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Does A Secondary Task Inhibit Vection in Virtual Reality?

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***Abstract*— Vection is commonly defined as the illusory sensation of self-motion. Research on vection can assist in improving the fidelity of motion simulators. Vection can be influenced through top-down factors, such as attention, but previous research on the effect of a secondary task on vection presented conflicting findings. We investigated the effect of a visual discrimination reaction time task on vection. Twenty-nine participants were visually and audibly immersed in virtual environments with different levels of ecological relevance wherein they used a joystick to continuously report on their vection experience. In contrast to previous research, our results showed no significant effect of a secondary task on vection measures nor an effect of sensory cues and environment context on secondary task performance. We conclude that participants' ability to report their vection experience was unaffected whilst performing a visual attention reaction time task.**

Keywords—Illusory Self-Motion, Attentional Load, Ecological Relevance, Vection Intensity.

I. Introduction

Classically defined as a visually-induced illusion, the term vection is used in contemporary research to describe the feeling of self-motion in the absence of physical self-motion. Besides visual stimulation, vection can be elicited by stimulating other sensory modalities, such as the auditory [1], [2], biomechanical [3], [4] or tactile (see [5] for a review) modality. Furthermore, vection can be modulated through multimodal stimulation [6], [7].

Researching vection is important as it can further our understanding how humans process motion information through our sensory systems as it appears that vection is used to perform **functionally significant tasks.** Palmisano et al. [8] suggested that vection is used in self-motion appraisal and control, which is important for self-navigation and orientation. Research has shown that perspective switching, which is used in spatial orientation, is facilitated by vection [9]. Besides this functional role, vection and spatial presence have been shown to positively correlate [10], indicating vection is a **desired sensation** and can be used to enhance **motion simulator fidelity** [11].

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Top-down cognitive factors apparently influence vection (see [12] for a review). For example, previous research has shown vection can be modulated by task instructions [13], ecological relevance of the stimulus [14], contextual factors [15], and attentional load [16], [17]. Palmisano and Chan [13] presented two participant groups with different instructions; one group had to press a button when they experienced vection and the other group pressed a button when they perceived object-motion. Participant groups were shown the same visual displays and the authors found that the object-motion group, on average, exhibited larger vection onset times (VOTs) and shorter vection durations compared to the vection group. Such a negative effect on vection was also found by Riecke et al. [14] when they modified the ecological relevance of their stimulus. Participants were shown a 360-degree image of a marketplace which rotated in respect to participants' yaw axis and was aimed to induce circular vection. The image was presented to participants either unmodified (i.e., naturalistic) or scrambled (i.e., sliced or mosaic pattern) to various degrees. The authors identified that, on average, increasing levels of abstraction increased VOTs and decreased vection intensities compared to the unmodified condition.

The aforementioned studies are indicative of the direction (i.e., positive or negative) of the effect of top-down factors on vection. However, research on the effect of attentional load on vection has shown conflicting evidence. Eight participants in the study by Trutoiu et al. [16] perceived to be moving through a tunnel and were asked to perform a counting task (i.e., working memory) or a visual attention task (i.e., press button when seeing a target). Participants reported the onset and convincingness of vection and the authors found VOTs to be reduced when participants were performing a secondary task compared to when participants just looked straight ahead on the screen. Conversely, Seno et al. [17] found through two experiments that VOTs increased when participants performed a secondary task compared to control conditions. In the first experiment, sixteen participants viewed a vertically moving grating whilst performing a secondary task wherein they had to count the occurrence of the letter '*X*' with letters appearing on the screen at a frequency of 4 or 8 Hz. Only the 8 Hz condition appeared to have a small effect on VOTs and moderate effect on vection duration. However, a strong effect of the secondary task on vection intensity was found, where vection was reduced when performing a secondary task. In the second experiment, participants tracked the movement of multiple objects while viewing vertically moving grating. VOTs increased considerably when participants tracked three and eight moving objects compared to control conditions. The contradictory findings between the two aforementioned studies may either be due to 1) differing tasks or 2) different environmental contexts. Firstly, in the study by Trotoiu et al. [16] participants had to count or respond to the presence of objects that were placed in various parts of their field-of-view whereas in the study by Seno et al. [17] which participants had to either count the letters that appeared in the centre of the screen or track the movement of objects across their field-of-view. As such, the spatial distribution of the targets involved in the secondary task and complexity of the task may affect the experience or reporting of vection. Secondly, the ecological relevance of the virtual tunnel used by Trotoiu et al. [16] was higher compared the abstract grating used by Seno et al. [17]. Previous research by Riecke et al. [10] has shown that stronger vection is experienced when participants are presented with naturalistic stimuli compared to abstract stimuli. Thus, as vection appears to be influenced by top-down factors, it could be that the environmental context co-modulates participants experience of vection while they are performing a secondary task.

