

Response activation and inhibition after exposure to virtual reality

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ARTICLE INFO

Keywords:

Virtual reality
Head mounted display
Exposure impact
Reaction time
Human factors

ABSTRACT

The widespread availability of affordable head-mounted displays and easy access to virtual reality (VR) applications and games has significantly increased the use of such technology by the general public. Thus there is increasing interest in determining any risks of using such technology and any aftereffect from exposure. Head-mounted display manufacturers provide general usage guidance but this is ad hoc and there is limited recent evidence comparing early virtual environment studies with experiences from modern head-mounted displays. The primary objective of this study was to explore response activation and inhibition after participants experienced a typical virtual environment in a head-mounted display. Reaction times were collected with a robust cued go/nogo test as pre- and post-tests. Participants ($n = 22$, female = 11) played Minecraft VR for 15 minutes using an Oculus Rift headset. In contrast to other studies, the results showed no significant impact on reaction times across response activation or inhibition. However, evidence of participant fatigue in the reaction time tests was found. This work confirms safe use of virtual reality experiences in modern head-mounted displays for short duration exposures and identifies issues with reaction time testing that are in need of further investigation.

1. Introduction

There is increasing use of virtual reality technology and the immersive experiences that such technology can provide. Much of this has been driven by the advent of affordable, commercially available virtual reality (VR) head-mounted displays (HMDs) [1]. HMDs encapsulate the visual senses and provide the user with altered, i.e. virtual, experiences. These experiences can be very realistic and many users experience states of presence and immersion [2]. However, a significant portion of the population suffer negative effects from VR technology use, commonly referred to as cybersickness [3]. This can happen in situ and linger post usage. Cybersickness is associated with feelings of illness, discomfort, dizziness and unease [4]. With the widespread availability of VR technology there is a need to quantify any negative impacts and consider health and safety implications [5,6], even for short exposures. Although there is considerable research on cybersickness, there has been less attention paid to the impact on behavioural control, inhibitory effects [7] and reaction time, or “speed of action” [8]. Our concern is the impact on post VR exposure activities that rely on such activation mechanisms for information processing, for example driving vehicles or cycling.

Inhibitory effects have been researched over numerous substance exposures, for example alcohol [7], cocaine [9] and energy drinks with

and without alcohol [10]. The current work explores HMD usage for immersive virtual environments as the exposure condition. Our research follows Fillmore’s protocol [7] with two primary measures of interest being participant’s failures to inhibit responses (failures of response inhibition) and their speed of responding (response activation) after experiencing a short exposure (15 min) to an immersive virtual environment. The aim is not to define new HMD guidelines but to provide an evidence-based approach to measuring the impact of short duration HMD usage. Contributions of this work include (i) measuring HMD impact in a realistic real-world use of VR technology, in this case use of commercial off-the-shelf (COTS) hardware and software, and duration of use within VR manufacturers’ guidelines, and (ii) use of a robust reaction time test and protocol [7] to determine the impact of VR technology on activation mechanisms for information processing.

2. Background

2.1. Guidance on the use of virtual reality technology

Currently there are no definitive recommendations for duration use of VR technologies and the makers of HMD technology note a variety of advice. Often recommendations are that users should limit their time in

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<https://doi.org/10.1016/j.array.2019.100010>

Received 24 June 2019; Received in revised form 19 September 2019; Accepted 10 October 2019

Available online 16 October 2019

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HMDs and take frequent breaks. However, what constitutes a good “limit” is unclear as the impact of VR technology can depend on the technology used, the nature of the environment being experienced [11] and the physical, cognitive and emotional state of the user [4]. An ad hoc time guide of 15 minutes for initial exposure to new VR environments is typically used. Example guidance with common HMD technology include:

- Oculus Rift: “Ease into the use of the headset to allow your body to adjust; use for only a few minutes at a time at first, and only increase the amount of time using the headset gradually as you grow accustomed to virtual reality.” “Take at least a 10–15 min break every 30 min, even if you don’t think you need it. Each person is different, so take more frequent and longer breaks if you feel discomfort. You should decide what works best for you.” [12].
- HTC VIVE: “Prolonged, uninterrupted use of the product should be avoided. It may negatively impact hand-eye coordination, balance, and/or cause other negative effects. While using the product frequently and for prolonged periods of time, you may experience tiredness or soreness in your muscles, joints, or other body parts. Take regular breaks from using the product. The length and frequency of necessary breaks may vary from person to person.” [13].
- Samsung Gear VR: “Ease into the use of the Gear VR to allow your body to adjust; use for only a few minutes at a time at first, and only increase the amount of time using the Gear VR gradually as you grow accustomed to virtual reality.” “Take at least a 10–15 min break every 30 min, even if you don’t think you need it. Each person is different, so take more frequent and longer breaks if you feel discomfort. You should decide what works best” [14].
- Google Daydream: “Take the time to get adjusted to the virtual reality experience before using Daydream View extensively. Begin by using Daydream View for only a few minutes at a time. Use that time to get adjusted to how the device reacts to your movements. As you become accustomed to the virtual reality experience, you can begin increasing the amount of time you use Daydream View. Take frequent breaks while using Daydream View. If you experience nausea, discomfort, eye strain, or disorientation, immediately discontinue using Daydream View. Each person reacts differently to virtual reality so you should base the frequency and length of breaks on what is right for you.” [15].
- Sony PlayStationVR: “Avoid prolonged use of PS VR. Take frequent breaks.” “Avoid prolonged use of PS VR. Take a 15-min break during each hour of play.” [16].

2.2. Virtual reality exposure impact

The negative impact of VR use has received the most attention in areas which traditionally had high use of the technology, for example virtual environment flight simulators and early VR entertainment centres. In the former, many air force bases have mandatory grounding policies for pilots after virtual environment simulation use from 12 to 24 hours. In the later, VR entertainment centres often require users not to drive for at least 30–45 minutes after exposure [17]. However, the difference between these two environments is the length of exposure time with entertainment users only spending minutes in the VR experience compared to potentially hours for pilots. However, the recent widespread availability of affordable HMD technology has increased public use and exposure to VR experiences.

The negative impact of engagement with virtual reality technology and virtual environments is typically considered in the context of cybersickness, which include symptoms of nausea, eye strain, pale skin, cold sweats, vomiting, disorientation, headache, increased salivation and fatigue [3,11,17].

Cybersickness as a result of HMD use has been an ongoing research topic (recent reviews on cybersickness include Davis et al. [11] and Rebenitsch and Owen [3]). Early work in this area also noted aftereffects

[18–20]. Stanney et al. [20] explored HMD-based VR exposure durations of 15, 30, 45 and 60 minutes and found that if a 95% HMD-based solution was required, virtual environment duration would need to be limited to less than 15 minutes. So and Lo [18] found that “In the absence of scene oscillation, viewing a stationary virtual environment for up to 15 minutes is not likely to cause a significant increase in the nausea level.” Although using significantly different technology, Virtual Research V6 with Virtual iO! Tracker [20] and VR4 LCD HMD with Polhemus FastTrack head tracking [18], these thresholds are similar to those promoted by current VR technology manufacturers.

Most cybersickness research measures the effect by use of questionnaires, e.g. the simulator sickness questionnaire (SSQ) [21], postural instability [22], or more recently biometric and physiological states [23, 24]. Recent work has also explored impacts on cognitive performance [4, 24,25].

Nalivaiko et al. [24] and Nesbitt et al. [25] found a significant relation between reaction time and cybersickness. They found prolongation of simple reaction time of 20–50 ms after up to 14 minutes in a virtual reality roller-coaster (the 14 minutes was an upper limit on exposure as subjects could terminate the experience early due to nausea sensations). However, both these studies used intentionally provocative VR environments, i.e. roller-coaster simulations, to elicit cybersickness symptoms; used environments that had limited interaction, e.g. the roller-coaster experience was “on rails” with only head tracking; used a relatively old HMD, in this case an Oculus Rift Development Kit 1 (DK1); and applied a simple 40 trial/2 minute reaction time test, i.e. the Deary-Liewald reaction time task [26].

Mittelstaedt, Wacker and Stelling [1] also found simple reaction times and choice reaction times deteriorated after VR exposure. They used the most recent Oculus Rift Commercial Version 1 (CV1) HMD and interaction was closer to realistic use with participants using either a physical bike ergometer (bike/HMD) or an Xbox One Controller (gamepad/HMD) for HMD conditions. The Deary-Liewald reaction time task [26] was used to collect reaction time data. Participants completed three 90 second biking tasks followed by a simulator sickness questionnaire (SSQ) symptom rating task. The participants spent a total of “about 10 minute in VR” [1].

