deal with not normally distributed and skewed data. Therefore, these models were preferred over traditional ANOVAs.

For the models, p-values of overall effects were determined using conditional F tests with Satterthwaite's approximation to degrees of freedom (Satterthwaite, 1946) using a Type III ANOVA, as implemented in the "anova" function from the lmerTest package (Kuznetsova et al., 2017). Estimated marginal means and standard errors were calculated using the *emmeans* function of the emmeans package (Lenth et al., 2018). Following the examples of Winter (2013), models were created for fixed effects (predictor variables) that showed a significant effect on the outcome variable. These models were compared to the null models missing the variable of interest using a likelihood ratio test, in order to obtain a difference in Bayes Information Criterion (ΔBIC), to estimate the strength of the evidence for a particular effect. ΔBIC is a criterion for model selection as it calculates a model's likelihood and can be seen as a way to estimate something comparable to the effect size of a predictor (Schwarz, 1978). The model with the lowest (ΔBIC) value is determined as the best fit model. Differences lower than 2 between two models are very weak and can be ignored or have to be interpreted with care. A negative difference in ΔBIC indicates evidence in support of the null model, rather than the alternative model (Berchtold, 2010; Kass & Wasserman, 1995). ΔBIC values reported here represent the difference between the full model's and the null model's ΔBIC values.

For all the models Satterthwaite's approximation was used to adjust the degrees of freedom for violations of sphericity (Luke, 2017; Satterthwaite, 1946). To investigate the relationship of illusion strength, vection measures and discomfort a Spearman correlation was conducted using the "rcorr" function within the Hmisc package (Harrell & Harrell, 2019).

Figures were produced using the *emmip* function within the emmeans package (Lenth et al., 2018) and the *plot* function within the graphics package (R Core Team, 2019) as well as the the "visreg" function within the visreg package (Breheny & Burchett, 2017).

Results

Illusion Strength

Illusion strength was predicted using a generalised linear model including Gamer type (AVGP vs NVGP) as fixed effect. The function of the model looks as followed:

$$\textit{Model} = \textit{glm (Illusion Strength} \sim \textit{Gamer Type)}$$

No significant effect of gamer type on illusion strength ratings was found, $F(1,514) = 0.720$, $p = .397$. See figure 3. The same result pattern was observed in a larger sample in a follow up study using the computer desktop, the results of this study can be found in the supplementary material.

Vection

Vection magnitude was predicted using a generalised linear model including Gamer type (AVGP vs NVGP) as fixed effect. The function of the model looks as followed:

Model = glm (Vection Magnitude~ Gamer Type)

Vection onset and duration were predicted using a linear mixed effect model including Gamer type (AVGP vs NVGP) as fixed effect and participant as random effect. The function of the model looks as followed:

Model = lmer (Vection Onset/Duration ~ Gamer Type +(1|Participant))

Vection Magnitude

A significant effect of gamer type on vection magnitude ratings was found, $F(1,514) = 4.48$, $p = .035$, $\Delta BIC = -6.05$. AVGPs (M = 2.52, 0.12 ±SE), [2.28, 2.84] experienced more vection compared to NVGPs (M = 2.05, 0.10 ±SE), [1.84, 2.31]. See figure 4.

Vection Onset

No significant effect of gamer type on vection onset times was found, $F(1,31.56) = 0.15$, $p = .700$.

Vection Duration

No significant effect of gamer type on vection duration was found, $F(1,37.14) = 1.29$, $p = .263$.

Discomfort

Discomfort was predicted using a generalised linear model including Gamer type (AVGP vs NVGP) as fixed effect. The function of the model looks as followed:

Model = glm (Discomfort ~ Gamer Type)

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A significant effect of gamer type on discomfort ratings was found, F(1,514) = 12.35, p <.001, ΔBIC = -5.50. AVGPs (M = 0.86, 0.05 ±SE), [0.77, 0.98] experienced less discomfort compared to NVGPs (M = 1.26, 0.07 ±SE), [1.12, 1.44]. See figure 5.

Correlation for Illusion Strength, Vection and Discomfort

A Spearman correlation was conducted to investigate the relationship between perceived illusion strength, vection measures and experienced discomfort for NVGPs and AVGPs respectively. Spearman's rho and significance values can be found in table 1 and 2. For AVGPs a strong positive correlation was found for illusion strength and vection magnitude (r_s=.69, p <.001, N=22) as well as negative moderate correlations between illusion strength and vection onset times (r_s= -.47, p=.037, N=20) and a moderate positive relation between illusion strength and discomfort (r_s =.52, p =.014, N=22). For NVGPs however illusions strength was only related to vection duration times (r_s =.56, p= .015, N=18). Additionally, a strong positive correlation between vection magnitude and vection duration (r_s =.74, p <.001, N=18) was found for NVGPs.

