2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)

2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct) | 978-1-6654-5365-3/22/$31.00 ©2022 IEEE | DOI: 10.1109/ISMAR-ADJUNCT57072.2022.00089

Comparing Visual Search between Physical Environments and VR

Floris van den Oever*
Department of Psychosocial Science
University of Bergen

Valentina Gorobets†
Institute of Machine Tools and Manufacturing
ETH Zurich

Bjørn Sætrevik‡
Department of Psychosocial Science
University of Bergen

Morten Fjeld§
Department of Information Science and Media Studies
University of Bergen

Andreas Kunz¶
Institute of Machine Tools and Manufacturing
ETH Zurich

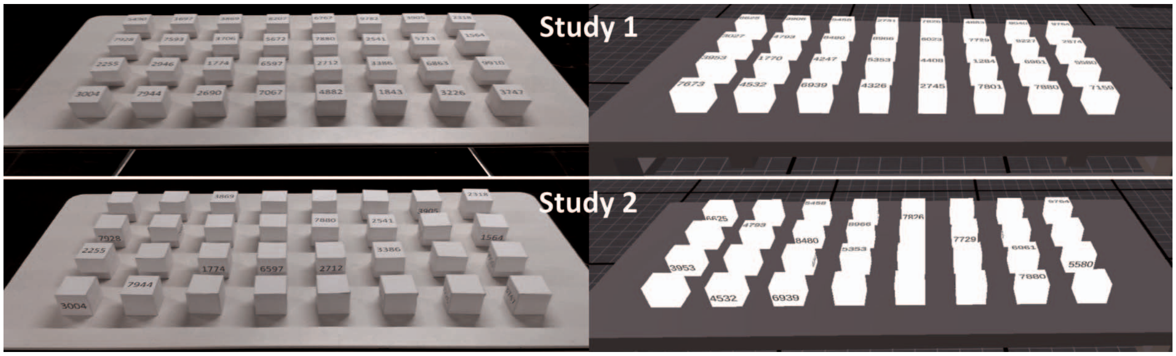

Figure 1: Study setups. From left to right and top to bottom: Study one in the physical environment, Study one in VR, Study two in the physical environment, and Study two in VR.

ABSTRACT

Virtual reality is used under the assumption that humans behave similarly in virtual reality and in physical environments. This assumption lacks extensive testing, thus risking unexpected human behavior when working with virtual reality. In the current study, we tested this assumption by comparing the performance on visual search tasks in physical environments and in virtual reality. The participants (n = 29) performed search tasks while standing still and search tasks that required walking in both physical environments and in virtual reality. We compared search speed, accuracy, workload, and cognitive absorption with Bayesian t-tests and factorial ANOVAs. Our results provide weak to moderate evidence that all are similar in virtual reality as in physical environments, even when controlling for virtual reality experience and personal innovativeness. Our findings provide some evidence for the assumption that virtual reality can simulate and replace visual search tasks in physical environments. This knowledge can be used to justify the use of virtual reality to, for example, study the human visual system, train surgeons, and remotely operate ships. We suggest further scrutiny of the underlying assumptions of virtual reality use, for example, by studying more naturalistic scenarios, the role of memory, and interaction with objects.

Index Terms: H.5.2 [User Interfaces]: User Interfaces—Graphical user interfaces (GUI); H.5.m [Information Interfaces and Presentation]: Miscellaneous

1 INTRODUCTION

Virtual Reality (VR) is used in various applications, such as remote operation of maritime vessels [7]; remote operation of aerial vehicles [13]; air traffic control [8]; maritime traffic control [37]; remote support during maintenance and inspection [23]; training [20,25,31]; architecture and design [2,31]; mental health treatment [10]; and surgery [3]. The ecological validity and applicability of VR for these operations should be evaluated to ensure its feasibility, safety, and effectiveness.

In such VR implementations, visual search plays an important role [12]. Therefore, it is important to study if visual search performance in VR correlates with physical environments. At the same time, Harris et al. point out the inadequate understanding of how VR impacts cognitive factors such as visual processing [19]. In the present study, we adopt Burack et al.'s [6] definition of visual search: *'Visual search is a goal-oriented activity that occurs regularly in daily life and involves the active scanning of the environment in order to locate a particular target among irrelevant non-targets, or distractors'*.

1.1 Related Work

The previous section shows the prevalence of direct use and evaluation of VR involving visual search. We, however, are interested in more fundamental empirical knowledge on visual search in VR to ground VR research and innovation. In this section, we discuss related work on visual search in VR, the comparison of visual search between VR and 2D displays, and the comparison of visual search related tasks between VR and physical environments.