In the work reported here, we have explored a more real-world, or ecological valid [27], use of VR HMD through the use of COTS hardware and software. This is representative of the more widespread use of VR HMD technology as might be found at a trade show, gaming convention, shop demonstration or causal home use. Our interest is in short duration (15 minutes) HMD use and exploring any inhibition impact or delayed response activation in this context. Thus the aim is to pair a real-world VR HMD interactive experience, across travel, selection and manipulation interactions, with a robust reaction time test.

3. Method

3.1. Participants

Participants were recruited until 22 volunteers (11 female) completed the HMD task. Three additional male volunteers could not complete 15 minutes in the HMD and were excluded from the study (see the Results section). The 22 volunteers that completed the HMD task had a mean age of 24.59 years (SD = 5.05). All participants had normal or corrected to normal vision with contact lenses. Participants with glasses were excluded as some glasses frames do not fit under the HMD. The study was approved by the University of Newcastle Human Research Ethics Committee (HREC #H-2017-0170).

3.2. Apparatus

3.2.1. Hardware

The virtual environment was presented on an Oculus Rift CV1 HMD. The CV1 has two separately rendered displays with a screen resolution of

1080 × 1200 pixels for each eye and a refresh rate of 90 Hz. It allows stereoscopic vision with a 110° horizontal field of view. Head tracking is integrated into CV1 use as the device includes an accelerometer, a gyroscope, and a magnetometer, and is tracked with a constellation tracking camera.

The Oculus Rift and all software in the experiment was run on an Alienware 15 R3 laptop (Intel Core i7-6700HQ 2.60GHz, 32 GB RAM, 64-bit Windows10, NVIDIA GeForce GTX 1070 graphics card). The laptop's Wi-Fi was disabled for the duration of all the experiments so that there were no software updates (for example for Windows10 or Oculus products) across the duration of all the experiments.

3.3. Virtual reality task

Minecraft VR version 1.1.5 (Mojang, www.minecraft.net) was used as the base environment for the VR task. The aim was to provide a virtual environment that (i) had a low entry level for the participants, so they could spend more time doing the task rather than learning the environment; (ii) was an environment with active interaction [28], rather than passive, e.g. travel "on rails" or just 360° viewing, but (iii) was not overly provocative to cybersickness effects, i.e. not a VR roller-coaster [25].

Minecraft is an open-world 3D video game that can be played in first-person perspective where players can travel over a 3D cartoon like landscape and utilise tools to both create and destroy environmental components and thus modify the virtual environment. Interaction in the experiments described here was via a wired Xbox controller (gamepad). Minecraft was run in single player Creative mode (i.e. no mobs/monsters or falling damage), on easy difficulty and with "always day" mode. The other primary Minecraft mode is Survival where there is a day/night cycle and at night enemy computer-controlled mobs, or monsters, spawn and can attack players.

A template Minecraft world was cloned for each participant so they all started in the same environment and consisted of an island environment and an example house (see Fig. 1). The VR task was for participants to build their own version of a house. They were given a time limit of 15 minutes. The house construction process required participants to utilise travel, selection and manipulation interaction techniques while using the HMD and gamepad.

Participants had a pre-populated building material interface with all the necessary building components in the standard Minecraft tool menu (see bottom of Fig. 1) and were encouraged to verbally discuss their design and progress while in the virtual environment. The conversation

during the VR session allowed the evaluator to subtly monitor the comfort level of participants and consider terminating the session if signs of distress, e.g. cybersickness, occurred [6].

3.4. Reaction time measurement

A cued go/no-go task was used to measure failures of response inhibition and response activation as pre and post VR exposure tests. Inquisit 5 Lab (Millisecond Software, www.millisecond.com) was run on the Alienware laptop with a script implementing the cued go/no-go task described in Fillmore et al. [9]. Participants were asked to press the laptop spacebar when they saw a green rectangle (=go) but refrain from pressing the spacebar when they saw a blue rectangle (=nogo). The blue and green rectangles were vertical or horizontal. The vertical rectangle had a high probability of being green (a go trial) and the horizontal rectangle had a high probability of being blue (a nogo trial). Participants got information about the orientation of the rectangle (=cue) shortly before the colour of the rectangle was revealed. The default Inquisit 5 Lab script was used for pre and post reaction time measures and provides a factorial design with:

- 5 x Stimulus-Onset Asynchrony (SOA) (100 ms, 200 ms, 300 ms, 400 ms, 500 ms)
- 2 x Cue (1 = vertical, 2 = horizontal)
- 2 x Target (Go, No-Go)

The vertical cue go/nogo ratio is 4:1 (80% go trials, 20% no-go trials) with a higher probability of go trials after a vertical cue and the horizontal cue go/no-go ratio is 1:4 (20% go trials, 80% no-go trials) with a higher probability of nogo trials after a horizontal cue. The minimum number of trials required to fulfil the above conditions is 50 and the default script runs 250 trials, i.e. each factor combination is repeated 5 times.