Discussion

Firstly, the present study aimed to investigate if AVGPs perceived more motion in optimised Fraser Wilcox illusions when presented using VR headsets compared to NVGPs. Stronger perception of the illusion was expected based on their improved perceptual skills and due to their increased contrast sensitivity reported in several previous studies (e.g. Chopin et al., 2019; He et al., 2020; Li et al., 2009, 2010). Contrary to predictions no difference in illusion strength ratings was found between AVGPs and NVGPs. A follow up study conducted online using both grey scaled as well as colourful versions of the Fraseer Wilcox illusions confirmed these results finding no difference in illusion strength ratings between AVGPs and NVGPs (for details see Supplementary material).

AVGPs experience more vection and less discomfort when viewing contrast illusions in VR

Secondly, the experience of vection when viewing the illusions was of interest. The sensation of illusory self-motion has been linked to attentional and cognitive processes and is believed to decrease with increased cognitive or attentional load (Seno et al., 2011). Playing action video games has been shown to improve attentional skills (Bavelier & Green, 2019; Föcker et al., 2018, 2019) and therefore, a stronger experience of vection in individuals that spend extensive time playing first person shooter games was expected and found in this experiment.

Finally, this study aimed to investigate whether AVGPs would experience less discomfort in the virtual environment compared to their non-video game playing counterparts. Due to their significant experience with virtual environments AVGPs are believed to experience less discomfort in VR in general based on adaptation and habituation processes (Domeyer et al., 2013; Hill & Haworth, 200; Keshavarz, 2016). This notion was confirmed by the current study as AVGPs experienced less discomfort while looking at the motion illusions in VR compared to NVGPs.

Our findings showed that based on self-reports, there were no differences in illusion strength perceived in the visual motion illusion between gamers and non-gamers. The lack of group differences in the perception of motion strength was rather unexpected given that previous literature has pointed to the enhanced perceptual abilities in gamers as well as improved contrast sensitivity and discrimination skills which in turn have been linked to increased self-reported susceptibility to optimised Fraser Wilcox illusions. He and colleagues (2020) found that individuals with better contrast discrimination perceived faster illusory motion in the presented stimuli. Illusory motion in their study was measured by adding physical rotation in the opposite direction of the illusory rotation to the stimulus and determining the physical speed required to cancel out the illusion (He et al., 2020). In the current study however the strength of the illusion was rated on a scale from 0-10 after the illusion was presented, with 0 representing no motion at all and 10 representing the strongest perception of illusory motion. The way illusion strength was measured in the current study might not have been sensitive enough to pick up differences in experienced illusion strength between gamers and non-gamers. In the current study difference in contrast sensitivity and discrimination thresholds between gamers and non- gamers were expected but not measured therefore it cannot be concluded that the AVGPs in this study had lower contrast discrimination thresholds. Follow up studies should include a measure of contrast discrimination prior to the experiment to ensure that a difference in contrast sensitivity between the gamer and non-gamer groups can be assured.

A possible difference in the perception of the motion illusion between gamers and non-gamers that was not measured in the current study could be the duration, onset and offset of the illusion rather than the perceived strength of the motion. Illusory motion perceived in these types of illusions tends to stop after a few seconds and start again after a “recovery phase” (Tomimatsu et al., 2011). AVGPs could have perceived the illusory motion for a longer period of time and/or had shorter onset times and perceived the illusion quicker compared to NVGPs. Therefore, further research should include measures of illusion onset and offset. In line with predictions AVGPs experienced a stronger sensation of vection which suggests that the experience of vection is not merely a bottom-up process and influenced by stimulus properties (size, speed) but also requires some form of cognitive processing “power” (Seno et al., 2011). Playing action video games improves attentional control functions meaning that the gamers in this experiment experience less cognitive load and therefore more vection compared to NVGPs.

Differences in the experience of vection between the gamer groups were only found for the magnitude of vection, but not for vection onset or duration times. This suggests that cognitive load might primarily affect the strength of the experienced vection rather than the temporal aspect of the experience. The three vection measures are likely to represent different processes involved during vection suggesting that previous experience with video games modulates the magnitude of the experienced vection but does not affect when and for how long this sensation is experienced (Seno et al., 2017).

The relationship between vection and discomfort experienced in virtual environments is rather complex with vection and discomfort often occurring together (Hettinger et al., 1990; Plouzeau et al., 2015), resulting in vection being associated with adverse symptoms experienced in VR. However, vection can also be a positive aspect of VR. The player's experience of VR can be improved through vection as it represents a more realistic sensation of self-motion (Riecke, 2010). Virtual environments that elicit more intense experiences of vection are often more immersive and lead to stronger feelings of presence (Weech et al., 2019). Presence is the feeling and belief of being in and being part of the virtual environment, reacting to stimuli as if they were in the real world (Heeter, 1992). Presence has also been related to the experience of discomfort in VR, with vection often seen as the link between these two phenomena (Weech et al., 2019). In an ideal VR experience presence and vection would be present with minimised or no discomfort.