Visual search tasks have been studied in VR to understand the human visual system; for example, the effects of distractions during visual search [27]; the effects of impairments on visual search [5]; or general visual search constructs, such as the relative importance of central and peripheral vision [9] and the search initiation effect [4]. Like the use of VR in practice, these studies lean on the assumption that visual search behavior and performance in VR can be mapped

---

*e-mail: floris.oever@uib.no
†e-mail: gorobets@iwf.mavt.ethz.ch
‡e-mail: bjorn.satrevik@uib.no
§e-mail: morten.fjeld@uib.no
¶e-mail: kunz@ethz.ch

2771-1110/22/$31.00 ©2022 IEEE
DOI 10.1109/ISMAR-Adjunct57072.2022.00089

to physical environments. As such, grounding this assumption in fundamental empirical findings is valuable to support further use of VR for visual search in research as well as in practice.

One approach toward increasing the validity of theories about visual search is that classic visual search experiments on 2D displays have been reproduced in VR. While knowledge generated in 2D display experiments has been generalized to phenomena in physical environments, the caveat of uncertain and probably low ecological validity has been mentioned [18]. To evaluate the concurrent validity of 2D computer experiments and 3D VR experiments, visual search tasks on 2D displays and in VR have been compared. For example, Hadnett-Hunter et al. [18] replicated experiments on feature search, wide field-of-view visual search, and eccentricity effects. Similarly, Li et al. [24] studied the role of spatial memory in visual search in both 2D and 3D environments and found that search behavior on 2D display and in VR environments was largely comparable but there was some behavioral difference signaling greater use of memory in VR. In like manner, Figueroa et al. [15] compared search efficiency on 2D displays and in VR, finding that visual search was faster and more accurate in VR. All three studies assumed higher ecological validity of VR than 2D displays and advocated for using VR for similar studies.

Differences and similarities in human behavior and performance between physical environments and VR in tasks related to visual searching have been researched too. For example, Kuliga et al. [22] studied the validity of VR as a representation of physical environments, finding that people experienced a VR and a real building similarly, suggesting that VR can be used as a research tool. Congruently, Feldstein et al. [14] found similar distance estimation in physical environments and VR, which supports VR's applicability for visual tasks, given that important factors such as eye height are equal in physical environments and VR. On the other hand, Peillard et al. [28] found differences in distance perception between physical environments and VR, and suggested methods to reduce this difference. Modes of information processing may be similar in VR as in physical environments but there is a need for more direct comparisons of behavior in physical environments and VR [30]. Based on a literature review, Wilson and Soranzo [35] stated that higher levels of visual fidelity and immersion in VR do not necessarily elicit realistic psychological responses, suggesting that physical and psychological side effects from VR exposure should be taken into account when generalizing from VR to physical environments.

1.2 Research Gap and Study Aim

The apparent difference in visual search performance and behavior between 2D displays and VR, in combination with the previous generalization of 2D display based experiment results to physical environments, motivated us to check the assumption of the generalizability of VR experiment results to physical environments. Although the face validity of VR being more generalizable to physical environments than 2D displays is high, we think the assumption of generalizability remains understudied. Furthermore, the higher similarity of VR to physical environments may make it a more ecologically valid method to study the human visual system [18].

In our search for relevant literature, we found no research specifically focused on a direct comparison of visual search performance in 3D between physical environments and VR, even though researchers call for the evaluation of VR as a methodological tool [18, 30, 35]. Concurrently, VR is being implemented to replace [7, 8, 13] and simulate [2,3,25] visual search tasks. Based on these considerations, we believe it is important to map the ecological validity of VR, thus paving the way for its feasible, safe, and effective use. Therefore, we empirically compared visual search performance between physical environments and VR. As such, our study contributes by testing the ecological validity of VR in visual search tasks and demonstrating a method for comparing visual tasks between physical environments and VR, which can be applied to other activities than visual search.

1.3 Hypotheses

To compare visual search performance between physical environments and VR we examined four hypotheses and carried out additional exploratory analyses. *Hypothesis 1:* People are similarly fast in physical environments and VR, even when walking. Researchers and practitioners seem to assume people behave and perform similarly in physical environments and VR, so we base our hypothesis on that assumption, even though Figueroa et al. [15] and Li et al. [24] found that search speed was higher in VR than in 2D, suggesting it may be even higher in physical environments. *Hypothesis 2:* People are similarly accurate in physical environments and VR, even when walking. Researchers and practitioners seem to assume people behave and perform similarly in physical environments and VR, so we base our hypothesis on that assumption, even though Figueroa et al. [15] and Li et al. [24] found that accuracy was higher in VR than in 2D, suggesting it may be even higher in physical environments. Search speed and accuracy are classic search task metrics [36]. Hypotheses 3 and 4 are specifically relevant to VR [1]. *Hypothesis 3:* People experience more workload in VR than in physical environments. Physical demands are different between physical environments and VR and in VR people experience a virtual environment while also being in a physical environment they do not see [19]. *Hypothesis 4:* People experience more cognitive absorption in a physical environment than in VR. Cognitive absorption is linked to agency [16] and control [1], which we expect to be higher in a physical environment. *Exploratory analysis:* Differences in speed and accuracy may be moderated by VR experience and innovativeness, meaning that people with little or no VR experience and low innovativeness may have a larger difference in performance between physical environments and VR than those with more prior experience and higher innovativeness [29]. Therefore, we explored the possible moderating effects of these variables.