To the best of our knowledge, there has not been a study conducted wherein the effect of a secondary task on vection was investigated across environments with differing levels of ecological relevance. In the current study we aimed to assess whether the effect of a secondary task on vection differs between environments of different ecological relevance. We hypothesized that participants who are visually focussed on a secondary task will experience vection quicker compared to when they are solely focussing on their experience of vection. Furthermore, we hypothesized that vection would be elicted faster in response to stimuli with high ecological relevance compared to stimuli with low ecological relevance.

The paper is structured as follows. Section II describes the equipment and the methodology used to conduct this study. Section III presents the results we found. We discuss our findings in Section IV and present our conclusions in Section V.

II. Methods

This study was approved by Deakin University Human Research Ethics Committee (DUHREC, 2021-181). Written informed consent was obtained from participants at the start of the experiment and no incentives (e.g., money or course credits) were offered to participants.

A. Participants

A total of 29 participants (9 female and 20 male) with a mean age (*SD*) of 30.4 (5.1) years volunteered in this study. Participants were recruited from the staff and student body of Institute for Intelligent Systems Research and Innovation at Deakin University as well as via snowball sampling.

B. Materials

Participants sat in the NLR Motion Platform V3, were visually immersed using the Varjo V3 Head-Mounted Display (HMD) and were audibly immersed using Sony WH-1000XM4 closed back, noise-cancelling headphones. The virtual environment (VE) was custom-built by the first author using Unity 2019.4.f21. A desktop computer running a 64-bit version of Windows 10 with Intel(R) Core(TM) i9-10900K CPU @ 3.70GHz, NVIDIA GeForce RTX 3090 24GB graphics card, Z490 AORUS ELITE MOBO and 64GB RAM was used to run the VE. Participants used a Thrustmaster HOTAS™ Warthog Flight Stick to provide feedback during the stimulus presentation. Lastly, participants wore an Equivital EQ02 monitoring device, however, the data obtained from this device will be reported elsewhere. Fig. 1 depicts a schematic representation how information from the VE was presented to some of the equipment and what information was stored. Furthermore, the Figure depicts the designed VEs from a holistic viewpoint as well. Fig. 2 shows the overall experimental set-up and equipment how a typical participant would experience it.

C. Design

During the first 10 seconds of each trial, participants acclimatised to the environment. Subsequently, objects in the environments accelerated linearly over a duration of 10 seconds after which they moved with a constant velocity for 60 seconds. After the 60 seconds of constant velocity the participant was switched to a new environment in which they answered a set of questions. As such, the total duration of a single trial was 80 seconds. The design was within-subject and comprised of three independent variables (IVs), each having two levels.

The first IV was the **feedback modality**, which consisted of 1) visual (V) and 2) visual and auditory (VA). The second IV was the **ecological relevance** of feedback type, namely abstract (A) and naturalistic (N). The abstract visual stimulus consisted of a moving point cloud simulating optic flow (see Fig. 3A), which has commonly been used in vection research (e.g., [18], [19]). The parameters of the optic flow conditions were similar to the "*slow*" condition in the study conducted by Keshavarz et al. [18]. Even though Keshavarz et al. [18] found that the slow condition elicited weaker vection than the fast condition (i.e., 75 $^{m}/_{s}$), we chose the slow velocity to make the velocity component of this condition comparable to the (naturalistic) train condition; it should be noted would appear extremely unrealistic to have a train accelerate to 270 $^{km}/_{h}$ (i.e., 75 $^{m}/_{s}$) within 10 seconds. The naturalistic visual stimulus depicted the participant to be seated in a train carriage adjacent to another train (see Fig. 3B), aimed to replicate the description of the train illusion (see [20], p. 91 for description) which has often been used to describe vection (e.g., [21], [22]). The adjacent train received a velocity of 15 $^{m}/_{s}$ (i.e., 54 $^{km}/_{h}$), similar to the velocity achieved in the optic flow condition. The naturalistic auditory stimulus was the sound of a train departing. The abstract auditory stimulus was an ascending Shepard-Risset glissando as previous research on auditory vection has shown that the Shepard-Risset glissando elicits vection [1], [23]. We have obtained the Shepard-Risset audio sample from the same source as used by Mursic et al. [1].

The third independent variable was the type of **secondary task** the participant was expected to perform, which varied between Focus (F) and a Visual Discrimination Reaction Time Task (VDRTT). "Focus" required participants to retain their focus on a specific marker in the far depth of their view. The use of a visual focus marker is common practice in vection research (e.g., see [28], [29]).