- 100 vertical cue-go targets (20 for each SOA); 25 vertical cue-nogo targets (5 for each SOA)
- 100 horizontal cue-nogo targets (20 for each SOA); 25 horizontal cue-go targets (5 for each SOA)

For each trial, Inquisit 5 Lab logs raw data across date, time, subject, blocknum, blockcode, trialcount, trialcode, cuetype, targettype, targetcondition, SOA, cuepic, targetpic, response, latency, correct, and error



Fig. 1. Target house for VR task in Minecraft VR.

data. Each pre- and post-test of 250 cued go/no-go trials took approximately 12 minutes.

3.5. Procedure

Each session took approximately 90 minutes and were held individually. Firstly, the research team collected signed consent forms. Secondly, the participant was given a short tutorial on the use of the Xbox gamepad which was to be used to interact with the Minecraft environment. Participants used the gamepad controller to briefly move around the laptop (non-VR) version of Minecraft. All participants showed aptitude in navigating and using the gamepad in less than 5 minutes.

To confirm that participants could easily determine the stimulus colours of the cued go/no-go task, they performed a colour vision test that required them to pick out the stimulus colours (green and blue) from an array of 12 colours. All participants successfully identified green and blue coloured rectangles.

Participants were then seated at the laptop and performed a practice test on the cued go/no-go task of 15 sample trials. Participants were instructed to press the space key as fast as possible when the green target appeared and not to respond to the blue target. Participants were given no information on the relation between the rectangle orientation and the target colours. After the 15 trials, participants verbally confirmed that they understood the task and then completed a full 250 trial test.

The participants were then shown a picture of the target house to be built (Fig. 1). Minecraft VR was then run on the Alienware laptop and the participants fitted with the Oculus Rift HMD and the first-person mode of Minecraft VR activated (see Fig. 2). A 15 minute countdown timer was set and participants then had 15 minutes to build in Minecraft VR. Participants sat in a swivel chair and the evaluator ensured free movement by managing the Oculus Rift and gamepad controller cables during the session.

After playing Minecraft VR, the participants removed the HMD and repeated the full 250 trial cued go/no-go task with the Inquisit 5 Lab script. Finally, they completed a demographic survey and a questionnaire to determine their susceptibility to motion sickness, i.e. use of the revised motion sickness susceptibility questionnaire (MSSQ) [29]. At the end of the session, each participant waited while their pre and post VR experience reaction times were compared. If the raw reaction times between tests were significantly different, i.e. a percentage change of greater than 5% from baseline reaction time [7], the participants were advised not to

drive or cycle for the next 30 min. Participants were given A\$60 in supermarket vouchers to compensate them for their time.

3.6. Analysis

Fillmore's [7] protocol had two primary measures of interest being participant's failures to inhibit responses to no-go targets (failures of response inhibition) and their speed of responding to go targets (response activation).

Failure of response inhibition: This was measured as the proportion of no-go targets in which a participant failed to inhibit a response during a reaction time trial, i.e. the participant reacted to a no-go target as if it was a go-target. Also no-go cues should support response inhibition of no-go targets. The p-inhibition failure scores were calculated for each cue condition (go and no-go) on each test.

Response activation: This was measured by the reaction time to go targets. The reaction time was collected as latency (ms) from the Inquisit 5 Lab raw data logs of each trial.

Response times of < 100 ms and > 900 ms were excluded from the raw data as the former indicates pre-emptive activation and the latter indicates loss of concentration/boredom and neither are indicative of accurate reaction times. Only 5 trials < 100 (0.09%) and 9 trials > 900 (0.16%) were removed across the 5500 go trials analysed. Data was cleaned and graphs produced in Excel (Office Professional Plus 2016) and all statistical analysis performed in SPSS (version 24.0.0.1). As reaction times are not normally distributed, non-parametric Wilcoxon signed-ranks test was used to analyse the pre- and post-test data pairs.