2 METHOD

A within-subjects, randomized, controlled trial experiment was conducted (see Fig. 2). Clarification of responsibility was given by the Cantonal Ethics Committee of the Zürich Canton. Participants gave informed consent. Data collection took place in week 14 of 2022.

2.1 Participants

Our study was conducted with 29 participants. Applicants were included if they had normal or corrected-to-normal vision and could walk. Descriptive statistics of the participants are portrayed in Table 1. We conducted a sample size calculation based on the planned analysis for the comparison of search speed. We calculated the sample size intending to have a power of 0.9 and a type 1 error rate allowance of .05. We based our assumptions of group means and standard deviations on the results of Figueroa et al. [15]. To have room for missing or excluding data, we aimed for a minimal sample of 20 participants, with the stopping rules of 30 participants and a fixed end date.

2.2 Experiment Design

Our experiment consisted of two studies in which participants searched for targets among distractors [36]. In Study one participants carried out search tasks while standing still; in Study two participants carried out search tasks for which they had to walk around. In both studies, participants saw similar setups in VR and a physical environment (see Fig. 1). Each setup consisted of a 70cm high table with a surface of 120×60cm. 32 white cubes with edges of 7.8cm were on the table in 4 rows and 8 columns, with 8.2cm spaces between the cubes. Each cube had a number between 1000 and 9999 in large black font randomly assigned to it. There were no numbers that risked misinterpretation when reading from another

Table 1: Descriptive statistics of the sample.

Category	Characteristic	Statistic
Gender	Man	23
	Woman	6
Occupation	Student	22
	PhD student or candidate	4
	Other	3
Vision	Normal	18
	Corrected to normal	11
VR experience	None	5
	0 - 5 hours	15
	5 - 20 hours	2
	20 - 100 hours	3
	>100 hours	4
Age in years, median (range)		24 (19, 49)
Personal innovativeness, mean (standard deviation)		5.2 (1.3)

angle than up front, such as 9969. In Study one, all numbers on the cubes faced upwards; In Study two, numbers were randomly located on different visible sides of the cubes (see Fig. 1) so participants had to walk around the table to find search targets but not touch the cubes. To prevent learning effects, numbers were randomized for all four conditions (Study one in the physical environment, Study one in VR, Study two in the physical environment, and Study two in VR). In like manner the orientations of the cubes in Study two were randomized. We choose white cubes with four-digit numbers in a rectangular array to prevent learning effects based on scene grammar [11] and memorization.

Fig. 2 shows the flow of the experiment. At the start, participants filled in descriptive questionnaires. Then, participants were randomly assigned to start with the physical environment condition or VR condition. After each condition, they filled in questionnaires.

In each of the four conditions, participants did 12 search trials. On the first click with a laser pointer, participants heard a number through headphones. Once they found the cube with that number, they pointed at it with the laser and clicked a button. On clicking, they heard the next number to search. At the start of the experiment, participants familiarized by listening to two example search tasks. Search targets were randomly selected.

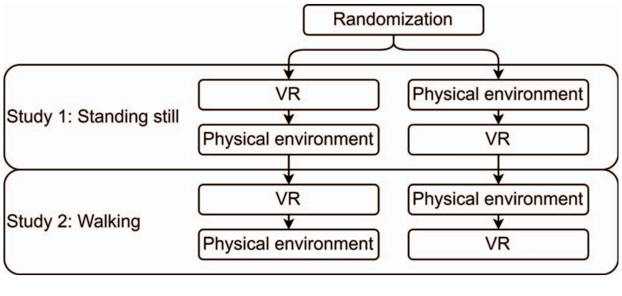

Figure 2: Experiment procedure

2.3 Technical Setup

In the physical environment setup, each cube was printed on paper and folded. The virtual environment was developed in Unity and implemented with an HTC Vive Pro headset and one controller. As visible in Fig. 1 there were only minimal remaining differences between the physical environment and VR, such as lighting. As the laser pointer we used a Logitech R400 in the physical environments and the HTC Vive Controller in VR. We captured timestamps when the button on the laser pointer was clicked, self-coded in VR and using Mini Mouse Macro Recorder in the physical environment [1]. The audio cues were created with a text-to-speech converter [2]. For all randomizations, a random number generator was used [17].