Again, as predicted AVGPs experienced less discomfort while viewing the illusions in VR compared to the NVGPs in this study. This difference in experienced discomfort can be explained by their significant experience with virtual environments. They experienced less discomfort in VR based on adaptation and habituation processes (Domeyer et al., 2013; Hill & Haworth, 200; Keshavarz, 2016). To our knowledge so far adaptation effects have only been investigated by exposing the individual to the same sickness inducing environment. Individuals experienced the same real or virtual environment (e.g. sea voyage, driving simulator, flight simulator) repeatedly or for long periods which in turn led to decreases in adverse symptoms (e.g. Keshavarz, 2016; Li et al., 2012; Reason, 1978). To our knowledge the current study is the first to investigate if adaptation effects to discomfort in VR can be gained with repeated exposure to virtual environments in action video games. Do individuals that spend long periods of time playing video games on the computer or console build up habituation to virtual environments that can translate to a virtual environment presented in a VR headset? AVGPs and NVGPs in this study did not differ in their experience with VR headsets, rather AVGPs gained their experience with virtual environments using different devices.

This can be of interest for individuals that are more susceptible to experience discomfort in virtual environments as adaptation can be time consuming and requires high motivation from the individual suffering from discomfort. An individual that experiences severe adverse symptoms when using a VR headset for the first time might not be willing to expose themselves to this uncomfortable experience again. Instead of using the exact stimulus and display type to train and build up habituation in these more susceptible individuals a less nauseating set up could be used. Additionally, individual differences in the experience of discomfort in VR could be taken into account when designing VR applications or games. They could include tutorials that enable the user to experience VR in a less sickness inducing environment first and slowly increase the sickness inducing stimuli (for example to speed of motion) to slowly allow the user to adapt to their surroundings and adapt.

When looking at the correlation results, we found that for AVGPs illusion strength was positively correlated with vection magnitude and discomfort whereas for NVGPs only vection duration times significantly correlated with illusion strength. The stronger the movement perceived in the illusion the more discomfort AVGPs experienced suggesting that the discomfort was caused by the contrast illusions rather than the virtual environment. This could be explained by the link between playing video games and the severity of headaches associated with migraine (Di Luzio et al., 2020). Individuals suffering from migraines often report increased symptoms when exposed to contrast striped patterns (similar to the illusions presented in this study) (e.g. Shepherd, 2000). Interindividual differences in the perception of motion illusions have been observed in individuals with migraine (Harle et al., 2006; Shepherd, 2000; Shepherd et al., 2013), with self-report measures revealing that individuals with migraine show a higher susceptibility to motion patterns compared to neurotypical observers especially for high contrast stationary images (He et al., 2020). This elevated pattern sensitivity in migraine can also be linked to improved contrast detection and prolonged motion aftereffects. However, it is important to note that He and colleagues (2020) showed that individuals with better contrast discrimination tended to perceive the illusions as moving faster *regardless of migraine status*. Enhanced contrast sensitivity has also been observed as a result of video game training (Li et al., 2009). In this experiment gamers were asked if a Gabor patch varying in contrast, occurs in the first or the second time intervals of a single trial. Individuals trained on action video games outperform participants in the control group on this task showing enhanced contrast sensitivity (Li et al., 2009). Additionally, a link between hours spent playing first person shooter games and migraine symptoms was found which could explain the positive relationship between illusions strength ratings and discomfort found for the AVGPs in this study (Di Luzio et al., 2020). The relationship between contrast sensitivity, migraine and video gaming should be further investigated to assess its influence on the perception of illusory motion. Migraine status of participants should be assessed, and their contrast sensitivity thresholds should be determined. This would allow for a comparison between gamers that show migraine symptoms and gamers that show no symptoms.

However, the results of this study need to be interpreted with caution, analysis with likelihood ratio tests for all significant effects found in this study showed that the strength of these effects were minimal. Model fit for full models and null models was compared in these tests resulting in negative BIC values indicating support for the null model over the full model. These negative BIC values suggest that the strength of evidence for the effect gamer type on the discomfort ratings was fairly small. The results of this study should be replicated with gamer groups equal for sex and age (e.g. Arns & Cerney, 2005; Chaumillon et al., 2017; Curry et al., Munafo et al., 2017)