In comparison to previous work with reaction time measures [4,24,25], the cued go/no-go task used here is significantly longer in duration and trials, i.e. the 40 trial/2 min Deary-Liewald reaction time task versus 250 trial/12 min cued go/no-go task. Also as previous work [19] has shown duration effects of VR exposure, in addition to full duration results, we have split the pre-test and post-test results into four time periods, namely pre-first (trials 1–126), pre-second (trials 127–250), post-first (trials 1–126) and post-second (trials 127–250).

3.7. Hypotheses

Our hypotheses consider response activation and inhibition scores across both the general pre- and post-tests and the two time periods, first 126 trials and second 126 trials, within each test.



Fig. 2. Minecraft VR setup with Oculus Rift CV1 and Xbox wired controller [Photographer: George Hyde. IG: dualityimages.].

- H1: Pre-Post scores will show response activation impact. We expect decreased response activation after HMD exposure.
- H2: Pre-Post scores will show failure of response inhibition impact. We expect increased failure of response inhibition after HMD exposure.
- Pre-first and pre-second trials will show no difference. We expect response activation (H3a) and response inhibition (H3b) to be consistent across the pre-test trials.
- Post-first and post-second trials will show a difference. We expect the response activation (H4a) to increase, i.e. improve, and response inhibition to decrease (H4b) across the post-test trials. The HMD exposure should decrease over time out of the VR experience and return to normal.

4. Results

Twenty-two participants (female = 11) completed the VR task and completed the house building task in Minecraft VR with 15 minutes in the Oculus Rift CV1 HMD. An additional three participants (male = 3) did not complete the VR task and exited the virtual environment at 4, 7.3 and 11.5 minutes into the experience.

4.1. Motion sickness susceptibility questionnaire (MSSQ)

The mean MSSQ score across the participants ($n = 22$) was 21.63 (SD = 17.03). Golding [29] noted a mean MSSQ score of 45.5 (SD = 37.6, $n = 147$) as an adult reference norm. The results reported here may indicate that the participants are less susceptible to motion sickness than a general population. However, this could be due to selection bias as participants self-selected their participation based on the study description that mentioned virtual reality and computer games. Also an exclusion criterion was for conditions that may be aggravated by use of a HMD, including vertigo, claustrophobia or epilepsy. The mean MSSQ scores of the participants ($n = 3$) who did not complete the VR task were calculated at 21.67 (SD = 17.40) and thus not indicative of difference from the other participants.

4.2. Response activation

For the pre-test and post-test analysis ($n = 22$) there was no significant difference between Go cue ($p = 0.36$) or the NoGo cue ($p = 0.57$) in terms of response activation. Also reaction time activation was reduced (i.e. faster reaction times) in the post-tests than in the pre-tests (See Fig. 3 and Table 1). Therefore, H1 is refuted.

In the pre-test ($n = 22$) for the Go cue, the second half trials (Mean =

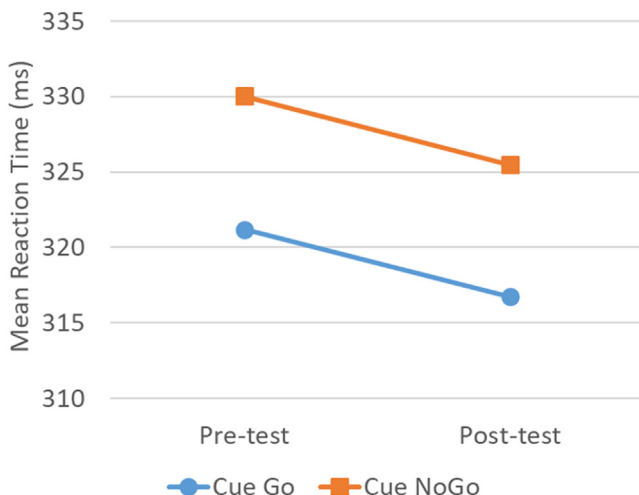


Fig. 3. Response activation for full Pre-test and Post-test results.

Table 1

Pre-test and Post-test data for response activation (RA) and response inhibition (RI).

