Safety and Health at Work 14 (2023) 303–308

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.net

Original article

Physiological and Subjective Measures of Anxiety with Repeated Exposure to Virtual Construction Sites at Different Heights

Sachini N.K. Kodithuwakku Arachchige [1,*], Harish Chander [2,3], Alana J. Turner [4], Alireza Shojaei [5], Adam C. Knight [2], Aaron Griffith [2], Reuben F. Burch [3,6], Chih-Chia Chen [2]

[1] Department of Exercise and Nutrition Sciences, Weber State University, Ogden, UT, USA
[2] Department of Kinesiology, Mississippi State University, MS, USA
[3] Human Factors & Athlete Engineering, Center for Advanced Vehicular Systems, Mississippi State University, MS, USA
[4] Department of Kinesiology, Coastal Carolina University, Conway, SC, USA
[5] Myers-Lawson School of Construction, Virginia Tech, Blacksburg, VA, USA
[6] Department of Industrial & Systems Engineering, Mississippi State University, MS, USA

A R T I C L E I N F O

Article history:
Received 26 February 2023
Received in revised form
11 July 2023
Accepted 24 July 2023
Available online 28 July 2023

Keywords:
Ergonomic
Falls
Virtual reality (VR)

A B S T R A C T

Background: Occupational workers at altitudes are more prone to falls, leading to catastrophic outcomes. Acrophobia, height-related anxiety, and affected executive functions lead to postural instabilities, causing falls. This study investigated the effects of repeated virtual height exposure and training on cognitive processing and height-related anxiety.
Methods: Twenty-eight healthy volunteers (age 20.48 ± 1.26 years; mass 69.52 ± 13.78 kg) were recruited and tested in seven virtual environments (VE) [ground (G), 2-story altitude (A1), 2-story edge (E1), 4-story altitude (A2), 4-story edge (E2), 6-story altitude (A3), and 6-story edge (E3)] over three days. At each VE, participants identified occupational hazards present in the VE and completed an Attitude Towards Heights Questionnaire (ATHQ) and a modified State-Trait Anxiety Inventory Questionnaire (mSTAIQ). The number of hazards identified and the ATHQ and mSTAIQ scores were analyzed using a 7 (VE; G, A1, A2, A3, E1, E2, E3) x 3 (DAY; DAY 1, DAY 2, DAY 3) factorial repeated measures analysis of variance.
Results: The participants identified the lowest number of hazards at A3 and E3 VEs and on DAY 1 compared to other VEs and DAYs. ATHQ scores were lowest at G, A1, and E1 VEs.
Conclusion: Cognitive processing is negatively affected by virtual altitudes, while it improves with short-term training. The features of virtual reality, such as higher involvement, engagement, and reliability, make it a better training tool to be considered in ergonomic settings. The findings of this study will provide insights into cognitive dual-tasking at altitude and its challenges, which will aid in minimizing occupational falls.

1. Introduction

Occupational worker categories such as roofers, firefighters, construction workers, and tree trimmers constantly work at heights due to the nature of their occupation. When working at heights, these workers must maintain their postural stability, perform motor tasks related to their occupation, and perform simultaneous cognitive tasks (e.g., identify hazards on-site). Thus, working at altitude is highly challenging, and those added secondary or tertiary tasks make it more confronting. As a result, falling from heights is extremely common among such workers. In 2019, ~81% of 880 fatal occupational injuries occurred due to

Sachini N.K. Kodithuwakku Arachchige: https://orcid.org/0000-0002-2947-0714; Harish Chander: https://orcid.org/0000-0001-9427-2936; Alana J. Turner: https://orcid.org/0000-0003-4908-9133; Alireza Shojaei: https://orcid.org/0000-0003-3970-0541; Adam C. Knight: https://orcid.org/0000-0001-6348-0468; Aaron Griffith: https://orcid.org/0000-0002-9597-3045; Reuben F. Burch: https://orcid.org/0000-0003-2944-1945; Chih-Chia Chen: https://orcid.org/0000-0001-6963-3795
* Corresponding author. Dept 2805, 1435 Village Dr, Ogden, UT 84408-5150, USA.
E-mail address: skodi@weber.edu (S.N.K. Kodithuwakku Arachchige).