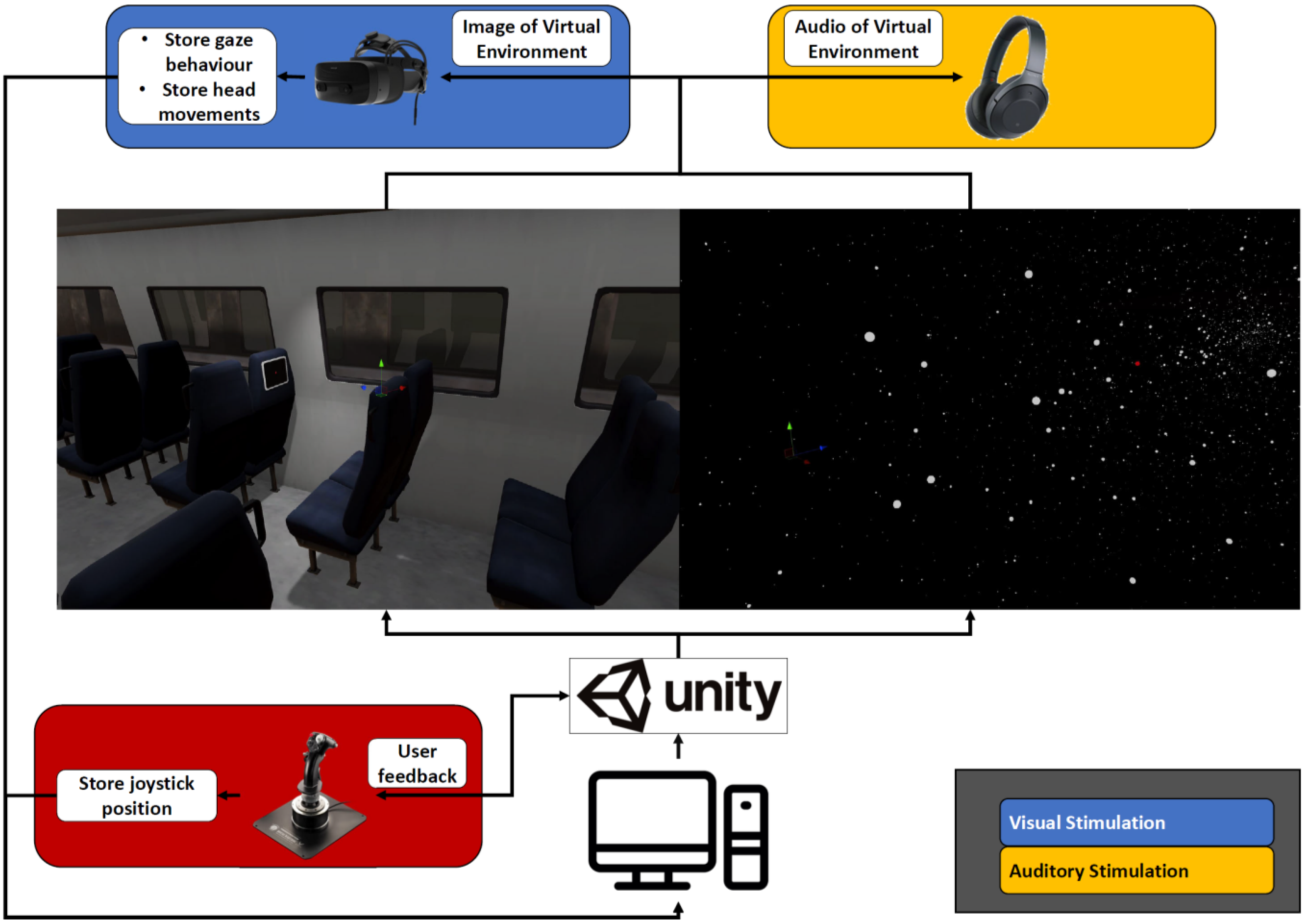

Fig. 1. Schematic representation of the design of the Virtual Environments (VE) and integrated components. The diagram shows how visual and auditory information from the VE presented by Unity is forwarded to the Varjo Head-Mounted Display and Sony Headphones. The information from the sensors in the Varjo are fed back to Unity and stored on the computer. Feedback from the joystick is used to interact with the VE and joystick positions are stored on the computer. The coordinate axis show the camera placement in Unity. Image of Varjo retrieved from [24]. Image of Sony Headphones retrieved from [25]. Image of HOTAS Joystick retrieved from [26]. Icon of computer retrieved from [27].