The differences in discomfort we found between gamers and non-gamers in this study could be affected by the uneven distribution of gender in the groups. The AVGP group consisted mainly of males and only a limited number of females (15 males, 7 females), whereas the NVGP group mainly consisted of females (4 males, 17 females). Females are believed to be more susceptible to motion sickness and discomfort experienced in real life scenarios, such as traveling on a bus (Turner & Griffin, 1999) as well as in driving simulators (e.g. Chaumillon et al., 2017; Schweig et al., 2018) and virtual environments presented using HMDs (e.g. Curry et al., 2020). Research investigating the effect of motion sickness susceptibility or an individual's motion sickness history however found that when susceptibility was kept constant between males and females no difference in VR sickness was found between genders (Stanney et al., 2003). This would suggest that rather than gender NVGPs predisposition to motion sickness could explain the differences in discomfort between the gamer groups. Individuals that are more prone to experience motion sickness-like symptoms might also be less likely to pick up gaming as a hobby suggesting that AVGPs do not experience less discomfort due to their increased exposure to virtual environments when playing video games, but rather that these individuals were predisposed to experience less discomfort in general which is why they picked up gaming in the first instance. To avoid gender or susceptibility to motion sickness affecting group comparisons instead of recruiting AVGPs and NVGPs naive participants could be trained using action video games or other types of video games to further investigate the beneficial effect of gaming on vection and discomfort.

As mentioned above, illusion onset and offset were not measured in this study and should be considered as a measure in future research. The results of this study showed that illusion strength ratings are not sensitive enough to indicate differences in the perception of the illusions between gamers and non-gamers. Including onset, duration and offset measures for illusory motion would allow us to further investigate the relationship between contrast sensitivity and susceptibility to illusory motion elicited by optimised Fraser Wilcox illusions (Keshavarz et al., 2017; Riecke et al., 2006; Seno et al., 2017). Onset times of the motion illusion would be expected to be shorter for individuals with higher contrast sensitivity. A different measure of illusion strength could also be applied to investigate the effect of contrast sensitivity. Instead of using ratings to report illusion strength a “nulling” method similar to the one used by He and colleagues could be applied. The illusory motion can be measured quantitatively by adding physical rotation into the test stimulus and determining the speed required to cancel out the illusory motion (e.g. He et al., 2020; Hisakata & Murakami, 2008; Thornton & Zdravković, 2020). This method was not chosen for the current experiment as it has only been applied to rotating but not expanding illusory motion. Although no differences between expanding and rotating illusions was found in this experiment we aimed to investigate whether both motion directions were able to elicit vection in the observer.

In conclusion, the current study showed that illusory motion is efficient in eliciting vection and no explicit physical motion is necessary. It also demonstrated that AVGPs are more susceptible to vection elicited by motion illusions confirming the notion that vection is affected by cognitive and attentional load as AVGPs have been shown to have better attentional control. AVGPs also experienced less discomfort overall compared to NVGPs which could be explained by them having more experience with virtual environments and therefore having adapted to the sickness inducing aspects of such environments. Additionally, the discomfort experienced by AVGPs was positively correlated with illusion strength suggesting that the discomfort that they experienced was caused by the contrast illusions rather than the virtual environment itself.

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Conflict of interest

The authors have no conflict of interest financial or otherwise to declare.

Data Availability

Associated data can be downloaded from https://doi.org/10.6084/m9.figshare.13398458

Authors' contribution

K.P. and J.F. conceived the study; K.P., L.O.H., J.F. and P.D. designed the experiment; K.P. performed the experiment; K.P. analysed the data; K.P., L.O.H., J.F., P.D., and A.P. wrote the paper.

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Figure and Table Captions

Figure 1: Example of an expanding optimised Fraser Wilcox illusion and the corresponding stimulus used in this study.

Figure 2: The 12 stimuli used in this study. a) displaying the rotating motion illusions and b) displaying the expanding motion illusion.

Figure 3: Estimated 95 confidence intervals for illusion strength ratings for AVGPs and NVGPs. The dark dots representing the model points, the blue bars representing the 95% confidence intervals and the arrows are for comparison among the groups if an arrow from one mean overlaps an arrow from another group the difference between them is not “significant”.

Figure 4: Estimated 95 confidence intervals for vection magnitude ratings for AVGPs and NVGPs. The dark dots representing the model points, the blue bars representing the 95% confidence intervals and the arrows are for comparison among the groups if an arrow from one mean overlaps an arrow from another group the difference between them is not “significant”.

Figure 5: Estimated 95 confidence intervals for discomfort ratings for AVGPs and NVGPs. The dark dots representing the model points, the blue bars representing the 95% confidence intervals and the arrows are for comparison among the groups if an arrow from one mean overlaps an arrow from another group the difference between them is not “significant”.

Table 1: Spearmen correlation of illusion strength ratings, vection measures (magnitude, onset, duration) and discomfort ratings for NVGPs.

Table 2: Spearmen correlation of illusion strength ratings, vection measures (magnitude, onset, duration) and discomfort ratings for AVGPs.