2093-7911/$ – see front matter
https://doi.org/10.1016/j.shaw.2023.07.005

falling from heights [1]. Postural instability is one of the major causes of falls and is frequently observed in ergonomic settings [2]. In addition, fear of heights (acrophobia) and height-related anxiety have been identified as significant contributing factors to postural instability at altitude [3,4]. Hence, training the working population to counteract this fear and prevent falling from heights is mandatory.

According to the American Psychiatric Association, acrophobia is the extreme fear of heights, which affects more than 5% of the general population [5]. Similar to panic disorders, individuals with acrophobia experience symptoms related to increased sympathetic activity, such as sweating, tachycardia, hyperventilation, and tremors [4,6]. Individuals who experience acrophobia in real environments usually experience a similar feeling upon exposure to virtual heights [6]. Besides the increased sympathetic activity, exposure to virtual heights triggers other emotions, including anxiety and stress [4,7]. The prefrontal cortex of the brain regulates a significant proportion of the major executive functions (e.g., working memory, task switching, and response inhibition). However, the prefrontal cortex gets affected by stress hormones (e.g., cortisol) released during stressful situations, such as exposure to heights. Thus, exposure to heights has the capability of affecting executive functions [8]. In addition, fear and anxiety are shown to affect motor functions such as postural control [4,9,10].

Addressing acrophobia includes gradual, repeated exposure to heights, known as exposure therapy [5]. However, exposing an agitated individual to a physical height could endanger their life. Conveniently, virtual reality (VR) has been introduced to assess, train, and address the fear of heights due to its convenience and the absence of physical danger [11,12]. Hence, VR is recognized as a great alternative to exposing individuals to different environments they otherwise avoid due to fear [4]. Due to these favorable features, VR is used as a training tool to overcome the fear of falling from heights, known as VR exposure therapy (VERT) [13]. Similar to the training to overcome the fear of falling, VR-based training could effectively help overcome height-related anxiety [14]. In addition to the benefits mentioned above, VR seems to be a promising solution to train workers on dual-tasking (DT) at altitudes. However, the appropriate duration of training and retention is still debatable.

Thus far, the studies conducted on the application of VR to address acrophobia, cognitive processing, and training have mainly focused on the elderly and pathological populations. The number of studies conducted on young, healthy adults and the occupational population is minimal. Moreover, the few studies conducted on VR-based altitude training in the occupational population were limited to ground-level training [15]. Due to this dearth of literature, little is known about the application of VR-based training at altitude among the ergonomic population. Therefore, the purpose of this study was to investigate the effects of virtual heights and training on cognitive processing and height-related anxiety among young, healthy adults. It was hypothesized that increasing virtual heights would negatively affect cognitive processing ability and cause height-related anxiety. In addition, it was also hypothesized that cognitive processing would improve over the two days of training and that the improvements would be retained after 48 hours of training.

2. Materials and methods

2.1. Participants

Twenty-eight, recreationally active [a minimum of aerobic exercises 3–4 days/week or 150 min/week and resistance training two days/week for the last three months- The American College of Sports Medicine (ACSM) guidelines [16]] young adults (14 M and 14 F; age 20.48 ± 1.26 years; height 172.67 ± 6.66 cm; mass 69.52 ± 13.78 kg) with no history of visual, vestibular, musculoskeletal, or neurological abnormalities were recruited for the study. Individuals with acrophobia, simulator sickness, and motion sickness were excluded from participating.

2.2. Study design

The study was approved by the university's Institutional Review Board (IRB # 21-416). The testing protocol followed a repeated measures design with a counterbalanced virtual environment (VE) assignment. The VEs were [ground level (G), altitude 1 (A1), edge 1 (E1), altitude 2 (A2), edge 2 (E2), altitude 3 (A3), and edge 3 (E3). A1 and E1 were at the two-story (9.18 m/30.11 feet) level; A2 and E2 were at the four-story (17.08 m/56.04 feet) level; while A3 and E3 were at the six-story (23.69 m/77.72 feet) level. These VEs were 360-degree pictures that were taken at a parking garage under construction. At different virtual altitudes (A1, A2, and A3), the participants were standing near a window at the corresponding altitude, while at different virtual edges (E1, E2, and E3), they were standing on a ledge outside the building. Each participant was exposed to the seven VEs on three days; two consecutive days and a third day, which was 48 hours after the second day. The total VE exposure time for a participant was about 30 minutes per day.