During the VDRTT, participants were required to press the "fire" button on the joystick as fast as possible when they saw the colour of the focus marker change, which was inspired by one of the tasks used in the study by Trutoiu et al. [16]. The moment when the colour of the focus marker changed from red to green, and vice versa, was pseudorandomized. The colour changes occurred at 22s +/- 1s, 30s +/- 1s, 38s +/- 1s, 46s +/- 1s, 54s +/- 1s, 62s +/- 1s, and 70s +/- 1s from the moment the experimental condition started. As such, the time between subsequent colour changes ranged between 6 and 10 seconds. We randomized the 8 (2 Sensory Modalities x 2 Ecological Relevance x 2 Secondary Task) combinations of independent variables and each combination was presented to participants once. As such, the total duration of the virtual conditions was (8 * 80s) / 60 = 11 minutes. Overall, the experimental procedure lasted for about 1 hour and 15 minutes.

D. Procedure

Participants were welcomed by one experimenter (first author) and informed about the goal of the experiment, namely to "*investigate if and how humans experience motion in virtual environments*". Subsequently, participants completed a COVID-19 screening form and were queried through a form about any pre-existing conditions, such as history of motion sickness, implanted medical devices, neuromuscular or heart issues. Participants with existing (medical) conditions were excluded from participating in the experiment. Participants then were asked to read the plain language statement and sign a consent form. After reading the plain language statement and signing the consent form, a pre-questionnaire was administered containing questions about, for example, demographics and imagery (see [30] for results).

After putting on the Equivital in private, participants were instructed how to use the HMD while seated in the motion platform. After the familiarization with the equipment, the position of the HMD was calibrated. Subsequently, the simulator was launched and a practice trial was initiated in which participants were familiarized with the tasks of the experiment. Task instructions were presented through the HMD and participants could proceed at their own pace by pressing the fire button of the joystick. The general task instructions were adapted from [13], [19]. Participants were asked to indicate if they felt they were moving by pulling on the joystick. Furthermore, participants were instructed that if their feeling of self-motion was stronger, they should incline the joystick more. Participants were also informed about a secondary task; in some conditions participants were expected to solely focus on the focus marker, whereas in other conditions participants were informed to pull the "fire" trigger as soon as the focus marker changed colour. For the practice trial, participants were to retain their focus on the marker.

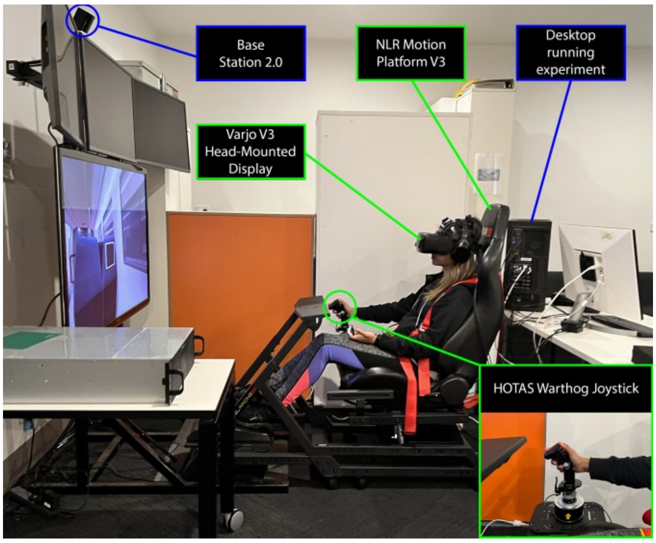

Fig. 2. Experimental set-up. A participant is shown wearing the Varjo V3 Head-Mounted Display while seated in the NLR Motion Platform using a HOTAS joystick to indicate their vection experience by pulling on the joystick and perform the secondary task by pushing the "fire" button.

After the practice trial, participants were shown a screen containing questions which they could answer using the joystick. Participants rated vection intensity using a Visual Analogue Scale (VAS). The statement was "*Please rate how strong your feeling of movement was*". The statement had left and right anchors: "*not at all*" and "*extremely intense*". Since vection research lacks a single robust measure (e.g., see [31]–[33]), we derived the wording of the vection statement from the recommendations in study by Soave et al. [34]. Furthermore, the marker that was used to rate these statements was be placed in the middle of the VAS line. Participants also rated Presence using a VAS line for the statement via the statement "*In the computer generated world I had a sense of "being there*" derived from [35] with left and right anchors being "*not at all*" and "*Very much*", respectively. Lastly, they rated their well-being by means of the Motion Illness Symptoms Classification (MISC; [36]) which ranged from 0 to 10, where 0 represents no problems, 1 asymptomatic uneasiness, 2 and 3 vague to slight discomfort and 4 and greater indicated more severe symptoms of discomfort. We terminated or paused the experiment if participants indicated a discomfort level greater than 4. Upon completion of the questions, participants were given noise-cancelling headphones and the experimental trials were initiated if the participants indicated they understood the tasks of the experiment. The same procedure for the practice round was repeated 8 times for the experimental conditions; participants were first presented with the instructions specific to the condition (primary and secondary task), after pressing continue the VE was shown and after the VE ended the screen was shown detailing the questions. Participants were free to take a break after they submitted their responses to the questions (i.e., before the start of the next stimulus presentation). After all combinations were completed, participants were instructed they could remove the HMD and were offered some water. After taking off the Equivital, participants completed a qualitative survey. The results of the survey will be detailed elsewhere. Upon completion of the survey, participants were thanked for their participation and provided with the opportunity to ask questions or were informally debriefed.