2.4 Outcome

We collected primary outcomes, secondary outcomes, and descriptive data. The primary outcomes were time measurements, operationalized as the time participants needed per trial in milliseconds (ms). This includes the time needed to listen to the search task. We did not remove this time because it does not cause bias as these audio cues were of equal length and we compared speed within subjects. The secondary outcomes were accuracy, workload, and cognitive absorption. We measured accuracy after Study two, operationalized as the proportion of trials in which participants correctly identified the search target. To measure accuracy, we visually observed where the participants pointed when they clicked. We only measured accuracy for Study two because we expected too few errors in Study one when all the numbers were constantly in view. We measured workload with a 10-point Likert-scale, unweighted SIM-TLX [19]. We measured cognitive absorption with a 7-point Likert-scale, unweighted cognitive absorption questionnaire [1]. Lastly, to check the moderating effects of experience and innovativeness, we measured innovativeness with the Personal Innovativeness in IT questionnaire [1, 32] and asked how many hours of experience participants had with VR with the answer options: this is my first time using AR, 0-5 hours, 5-20 hours, 20-100 hours, and >100 hours. Descriptive data were collected with questionnaires.

2.5 Analysis

To test hypotheses 1-4, we used Bayesian t-tests. To compare search speed, we took the average time of the 12 trials. We pairwise excluded search speed data of participants with lost tracking data. Outlying individual search task times with known causes were excluded before taking the averages of search task time (e.g., accidental double clicks, headset problems, or interruptions). We chose to not exclude outliers not caused by such technical issues because we believe that they were part of the phenomena we were interested in [26]. We used Bayesian paired samples t-tests to compare search speed. To compare accuracy, workload, and cognitive absorption between physical environments and VR we took average scores of each variable and conducted Bayesian paired samples t-tests.

For the exploratory analyses, we used Bayesian factorial ANOVAs. We analyzed the moderating effects of the factors VR experience and personal innovativeness on speed and accuracy. To make subgroups larger, we made both variables binary. For VR experience, we grouped participants with no or 0-5 hours of VR experience in "inexperienced" and participants with 5 or more hours of experience in "experienced". For personal innovativeness, we grouped participants scoring higher than the median in "more innovative" and participants scoring lower than the median in "less innovative".

We used Bayesian parametric tests (t-tests and ANOVAs). We used Bayesian statistics as opposed to frequentist statistics so we could obtain evidence of the absence of effects and categorize the evidence as weak, moderate, or strong [34]. We used default priors because related literature either focused on slightly different topics or did not provide sufficient insights into their statistics for us to build priors on. We used parametric tests (t-tests and ANOVAs) to analyze raw reaction time data, which is a frequently applied method [26]. All statistics were carried out using JASP [21]. Our analysis files are available on OSF.io.

---

[1] https://www.turnssoft.com/mini-mouse-macro.html
[2] https://www.ttsmp3.com

3 RESULTS

In this section, we present the results per hypothesis as well as exploratory analyses of the moderating effects of personal innovativeness and VR experience on search speed and accuracy.

3.1 Differences in Speed

Our findings support the first hypothesis. There is moderate evidence that people are equally fast in physical environments and VR based on Study one (Bayes $\text{Factor}_{01} = 4.485$) as well as based on Study two ($BF_{01} = 3.692$). This means that the observed data are approximately 4.5 and 3.7 times more likely to occur if people are equally fast in physical environments and VR than if there is a speed difference. The error percentage of the numerical algorithms used to obtain the results in Study one was 0.027% and in Study two was 0.029%, which indicates great stability of the algorithms. Fig. 3 shows arrow plots of the difference in speed in Studies one and two with 95% credible intervals. In order to assess the robustness of the Bayes Factor (BF) to our prior specifications, Fig. 4 shows BF_{01} as a function of the prior width r. Across a wide range of widths, the BF does not change our conclusion and can thus be seen as robust.

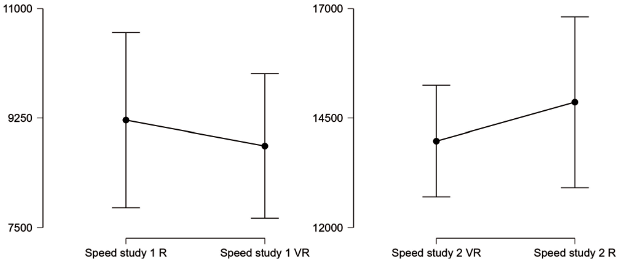

Figure 3: Relative search speed in ms in Study one (left) and Study two (right).

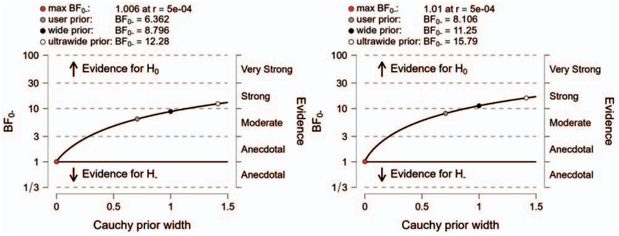

Figure 4: BF robustness check of speed in Study one (left) and Study two (right).