Fig. 1. Oculus go headsets (Facebook Technologies, Qualcomm, and Xiaomi) were used in the study (left). A participant wearing the Oculus headset (right).

2.3. Instrumentation

The VEs used in the study were captured using a 360-degree GoPro fusion camera due to its ability to capture high-quality, high-resolution images [17]. VEs were administered through a first-generation Oculus Go headset (Facebook Technologies, Qualcomm, Xiaomi) (Fig. 1). In order to assess the level of simulator sickness in the participants, at certain points of the study, a Simulator Sickness Questionnaire (SSQ) was administered [18]. The SSQ is a questionnaire with 16 symptoms (general discomfort, fatigue, headache, vertigo, stomach awareness, dizziness with eyes opened and closed, blurred vision, eyestrain, difficulty focusing, increased salivation, fullness of head, sweating, nausea, difficulty concentrating, and burping). The participants indicated how they currently felt about each symptom as none, slight, moderate, and severe (graded as none = 0, slight = 1, moderate = 2, and severe = 3). In the end, the scores of each item were summed, and if the sum was equal to or greater than 5 at any point in the study, the data collection was halted [18]. As a method to assess the anxiety level, a Polar H10 heart rate (HR) monitor (Polar, USA) was attached to the participant's chest [6]. At specific points in the study, an Attitudes Towards Heights Questionnaire (ATHQ) and a modified State-Trait Anxiety Inventory Questionnaire (mSTAIQ) were used to assess acrophobia and anxiety levels, respectively. ATHQ is a short, 6-item questionnaire regarding how the subjects feel about heights. In ATHQ, the feelings are listed as dichotomous pairs (good/bad, brilliant/terrible, pleasant/unpleasant, safe/dangerous, non-threatening/threatening, and not-prejudicial/prejudicial), in which each first adjective is given 0 points and the second adjective is given 10 points [19]. mSTAIQ is also a short, 6-item questionnaire that aids in determining an individual's anxiety level. It includes responses like "I feel calm, I'm tense, I feel upset, I'm relaxed, I'm content, and I'm worried," that needed to be answered on a scale of 0 = not at all, 1 = somewhat, 2 = moderately, and 3 = very much [20]. Additionally, at the end of the study, a presence questionnaire (PQ) was administered to understand the participants' perceptions of the VEs and how closly the VEs resembled real-world scenarios. This questionnaire includes 19 questions on a 7-point scale (0 = not at all, 4 = somewhat, 7 = completely) [21]. The questions in PQ are categorized into four subcategories: involvement, immersion, visual fidelity, and interface quality.

2.4. Experimental procedures

The study was conducted over three days; the first two days were consecutive, and the third day was scheduled after a 48-hour retention period. On day one the participants completed an informed consent document and a Physical Activity Readiness Questionnaire (PRAQ). In addition, they completed an initial SSQ to assess any existing simulator sickness. Since the study involved the identification of occupational hazards and safety signs, the participants were familiarized with the different hazards/signs that could appear in the VEs they observed. Then the participants were advised to wear the Oculus headset and were shown a neutral VE to familiarize them with the headset. Immediately after the familiarization with the Oculus headset, another SSQ was administered to detect whether the participant had developed any simulator sickness.

After the second round of SSQ, the participants wore the Polar HR monitor. Upon wearing it, they were advised to sit quietly for 5 minutes before their resting HR (RHR) was recorded. Then, the participants were advised to stand up on a firm platform and were exposed to the VEs, which always started with the ground level VE as a baseline, followed by the remaining VEs (A1, A2, A3, E1, E2, E3) in a randomized order. At each VE, the participants completed two trials. The first trial was considered single-tasking (ST), where they were asked to look around only by moving their heads while keeping their arms along the body and without moving their body/feet. The second trial was considered dual-tasking (DT), in which the participants looked around the same way while identifying different occupational hazards/signs seen in the VE. A picture without any hazards/signs was provided for the ST trial, and the same VE with hazards/signs was presented for the DT trial. For this, the researchers took two sets of pictures, with and without occupational signs/hazards (Fig. 2). The researchers placed eight occupational hazards/signs at each VE to take pictures for DT trials and