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Correlation between illusion strength, vection measures and discomfort for NVGPs

	Illusion Strength	Vection Magnitude	Vection Onset	Vection Duration
Vection Magnitude	.40	-		
Vection Onset	-.21	-.34	-	
Vection Duration	.56*	.74***	-.18	-
Discomfort	.25	.27	-.31	-.03

*p < .05. **p < .01. ***p < .001., N =21, $N_{Vection\ Onset}$ = 18, $N_{Vection\ Duration}$ = 18

Correlation between illusion strength, vection measures and discomfort for AVGPs

	Illusion Strength	Vection Magnitude	Vection Onset	Vection Duration
Vection Magnitude	.69***	-		
Vection Onset	-.47*	-.42	-	
Vection Duration	.14	.42	-.30	-
Discomfort	.52*	.31	-.27	.03

*p < .05. **p < .01. ***p < .001., N =22, $N_{Vection\ Onset}$ = 20, $N_{Vection\ Duration}$ = 20

Figure 1

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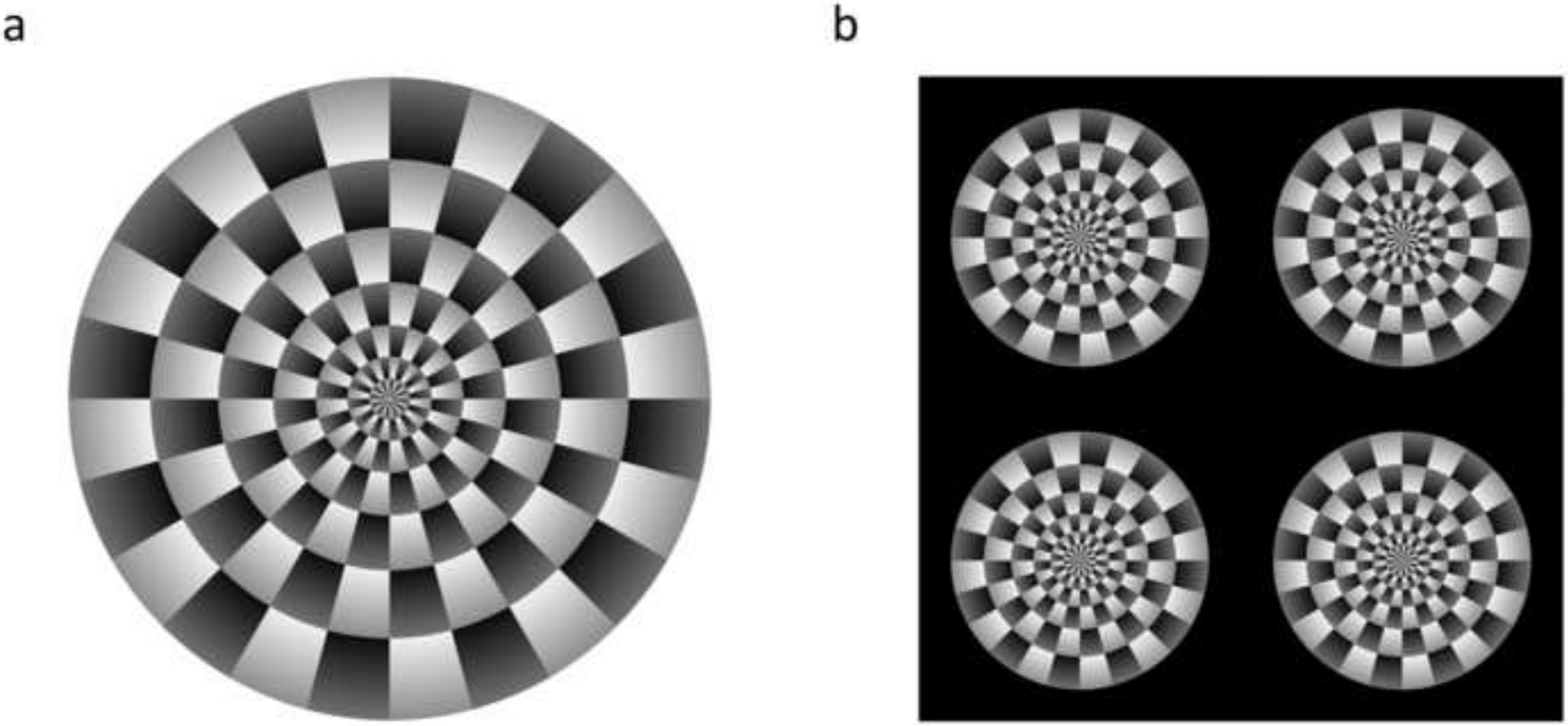