3.2 Differences in Accuracy

Our findings support hypothesis two. There is weak evidence that people are equally accurate in physical environments and VR ($BF_{01} = 1.571$). This means that the observed data are approximately 1.5 times more likely to occur if people are equally accurate in physical environments and VR than if there is a difference in accuracy. The error percentage of the numerical algorithms used to obtain the results was 0.027%, which indicates great stability of the algorithms. However, the Bayes factor (BF) is not very robust. Fig. 5 shows on the left an arrow plot of the difference in accuracy between physical environments and VR. The BF robustness check on the right shows the BF would have been different with different prior distributions. Furthermore, there might be a ceiling effect; the actual difference in accuracy may be dampened by most participants correctly identifying all or most search targets [33]. As such, our finding does not warrant an all-or-none acceptance of hypothesis two.

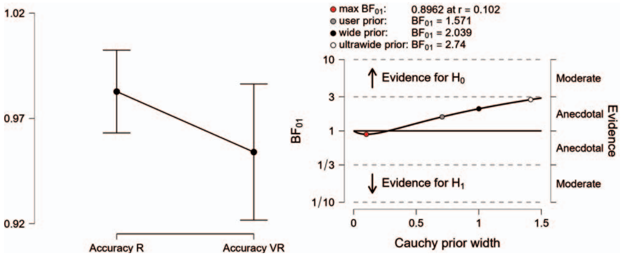

Figure 5: Relative accuracy in finding search targets (left) and BF robustness check (right).

3.3 Differences in Workload

Our findings do not support hypothesis three. There is weak evidence that people experience equal workload in physical environments and VR based on Study one ($BF_{01} = 2.522$) and moderate evidence based on Study two ($BF_{01} = 4.584$). This means that the observed data are approximately 2.5 and 4.6 times more likely to occur if people experience equal workload in physical environments and VR than if they experience more workload in VR. The error percentage of the numerical algorithms used to obtain the results in Study one was <0.001% and in Study two was 0.034%, which indicates great stability of the algorithms. Fig. 6 shows arrow plots of the difference in workload in Studies one and two with 95% credible intervals. Fig. 7 shows that across a wide range of widths, the BF does not change our conclusion and can thus be seen as robust. Generally, participants experienced a moderately low workload in both, Study one (M = 2.879, SD = 1.169) and two (M = 3.138, SD = 1.429) on a 10-point Likert scale.

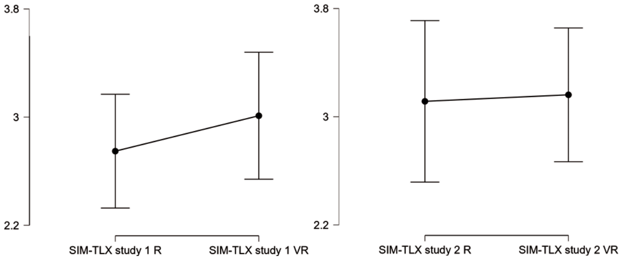

Figure 6: Relative workload in Study one (left) and Study two (right).

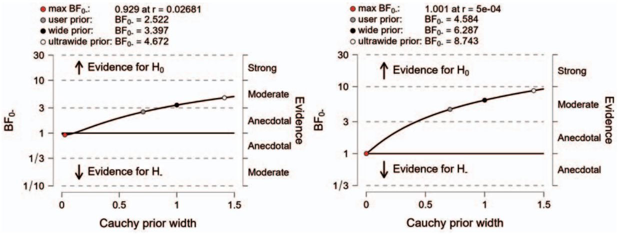

Figure 7: BF robustness check of workload in Study one (left) and Study two (right).

3.4 Differences in Cognitive Absorption

Our findings do not support hypothesis four. There is strong evidence that people feel equally cognitively absorbed in physical environments and VR based on Study one (BF_{01} = 13.673) and Study two (BF_{01} = 10.446). This means that the observed data are approximately 13.6 and 10.4 times more likely to occur if people feel equally cognitively absorbed in physical environments and VR than if they feel more absorbed in physical environments. The error percentage of the numerical algorithms used to obtain the results in Study one was 0.086% and in Study two was $<0.001\%$, which indicates great stability of the algorithms. Fig. 7 shows that across a wide range of widths, the BF does not change our conclusion and can thus be seen as robust. Fig. 9 shows arrow plots of the difference in workload in studies one and two with 95% credible intervals. Generally, participants experienced high cognitive absorption in studies one (M = 5.931, SD = 0.999) and two (M = 5.834, SD = 1.015) on a 7-point Likert scale.