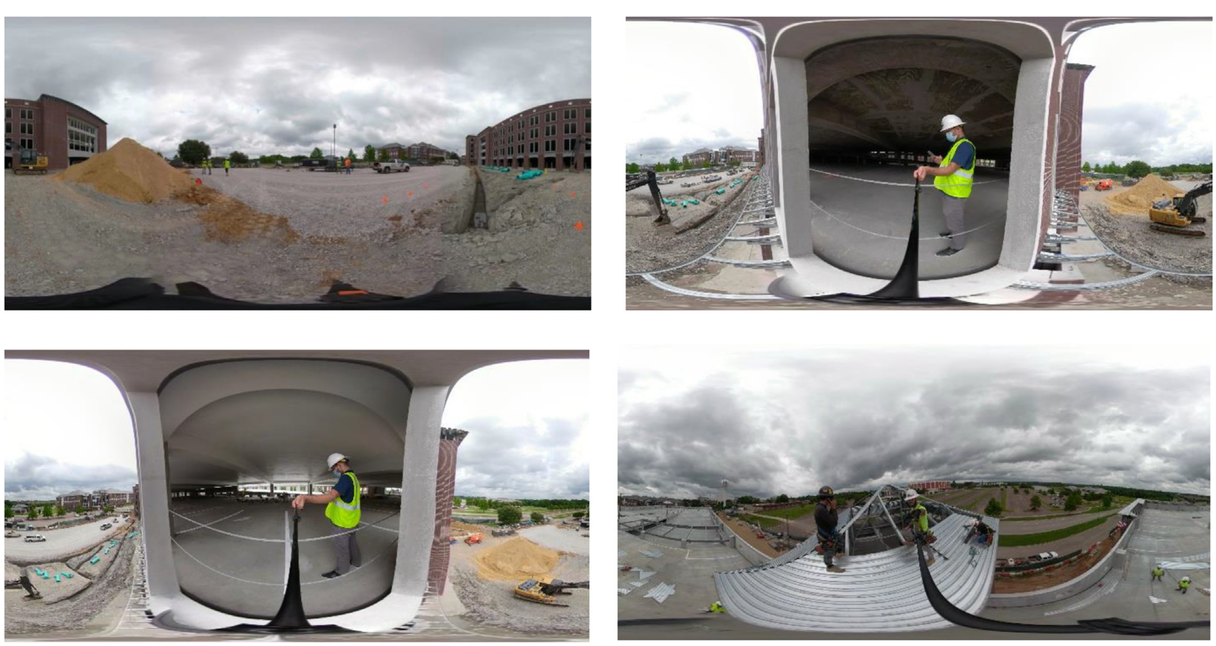

Fig. 2. Different virtual environments were used in the study. Top left: ground level; top right: two-story level; bottom left: four-story level; bottom right: six-story level.

then removed the signs/hazards to take pictures for ST trials. During each DT trial, the number of hazards identified by each participant was recorded. In addition, the participant's heart rate (HR) was recorded during each trial. After completing each VE (after ST and DT trials in the particular VE), the participants completed an ATHQ and a modified STAIQ to assess their acrophobia and anxiety levels. After every third VE, the participants were allowed a 5-minute break in order to prevent the development of simulator sickness as well as to administer an SSQ to assess any simulator sickness developed during testing [22]. Upon completing the final VE, the participants completed a final SSQ, ATHQ, modified STAIQ, and PQ. The participants underwent the same procedure on the second and third days at the same VEs but with different pictures.

2.5. Statistical analysis

For each trial, the number of identified hazards was counted, and the scores for ATHQ and mSTAIQ were totaled. Participants' HR during each trial was divided by the corresponding day's RHR to calculate the percentage increase of RHR during individual trials. The number of hazards identified and the scores for ATHQ and mSTAIQ were separately analyzed using a 7 (VE; G, A1, A2, A3, E1, E2, E3) x 3 (DAY; DAY 1, DAY 2, DAY 3) factorial repeated measures analysis of variance (RM-ANOVA). Participants' percentage increase in RHR was analyzed using a 7 (VE; G, A1, A2, A3, E1, E2, E3) x 3 (DAY; DAY 1, DAY 2, DAY 3) × 2 (TASK; ST, DT) factorial RM-ANOVA. For all analyses, the alpha level was set at apriori 0.05, and all analyses were performed using the SPSS 27 statistical software package (IBM® SPSS® V27.0, Armonk, New York 10504-172). Initially, the results were observed for VE x TASK, VE x DAY, TASK x DAY, and VE x TASK × DAY interactions when appropriate. If a significant interaction existed, the main effects were ignored and simple main effect analyses were conducted. If significant interactions were not evident, significant differences were further analyzed using Bonferroni post hoc comparisons.