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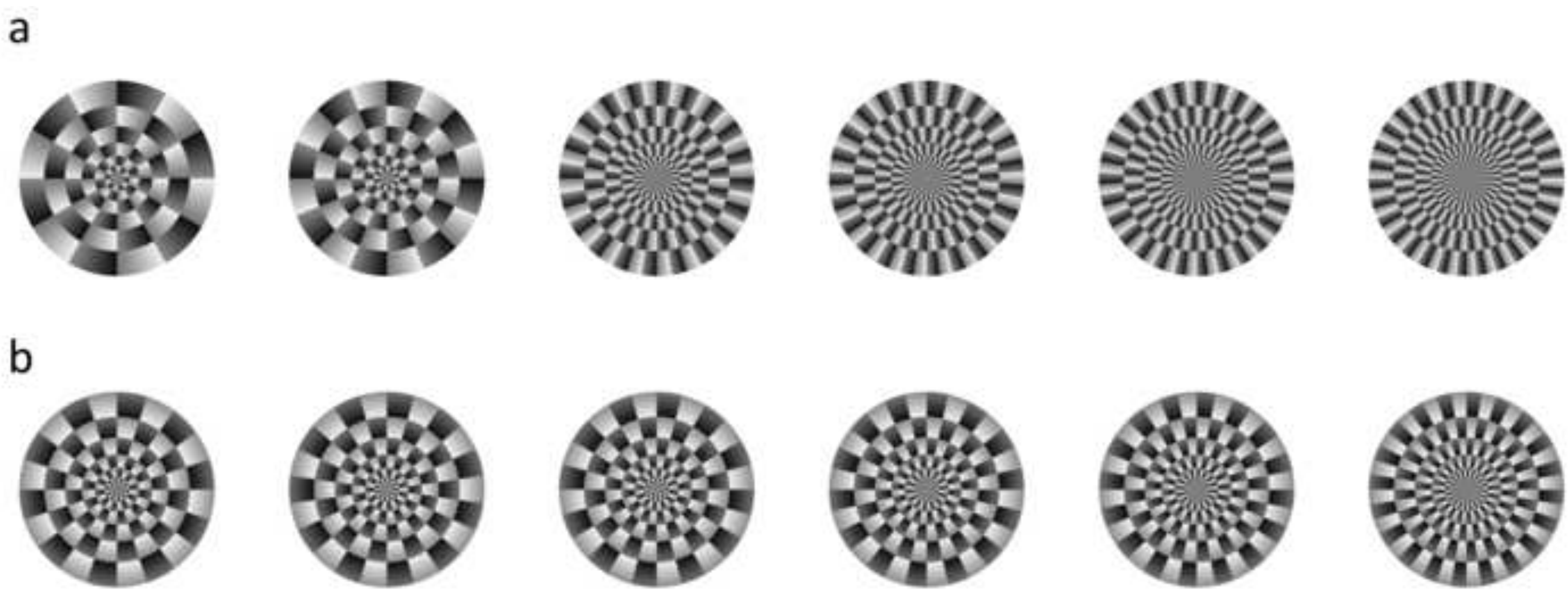

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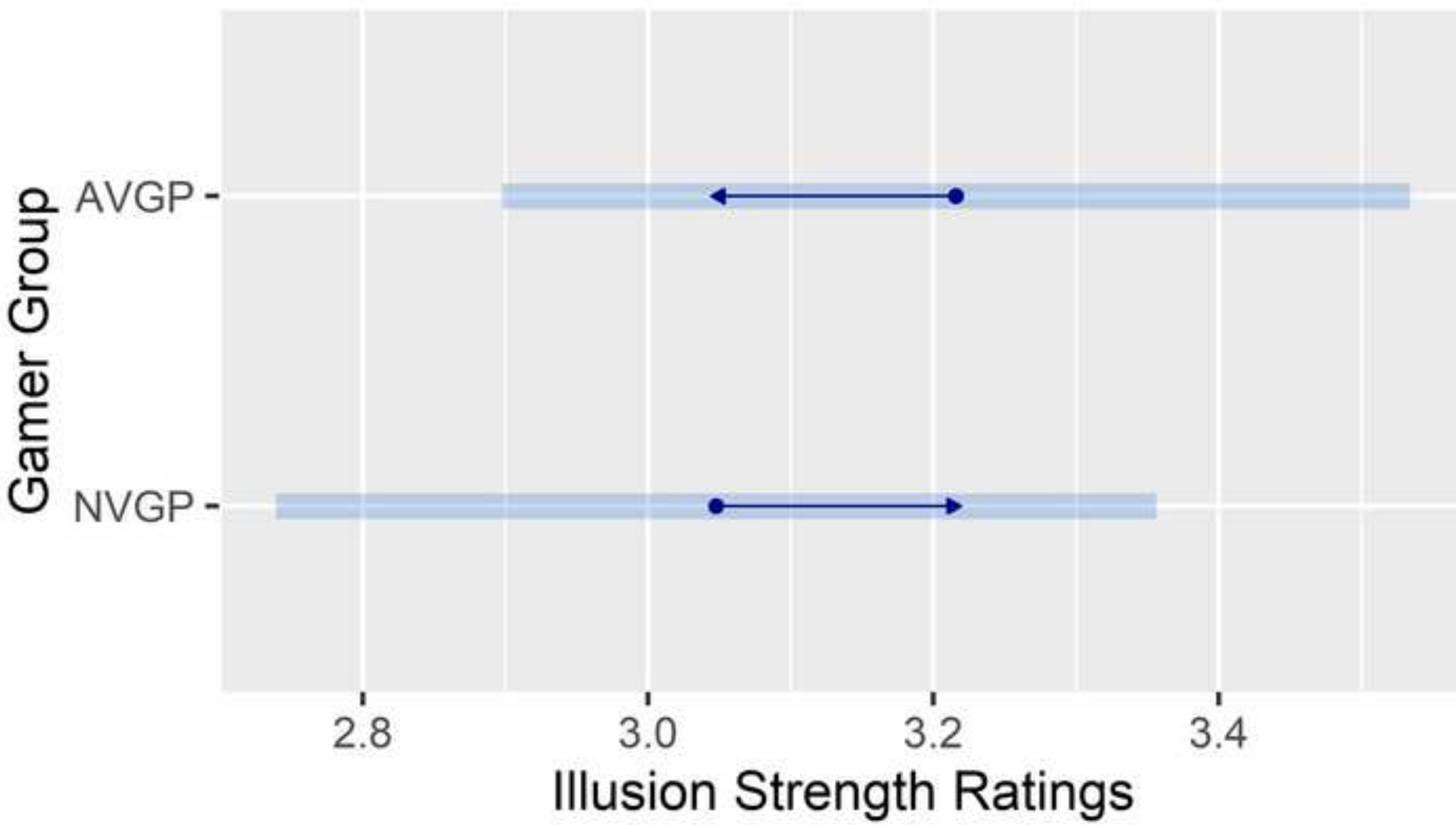