E. Data Processing

Joystick data and questionnaire responses were processed using a custom-written MATLAB script. We derived the measure of vection intensity and Presence on a 0 to 100 scale from the VAS ratings. Joystick data were interpolated to 100Hz and filtered using a moving average filter with a window size of (100Hz / 60s) 2 samples. From the joystick data we computed the following dependant variables.

Vection Onset Time (*VOT* in seconds): The difference between the moment the experimental condition started (t_s) and the moment the joystick angle exceeded 0 (t_{vo}) [37]. If the participant did not move the joystick during a trial, a *VOT* of 80 seconds was used.

$$VOT = t_{vo} - t_s \tag{1}$$

VOTs were computed for every condition, including the conditions wherein participants performed a secondary task, as participants were instructed to indicate their vection experience in every condition. Furthermore, trials wherein participants moved the joystick were counted as a vection trial and for each condition a percentage was computed for the number of participants who experienced vection in that condition.

For the trials wherein participants had to perform the VDRTT, the response time (*RT* in seconds) was calculated for each time the participant pulled the "fire" button when the focus target changed colour. *RT* was defined as follows:

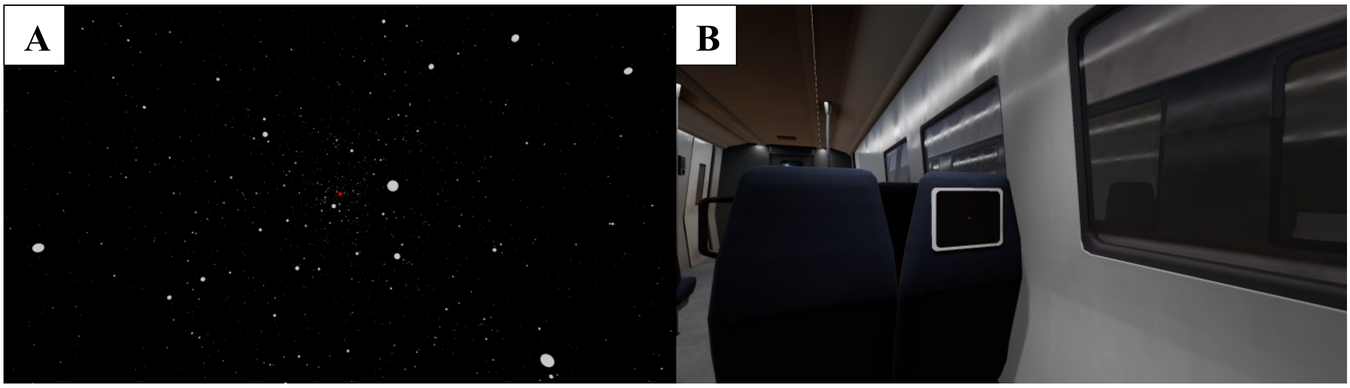

Fig. 3. Visual content of experimental conditions. A) A cloud of white points with a red focus marker. B) A train carriage with a tablet display on the back of a seat showing a red focus marker. The adjacent moving train can be seen through the windows on the right-hand side. The windows on the left-hand side were blinded.

Response Time (RT in seconds): The difference between the moment the focus marker changed colour (t_{colour}) and the moment the participant pulled the "fire" button (t_{fire}). If participants provided no response within 4 seconds from the moment the colour of the focus target changed, an RT of 4 s was used.

$$RT = t_{fire} - t_{colour} \tag{2}$$

Participants that did not provide a single response throughout the VDRTT conditions were excluded from the analysis. The RT per experimental condition was computed by taking the average of the 7 reaction times to the colour changes in each trial.

The use of the *p*-value as a threshold to interpret (non)significant effects has been criticized in scientific literature [38], [39]. As such, we will depict within-subject compatibility intervals (i.e., normalized 95% confidence intervals) for each variable to help interpret differences. These compatibility intervals were computed according to the method detailed by Morey [40] by subtracting the mean score of all conditions per participant. Additionally, we performed conventional statistical comparisons at the level of the participants by subjecting the dependant variables to ANOVAs to assess the effect of feedback modality, ecological relevance, and a secondary task. Lastly, Spearman rank correlations were performed between vection intensity and Presence ratings. An alpha level of 0.05 was used.