Condition	Pre-test [Mean (std.)]	Post-test [Mean (std.)]
Go cue (RA)	321.21(38.72)	316.73(34.06)
NoGo cue (RA)	330.02(37.83)	325.46(33.42)
Go cue (RI)	0.0016(0.00236)	0.0016(0.00236)
NoGo cue (RI)	0.0018(0.00268)	0.0020(0.00321)

325.96) were significantly higher (i.e. slower response activation) than in the first half trials (Mean = 316.84), $T = 6$, $p = 0.013$, $r = -0.37$. This was also true for the NoGo cue with the second half trials (Mean = 337.45) significantly higher than in the first half trials (Mean = 323.88), $T = 6$, $p = 0.022$, $r = -0.35$ (see Fig. 4). Therefore, H3a is refuted.

In the post-test ($n = 22$) only the NoGo cue was significantly different between the second half trials (Mean = 331.99) and the first half trials (Mean = 319.83), $T = 5$, $p = 0.24$, $r = -0.34$ (see Fig. 5). Therefore H4a is refuted for NoGo cues.

4.3. Response inhibition

For the pre-test and post-test analysis ($n = 22$) there was no significant difference between Go cue ($p = 1$) or the NoGo cue ($p = 0.80$) in terms of response inhibition (also see Table 1). Therefore, H2 is refuted.

There was also no significant difference across the first trials, [Go cue ($p = 0.71$), NoGo cue ($p = 1$)] or second trials [Go cue ($p = 0.26$), NoGo cue ($p = 0.76$)] in terms of response inhibition. Therefore, H3b is confirmed and H4b is refuted.

5. Discussion

The full group results (pre-test to post-test) showed no significant differences in response activation or response inhibition of the participants after brief exposure to the Minecraft VR environment using an Oculus Rift CV1 HMD. From one perspective this validates the health and safety advice from VR hardware companies that there should be no ill effects after short duration use of VR technology (see Section 2.1). Our results are evidence that this is valid for response activation and inhibition in a participant population that is not generally susceptible to motion sickness. However, this conclusion does need to be contextualised with the small participant group ($n = 22$), although the participant group was balanced for gender (female = 11) which contributes to it being representative of general users. A statistical power analysis was conducted

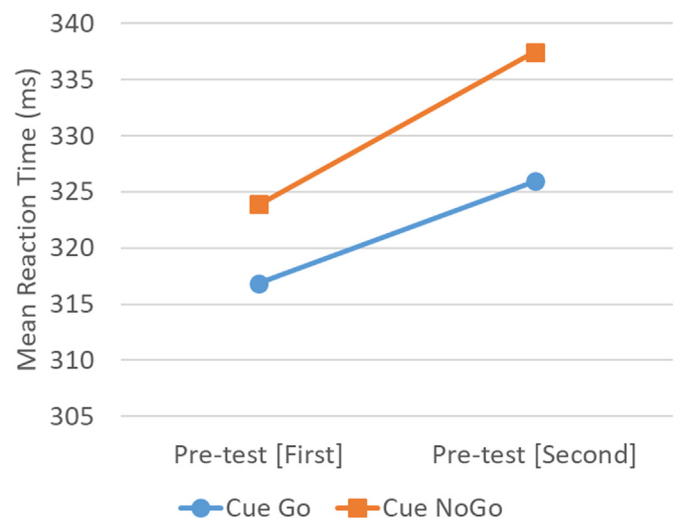


Fig. 4. Response activation for Pre-test across trials 1-125 (first) and 126-250 (second).

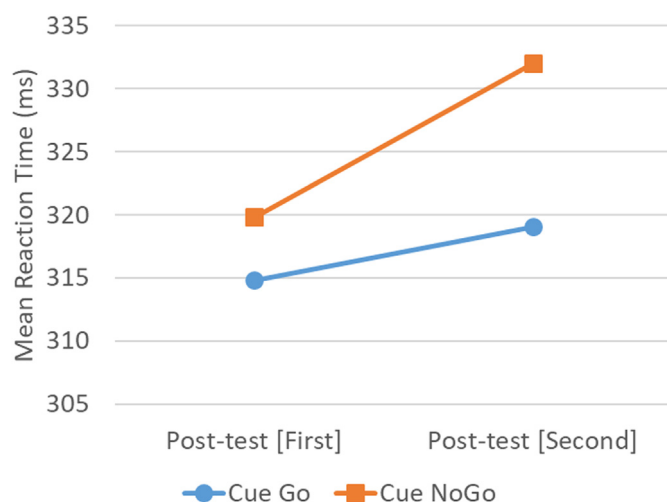


Fig. 5. Response activation for Post-test across trials 1–125 (first) and 126–250 (second).

using G*Power (v3.1.9.4) [30] to define the sample size requirements for the Wilcoxon signed-ranks test as used in the analysis reported here. With a standard significance level (α error probability, $p \leq 0.05$) and level of power ($1 - \beta = 0.8$) [31], to demonstrate a large effect ($r \leq 0.50$) the suggested sample size ranges from $n = 23$ (Laplace parent distribution) to $n = 35$ (normal parent distribution). The results presented here fall just outside this range but only by one participant pair (i.e. one female/male pair). However, follow-on work should explore female/male balanced sample sizes within this range.