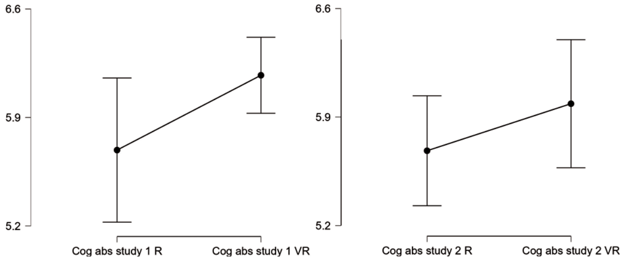

Figure 8: Relative cognitive absorption in Study one (left) and Study two (right).

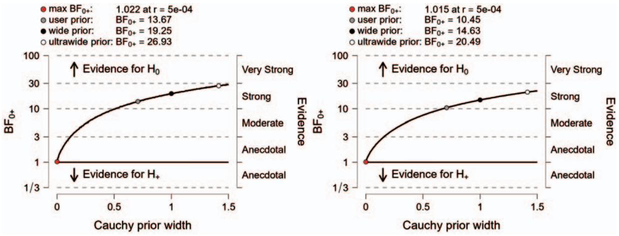

Figure 9: BF robustness check of cognitive absorption in Study one (left) and Study two (right).

3.5 The Moderating Effects of Innovativeness and VR Experience

In addition to hypothesis testing, we conducted exploratory analyses of the moderating effects of VR experience and personal innovativeness. For this, we used Bayesian factorial ANOVAs for search speed and accuracy with the fixed factors of condition (physical environment or VR), VR experience, and personal innovativeness.

For speed, the Bayesian factorial ANOVAs indicated that the data were 2.667 times more likely in Study one and 1.37 times more likely in Study two to occur under the null model than under the second most predictive model. This indicates weak evidence that there is no moderating effect of VR experience nor of personal innovativeness. The error percentage of the numerical algorithms used to obtain the results was 0.009% in both Studies one and two, which indicates great stability of the algorithms. For accuracy, the Bayesian factorial ANOVA indicated that the data were 1.379 times more likely to occur under the null model than under the second most predictive model. The error percentage of the numerical algorithms used to obtain the results was 0.009%, which indicates great stability of the algorithms. This indicates weak evidence that there is no moderating effect of VR experience nor of personal innovativeness.

4 DISCUSSION

We compared the performance of people on a visual search task in physical environments and VR. We measured search speed, accuracy, workload, and cognitive absorption and analyzed these using Bayesian statistics. Our results provide weak to moderate evidence that search speed, workload, accuracy, and cognitive absorption are similar in VR as in physical environments, even when controlling for VR experience and personal innovativeness. This confirms the assumptions [9,27] and findings [14,22] that VR can represent physical environments, thus providing some support for the assumption that VR can be used to replace [7,8,13] and simulate [2,3,25] visual search tasks.

Our findings contribute knowledge to the field of visual search. They answer the call for the evaluation of this novel tool [18,30,35]. This knowledge can be used to justify the use of VR to, for example, study the human visual system [4], train surgeons [3], and remotely operate ships [7]. Furthermore, future research can conform and build upon our work by studying more naturalistic scenes; using behavioral measures such as eye- and movement-tracking; studying the role of memory; evaluating other existing visual search tests; including interaction with objects; and isolating VR characteristics that are suspected to cause differences in behavior and performance such as limited field-of-view [18] and being able to move through virtual objects and allowing interaction with objects. For this, our analysis files can be used to inform hypotheses and prior distributions, available on OSF.io.

Several limitations should be taken into consideration when interpreting our findings. First, we used uninformed priors for our Bayesian tests. We considered using informed priors but could not find satisfying previous research results to inform them. Second, as can be seen in Fig. 8, there was an initially surprising finding that our participants experienced higher cognitive absorption in VR than in physical environments. If we had hypothesized that people are more cognitively absorbed in VR, we could have collected evidence for a difference. This might be related to the novelty effect of VR [29]. Third, we measured memory performance but found a large confounding variable due to our experiment setup, therefore we decided not to analyze memory performance. Fourth, as visible in Fig. 1 there were minimal remaining differences between the physical environment and VR, such as lighting. However, these can be seen as part of the phenomena we were interested in. Lastly, we focused on performance measures. Including behavioral measures such as eye-tracking may give extra insight into similarities and differences in human behavior between physical environments and VR.

5 CONCLUSION

Our findings support the assumption that VR can simulate and replace visual search tasks in research and practice, thus endorsing its use for, for example, research into the human visual system, training, and remote operations. On a higher abstraction level, our findings provide some support for the assumption that people behave and perform similarly in physical environments and VR. Studies like ours can demonstrate whether VR can safely and effectively replace or simulate physical reality in both research and practice, so that safe and effective VR use can be achieved.