III. Results

A total of eight participants either forgot to push the fire button or misinterpreted the task instructions as they did not push the fire button during the VDRTT trials. As such, these participants were excluded from the analysis, leaving a total of twenty-one participants (F = 5, M = 16) with a mean age (SD) of 29.8 (5.1) years.

A. Task Performance

The mean (*SD*) RT for the abstract visual condition was 0.51 (0.22) seconds, whereas the mean (SD) RT for the abstract visual-audio condition was 0.51 (0.15) s. RTs for the realistic visual and visual-audio conditions were 0.51 (0.16) s and 0.51 (0.19) s, respectively.

A two-way repeated-measures ANOVA was conducted to investigate the effects of sensory modality and ecological relevance on RTs. No main effects were found for sensory modality: $F(1,20) = .01$, $p = .923$, $\eta_p^2 < 0.01$ and ecological relevance: $F(1,20) < .01$, $p = .962$, $\eta_p^2 < 0.01$ on RTs. Similarly, no interaction was found between sensory modality and ecological relevance: $F(1,20) = .03$, $p = .870$, $\eta_p^2 < .01$.

B. Vection

From the joystick data, vection was reported by 85.7% of participants in the abstract condition with visual feedback and 76.2% of participants in the abstract condition with visual-auditory feedback. The naturalistic condition with visual feedback and visual-auditory feedback elicited less vection with 66.7% and 62% of participants reporting vection, respectively. More participants reported vection when performing the VDRTT in the abstract conditions with visual and visual-auditory feedback as vection was reported by 95.2% and 81% of participants, respectively. However, less participants reported vection in the naturalistic condition with visual and visual-auditory feedback while performing the VDRTT as vection was reported by 62% and 57.1% of participants, respectively.

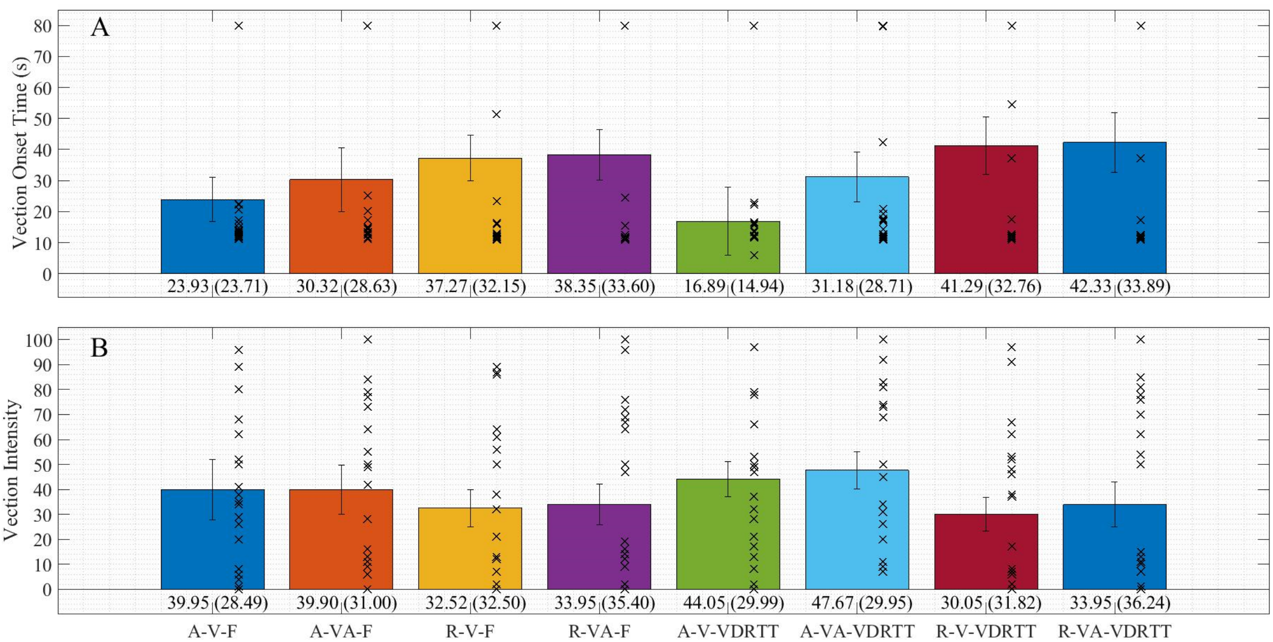

Fig. 4. Bar chart of vection intensity and vection onset time. A. Mean vection onset times for each of the experimental conditions separated. B. Mean vection intensity ratings for each of the experimental conditions separated. Individual data points are marked with 'x'. Means and standard deviations for each dependent variable are denoted in numerical format below the bar. Errorbars represent the compatibility intervals. Condition abbreviations indicate ecological relevance, sensory modality and secondary task separated by a hyphen. A = Abstract, F = Focus Task, R = Realistic, V = Visual cues, VA= Visual-Auditory cues, VDRTT = Visual Discrimination Reaction Time Task.A = Abstract, F = Focus Task, R = Realistic, V = Visual cues, VA= Visual-Auditory cues, VDRTT = Visual Discrimination Reaction Time Task