Figure 4

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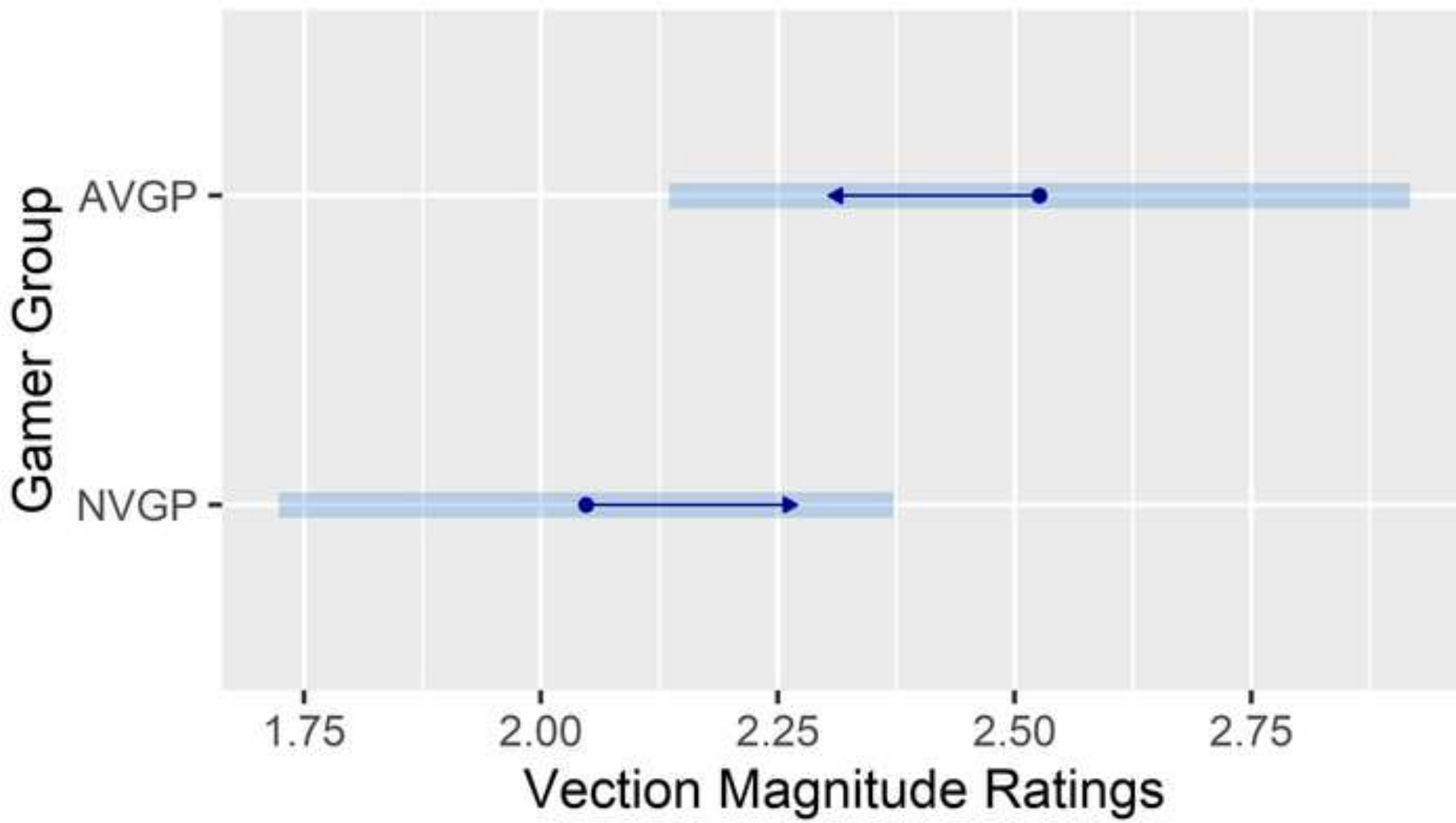