Also it should be noted that 3 participants (all male) did not complete the HMD component of the study. Although we were not explicitly measuring cybersickness, all three participants verbally indicated increased head temperature, which is indicative of cybersickness [24], and were unwilling to continue with the Minecraft VR task. Their removal was part of the study protocol but this did bias the reaction time results to only participants that could complete the 15 minute VR task. However, self-exclusion like this is what typically happens with HMD usage. Users who encounter obvious negative effects stop using, and typically avoid future use of, the technology. It is interesting to note that these participants did self-select to participate and did not have indicative MSSQ scores. Nevertheless, our interest here was in exploring potentially hidden negative HMD impacts, i.e. on activation mechanisms for information processing, that might come from brief VR use. Measuring the reaction time impact on participants that had experienced explicit cybersickness symptoms was out of the scope of the current research but would be a useful avenue for further work.

In contrast to previous research [4,24,25], the results here showed an improvement in reaction times (although not statistically significant, see Section 4). There were a number of differences in our study where the aim was to provide a more ecologically valid VR usage experience. Other studies with reaction time impact had more provocative cybersickness invoking environments [24,25], more limited interaction and used a much shorter duration reaction time task [4,24,25]. However, our results did show that the longer cued go/no-go test had evidence of participant fatigue during the test. This was evident in both the pre- and post-tests. As this was present in the pre-test, this indicates that the longer duration of the reaction test could be the cause.

Increases in test length times can result in cognitive fatigue [32], where the length of the test is taxing the participants' mental functions to the point that is causing a decrease in their performance. This can be mental fatigue, boredom, and reduced attention over time [33,34]. Cognitive fatigue is a topic of continued importance in applied psychology [35] and specifically how individual differences in personality or

other traits can impact cognitively fatiguing conditions. Cognitive fatigue is commonly measured through changes in test performance and subjective reports via questionnaires [35] or course/test evaluations [32]. Duration of testing and any physical conditions of the test environment are also relevant, for example movement time [33]. In our reaction time trials the participants were seated for the test duration and any physical duress was limited to concentrating on the reaction time trials. Also the go/no-go trials are very repetitive and it is possible that boredom and/or reduced attention is what we have detected as fatigue. Adding a post-session question to capture subjective experiences of the reaction time task, in the context of reported fatigue, would be useful for future work in this area. However, to mitigate potential cognitive fatigue, repeated short tests with rest times between may be better than single short (as in previous work [4,24,25]) or single long (as reported here) reaction time tests.

Given the use of reaction time measures in VR experience and cybersickness research and the results from the work described here, there may be considerable benefit in factoring in cognitive fatigue and the measures that contribute to this, i.e. personality or other traits [35], in order to increase the relevance of the reaction time data for aftereffect analysis. This is a focus for future work.

6. Conclusion

The widespread availability of COTS HMD and easy access to VR applications and games has significantly increased the use of such technology by the general public. With more users, risk exposure from this technology is increasing. VR technology manufacturers provide guidelines for usage but this guidance can be overly general and there is a limited evidence base for these recommendations.

Explicit negative effects of HMD use, such as cybersickness, often lead to self-selection as users who experience negative effect stop using or avoid the technology. However, activation mechanisms for information processing, such as response activation and inhibition, are more difficult to determine ad hoc and can have significant impact on response critical activities, such as driving vehicles or cycling.

The research reported here has explored response activation and inhibition in pre- and post-tests after participants experienced a typically VR experience, in this case Minecraft VR using an Oculus Rift CV1 HMD, for 15 minutes. Participants ($n = 22$) experienced no significant reaction-based negative effects. This provides evidence in support of current VR technology use approaches, at least for response activation and inhibition impact. Participants did however demonstrate trial fatigue during the reaction test process and this should be factored into future studies involving reaction time measures.

Declaration of Competing Interest

The authors declare no conflict of interest.

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