Vection onset times (*VOTs*) are shown in Fig. 4A. On average, *VOTs* increased when bimodal cues were presented compared to unimodal cues. Furthermore, *VOTs* were, on average, higher in the naturalistic conditions compared to the abstract conditions. The non-overlapping confidence intervals between the abstract visual-only condition and the naturalistic conditions during the VDRTT suggests that vection was elicited quicker during this abstract condition compared to the naturalistic conditions when performing a secondary task. Vection intensities are shown in Fig. 4B. Vection intensity was, on average, higher during the abstract conditions compared to the naturalistic conditions. Notably, the non-overlapping compatibility intervals between the abstract and naturalistic conditions combined with a secondary task suggest that vection was experienced to be more intense in the abstract condition compared to the naturalistic condition whilst performing a secondary task.

A three-way repeated-measures ANOVA was conducted to examine the main effects of feedback modality, ecological relevance, and secondary task, as well as their interaction on *VOTs*. A main effect of ecological relevance ($F(1,20) = 7.06$, $p = .015$, $\eta_p^2 = .26$) was found for *VOTs* indicating that *VOTs* were lower in the abstract conditions compared to the naturalistic. No main effects were found for sensory modality ($F(1,20) = 2.90$, $p = .104$, $\eta_p^2 = .13$) and secondary task ($F(1,20) = 0.01$, $p = .907$, $\eta_p^2 < .01$) for *VOTs*. Lastly, neither of the interactions displayed a substantial effect on *VOTs*.

Another three-way repeated-measures ANOVA was conducted to examine the main effects of feedback modality, ecological relevance, and secondary task, as well as their interaction on vection intensity. No main effects were found for sensory modality ($F(1,20) = 1.33$, $p = .262$, $\eta_p^2 = .06$), ecological relevance ($F(1,20) = 2.84$, $p = .107$, $\eta_p^2 = .12$) and secondary task ($F(1,20) = 0.80$, $p = .383$, $\eta_p^2 = .04$) on vection intensity. Furthermore, neither of the interactions displayed a substantial effect on vection intensity.

C. Cybersickness and Presence

Throughout the experiment, fifteen participants reported they experienced no discomfort at all, four participants reported asymptomatic uneasiness, and two participants reported vague symptoms of discomfort. Please note, a correlation analysis investigating the potential negative effect of Cybersickness on the relationship between vection and Presence has been reported elsewhere [41].

Table 1 shows the mean, standard deviation, and compatibility intervals for the Presence ratings for each condition. Presence ratings were, on average, higher for conditions wherein bimodal cues were presented compared to unimodal cues except for the abstract conditions wherein participants did not perform a secondary task. However, the overlapping compatibility intervals indicate that these differences were not substantial.

A three-way repeated-measures ANOVA was conducted to examine the main effects of feedback modality, ecological relevance, and secondary task, as well as their interaction on Presence. No main effects were found for ecological relevance ($F(1,20) = 0.20$, $p = .660$, $\eta_p^2 = .01$), sensory modality ($F(1,20) = 1.73$, $p = .203$, $\eta_p^2 = .08$), and secondary task ($F(1,20) < 0.01$, $p = .955$, $\eta_p^2 < .01$) for Presence. Lastly, neither of the interactions displayed a substantial effect on Presence, except for the interaction between ecological relevance and sensory modality ($F(1,20) = 8.79$, $p = .008$, $\eta_p^2 = .31$), suggesting that the addition of auditory feedback increased Presence more in the naturalistic conditions compared to the abstract conditions.

TABLE I. MEANS, STANDARD DEVIATIONS, AND COMPATIBILITY INTERVALS FOR PRESENCE AND SPEARMAN RANK CORRELATIONS TO VECTION INTENSITY

Experimental Condition	Presence			Correlation	
	Mean	*SD*[a]	*CI*[b]	*r*[c]	*p*[d]
A-V-F	51.76	27.52	39.71, 63.81	.66	**.001**
A-VA-F	48.81	31.12	35.63, 61.99	.65	**.001**
N-V-F	48.19	32.74	36.72, 59.66	.40	.071
N-VA-F	53.67	30.00	41.36, 65.98	.64	**.002**
A-V-VDRTT	46.81	30.72	37.78, 55.84	.89	**<.001**
A-VA-VDRTT	50.14	30.40	42.15, 58.14	.83	**<.001**
N-V-VDRTT	49.62	32.53	38.26, 60.98	.47	**.033**
N-VA-VDRTT	56.29	32.19	41.39, 71.19	.60	**.004**

a. *SD* = Standard Deviation

b. *CI* = Compatibility Interval

c. Degrees of freedom for correlations are df = 19

d. Statistically significant p-values are indicated in bold font.