ACKNOWLEDGMENTS

The authors wish to thank Marco Ketzel for helping with the VR development and Joy Gisler for helping with the clarification of responsibility. This work was supported in part by the mobility fund of the University of Bergen.

REFERENCES

[1] R. Agarwal and E. Karahanna. Time flies when you're having fun: Cognitive absorption and beliefs about information technology usage. *MIS Quarterly*, 24(4):665–694, 2000.

[2] K. Aylward, J. Dahlman, K. Nordby, and M. Lundh. Using operational scenarios in a virtual reality enhanced design process. *Education Sciences*, 11(8), 2021. doi: 10.3390/educsci11080448

[3] A. Ayoub and Y. Pulijala. The application of virtual reality and augmented reality in oral & maxillofacial surgery. *BMC Oral Health*, 19(1), Nov. 2019. doi: 10.1186/s12903-019-0937-8

[4] J. Beitner, J. Helbing, D. Draschkow, and M. L.-H. Võ. Get Your Guidance Going: Investigating the Activation of Spatial Priors for Efficient Search in Virtual Reality. *Brain Sciences*, 11(1):44, Jan. 2021. doi: 10.3390/brainsci11010044

[5] C. R. Bennett, E. S. Bailin, T. K. Gottlieb, C. M. Bauer, P. J. Bex, and L. B. Merabet. Virtual Reality Based Assessment of Static Object Visual Search in Ocular Compared to Cerebral Visual Impairment. In M. Antona and C. Stephanidis, eds., *Universal Access in Human-Computer Interaction. Virtual, Augmented, and Intelligent Environments*, pp. 28–38. Springer International Publishing, Cham, 2018.

[6] J. Burack, T. Dawkins, J. Stewart, H. Flores, G. Iarocci, and N. Russo. "the mysterious myth of attention deficit..." revisited: A discussion of how the developmental approach is transforming the understanding of intellectual disability. *International Review of Research in Developmental Disabilities*, 42(C):147–177, Jan. 2012. doi: 10.1016/B978-0-12-394284-5.00006-1

[7] H.-C. Burmeister, R. Grundmann, and B. Schulte. Situational awareness in ar/vr during remote maneuvering with mass: The tug case. In *Global Oceans 2020: Singapore – U.S. Gulf Coast*, pp. 1–6, 2020. doi: 10.1109/IEEECONF38699.2020.9389455

[8] M. Cordeil, T. Dwyer, and C. Hurter. Immersive solutions for future air traffic control and management. In *Proceedings of the 2016 ACM Companion on Interactive Surfaces and Spaces*, ISS '16 Companion, p. 25–31. Association for Computing Machinery, New York, NY, USA, 2016. doi: 10.1145/3009939.3009944

[9] E. J. David, J. Beitner, and M. L.-H. Võ. The importance of peripheral vision when searching 3d real-world scenes: A gaze-contingent study in virtual reality. *Journal of Vision*, 21(7), Jul 2021. doi: 10.1167/jov.21.7.3

[10] L. Dellazizzo, S. Potvin, M. Luigi, A. Dumais, et al. Evidence on virtual reality–based therapies for psychiatric disorders: meta-review of meta-analyses. *Journal of medical Internet research*, 22(8):e20889, 2020.

[11] D. Draschkow and M. L.-H. Võ. Scene grammar shapes the way we interact with objects, strengthens memories, and speeds search. *Scientific Reports*, 7(1), Nov 2017. doi: 10.1038/s41598-017-16739-x

[12] M. P. Eckstein. Visual search: A retrospective. *Journal of Vision*, 11(5):14–14, 12 2011. doi: 10.1167/11.5.14

[13] J. M. Ernst and L. Ebrecht. Virtual cockpit instruments on head-worn displays for helicopter offshore operations in confined areas. In *2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC)*, pp. 1–10, 2020. doi: 10.1109/DASC50938.2020.9256681

[14] I. T. Feldstein, F. M. Kölsch, and R. Konrad. Egocentric distance perception: A comparative study investigating differences between real and virtual environments. *Perception*, 49(9):940–967, Sep 2020. doi: 10.1177/0301006620951997

[15] J. C. M. Figueroa, R. A. B. Arellano, and J. M. E. Calinisan. A Comparative Study of Virtual Reality and 2D Display Methods in Visual Search in Real Scenes. In D. N. Cassenti, ed., *Advances in Human Factors in Simulation and Modeling*, pp. 366–377. Springer International Publishing, Cham, 2018.

[16] H. Freude, C. Reßing, M. Müller, B. Niehaves, and M. Knop. Agency and body ownership in immersive virtual reality environments: A laboratory study. In *Proceedings of the 53rd Hawaii International Conference on System Sciences*, 2020.