Figure 5

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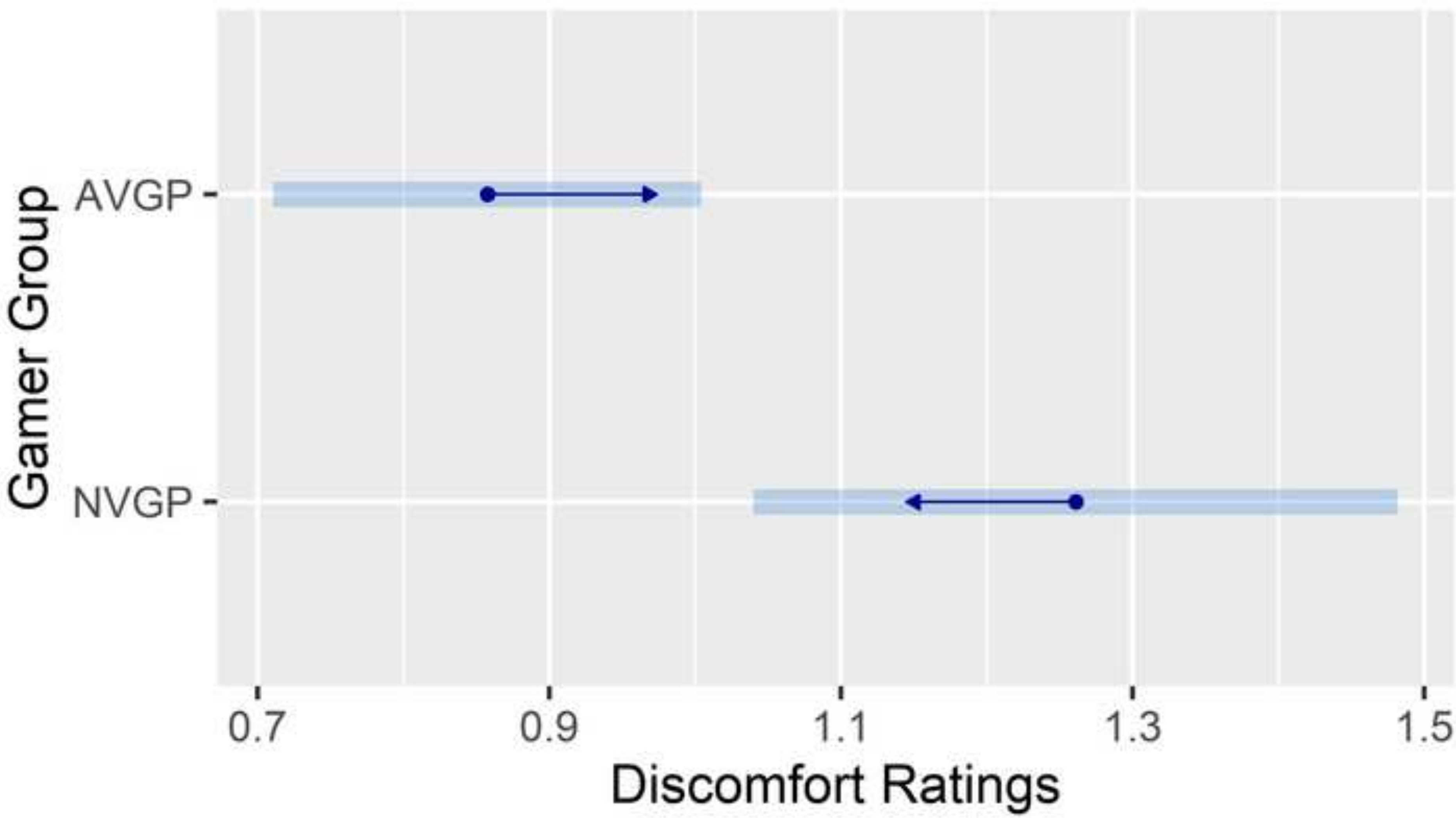

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