Table 1 also details the results of Spearman rank correlations between Presence and vection intensity ratings. The results show a moderate to strong significant positive correlation between Presence and vection for seven of the eight experimental conditions. Vection intensity and Presence presented a moderate positive relationship in the naturalistic visual audio condition wherein participants did not perform a secondary task, however, the relationship was not significant.

IV. DISCUSSION

Herein we aimed to investigate whether performing a secondary task affects vection across environments with differing levels of ecological relevance. We immersed participants visually and visual-audibly in different virtual environments that were high or low in ecological relevance. We hypothesized that participants who were focussed on a secondary task would experience vection quicker compared to when they were were solely focussing on vection. Our results showed that vection experience was unaffected by the performance of a Visual Discrimination Reaction Time Task (VDRTT) and participants' performance on the VDRTT did not differ between conditions with different levels of ecological relevance and the type of sensory feedback.

The pattern of our results is inconsistent with previous research by Trotoiu et al. [16], where *VOTs* were shown to be reduced, and Seno at al. [17], where *VOTs* were shown to be increased while performing a secondary task. We found no substantial difference in *VOTs* between conditions in which participants did and did not perform a secondary task. The lack of an effect of a secondary task on vection in our study could, in part, be explained by the type of task that was used. Participants in our study focused on a marker in both the control conditions and conditions with a secondary task where the same marker was utilized to perform the secondary task. Thus, participants were not required to locate and identify potential targets throughout their field-of-view, as was the case in the study by Trotuio et al. [16], which may have reduced the attentional resources required to perform the secondary task in our study. However, Seno et al. [17] had participants track multiple objects across their field-of-view, but these objects moved independently from the grating. As such, it is possible that integrating the secondary task into the dynamic content of the stimulus may have a different (beneficial) effect. In sum, it may be possible that the VDRTT did not increase attentional load on participants as the focus target was the sole object of attention. Further research could consider increasing the complexity of the VDRTT by presenting color changes of objects moving throughout participants' field-of-view and measuring participants' (mental) workload by administering, for example, the NASA-TLX.

We identified that *VOT* was lower during the abstract visual condition compared to the naturalistic conditions, and vection intensity higher during the abstract condition compared to the naturalistic condition while performing a secondary task. Also these findings are opposite to previous research where stimuli of high ecological relevance elicited stronger vection compared to stimuli of increased abstraction [10]. Our findings could be explained, in part, by the dynamic content of the scenes. The dynamic content of the naturalistic scene was limited to the area visible through the window, whereas in the abstract conditions motion cues were visible throughout the whole field-of-view. The difference in the dynamic content might have reduced the possibility of vection occurring for participants in the naturalistic scene. The difference in dynamic content may also explain why results show that even though Presence was often, on average, rated higher in naturalistic compared to abstract conditions, no robust effect of ecological relevance on Presence was identified. As such, it may be that the naturalistic environment was not more immersive compared to the abstract environment due to the low dynamic content. Overall, our results show that vection and Presence are positively related, which is in line with previous research [10].

There are some potential limitations to our research. Our results for *VOT* may have been limited by our use of the joystick inclination method instead of a button-press as the differences between the percentage of participants who experienced vection was lower based on the joystick data compared to the data from the questionnaires. Participants may have extended their arms without inclining the joystick. Secondly, the data of over a quarter of participants had to be excluded from the analysis as they had not performed the secondary task at all. Participants may have had difficulty interpreting the task instructions.

Despite these limitations, our results have some theoretical and practical implications. Our results underly the notion that vection is a desired sensation as vection and presence ratings correlated strongly. Furthermore, our results show that, practically, participants can reliably perform a secondary visual attention task while reporting on their experience of vection concurrently. Furthermore, the performance on this task is unaffected by the environmental context. These findings can add to the understanding how mental load induced by a secondary task can influence either participants' reporting or experience of vection. Further research could present participants with secondary tasks of incremental complexity and with differing spatial distributions to identify the limit of secondary task complexity up to which the reporting or experience of vection is unaffected.

V. Conclusions

It is concluded that participants' ability to report on their vection experience was unaffected whilst performing a visual attention reaction time task. Furthermore, the dynamic content of the visual stimulus may outweigh the ecological relevance in terms of the probability of eliciting vection.

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