[17] M. Haahr. True random number service.

[18] J. Hadnett-Hunter, E. O'Neill, and M. J. Proulx. Contributed session ii: Visual search in virtual reality (vsvr): A visual search toolbox for virtual reality. *Journal of Vision*, 22(3):19, Feb 2022. doi: 10.1167/jov.22.3.19

[19] D. Harris, M. Wilson, and S. Vine. Development and validation of a simulation workload measure: the simulation task load index (SIM-TLX). *Virtual Reality*, 24(4):557–566, Dec. 2019. doi: 10.1007/s10055-019-00422-9

[20] C. Hirt, M. Spahni, Y. Kompis, D. Jetter, and A. Kunz. Virtual reality training platform for a computer numerically controlled grinding machine tool. *International Journal of Mechatronics and Manufacturing Systems*, 14(1):1–17, 2020. doi: 10.1504/IJMMS.2021.115460

[21] JASP Team. JASP (Version 0.16.2)[Computer software], 2022.

[22] S. Kuliga, T. Thrash, R. Dalton, and C. Hölscher. Virtual reality as an empirical research tool — exploring user experience in a real building and a corresponding virtual model. *Computers, Environment and Urban Systems*, 54:363–375, 2015. doi: 10.1016/j.compenvurbsys.2015.09.006

[23] M. Le Chénéchal, T. Duval, V. Gouranton, J. Royan, and B. Arnaldi. Help! i need a remote guide in my mixed reality collaborative environment. *Frontiers in Robotics and AI*, 6, 2019. doi: 10.3389/frobt.2019.00106

[24] C.-L. Li, M. P. Aivar, D. M. Kit, M. H. Tong, and M. M. Hayhoe. Memory and visual search in naturalistic 2d and 3d environments. *Journal of Vision*, 16(8), Jun 2016. doi: 10.1167/16.8.9

[25] S. C. Mallam, S. Nazir, and S. K. Renganayagalu. Rethinking maritime education, training, and operations in the digital era: Applications for emerging immersive technologies. *Journal of Marine Science and Engineering*, 7(12), 2019. doi: 10.3390/jmse7120428

[26] L. Morís Fernández and M. A. Vadillo. Flexibility in reaction time analysis: many roads to a false positive? *Royal Society Open Science*, 7(2):190831, 2020. doi: 10.1098/rsos.190831

[27] B. Olk, A. Dinu, D. J. Zielinski, and R. Kopper. Measuring visual search and distraction in immersive virtual reality. *Royal Society Open Science*, 5(5):172331, 2018. doi: 10.1098/rsos.172331

[28] E. Peillard, T. Thebaud, J.-M. Normand, F. Argelaguet, G. Moreau, and A. Lécuyer. Virtual objects look farther on the sides: The anisotropy of distance perception in virtual reality. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 227–236, 2019. doi: 10.1109/VR.2019.8797826

[29] J. Poppenk, S. Köhler, and M. Moscovitch. Revisiting the novelty effect: when familiarity, not novelty, enhances memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 36(5):1321, 2010.

[30] M. Rubo and M. Gamer. Virtual reality as a proxy for real-life social attention? In *Proceedings of the 2018 ACM Symposium on Eye Tracking Research & Applications*, ETRA '18. Association for Computing Machinery, New York, NY, USA, 2018. doi: 10.1145/3204493.3207411

[31] P.-L. Sanchez-Gonzalez, D. Díaz-Gutiérrez, T. J. Leo, and L. R. Núñez-Rivas. Toward digitalization of maritime transport? *Sensors*, 19(4), 2019. doi: 10.3390/s19040926

[32] H. Sun, R. T. Wright, and J. B. Thatcher. Revisiting the impact of system use on task performance: An exploitative-explorative system use framework. *Journal of the Association for Information Systems*, p. 398–433, Apr 2019. doi: 10.17705/1jais.00539

[33] G. R. Van den Bos and A. P. Association. Ceiling effect.

[34] J. van Doorn, D. van den Bergh, U. Böhm, F. Dablander, K. Derks, T. Draws, A. Etz, N. J. Evans, Q. F. Gronau, J. M. Haaf, and et al. The jasp guidelines for conducting and reporting a bayesian analysis. *Psychonomic Bulletin & Review*, 28(3):813–826, Oct 2020. doi: 10.3758/s13423-020-01798-5

[35] C. J. Wilson and A. Soranzo. The use of virtual reality in psychology: A case study in visual perception. *Computational and Mathematical Methods in Medicine*, 2015:1–7, Aug 2015. doi: 10.1155/2015/151702

[36] J. M. Wolfe. Visual search: How do we find what we are looking for. *Annual review of vision science*, 6(1):539–562, 2020.

[37] P. Zuesongdham. Port of hamburg – virtual reality for model-based port infrastructure management, 2017.