3. Results

The factorial repeats measures ANOVA of the number of hazards identified in each VE and DAY revealed a significant main effect in VEs (F (6, 162) = 12.82; $p < 0.001$; $\eta p^2 = 0.32$) and DAY (F (2, 54) = 5.94; p = .049; $\eta p^2 = 0.11$). Post hoc analysis showed

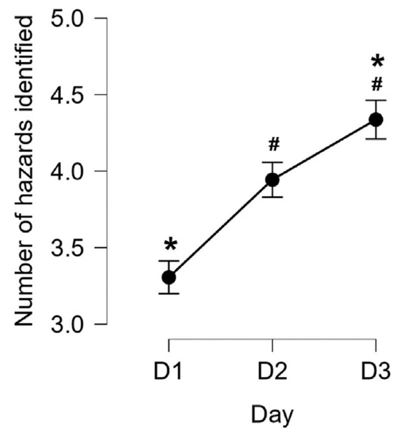

Fig. 4. The number of hazards identified during each day. D1: DAY 1; D2: DAY 2; D3: DAY 3. Bars represent standard errors. # denotes significant differences from D1. * denotes significant differences from D2.

significant differences in hazard identification between A3 and all other VEs, as well as E3 and all other VEs, with a lower number of hazards identified on A3 and E3, respectively (Fig. 3). The post hoc comparisons for DAY revealed significant differences between DAY 1 and DAY 2 ($p < 0.001$), DAY 1 and DAY 3 ($p < 0.001$), and DAY 2 and DAY 3 ($p = 0.002$), with the lowest number of hazards identified during DAY 1, while the highest number of hazards were identified during DAY 3 (Fig. 4).

In the analysis of ATHQ, significant main effect differences were evident among VEs (F (6, 150) = 11.92; $p < 0.001$; $\eta p^2 = 0.11$), with significant differences between G and A2 ($p < 0.001$), G and A3 ($p < 0.001$), G and E2 ($p < 0.001$), and G and E3 ($p < 0.001$) with lower ATHQ scores in G compared to the other conditions; significant differences between A3 and A1 ($p < 0.001$) with lower scores in A1; and significant differences between A3 and E1 ($p < 0.001$), E2 and E1 ($p = 0.04$), and E3 and E1 ($p = 0.031$) with lower scores in E1 (Fig. 5).

The factorial RM-ANOVA of percentage RHR increase revealed significant interactions between VE × DAY (F (12, 324) = 3.97; p = .002; $\eta p^2 = 0.13$) and DAY x TASK (F (2, 54) = 6.60; p = .003; $\eta p^2 = 0.20$). Simple main effects analysis of the VE × DAY interaction revealed significant differences in A2, A3, E1, E2, and E3 during DAY 1 and DAY 2, with the highest values in E2 on DAY 2 and

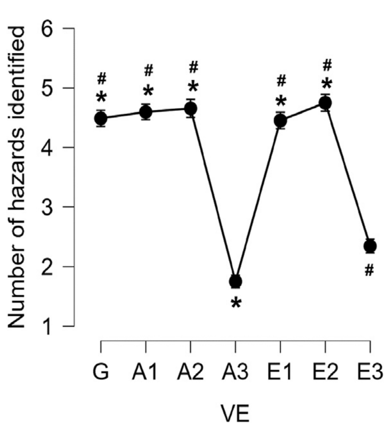

Fig. 3. The number of hazards identified in different virtual environments. G: ground level; A1: 2-story level, A2: 4-story level, A3: 6-story level; E1: edge of the 2-story level; E2: edge of the 4-story level; A3: edge of the 6-story level. Bars represent standard errors. # denotes significant differences from A3. * denotes significant differences from E3.

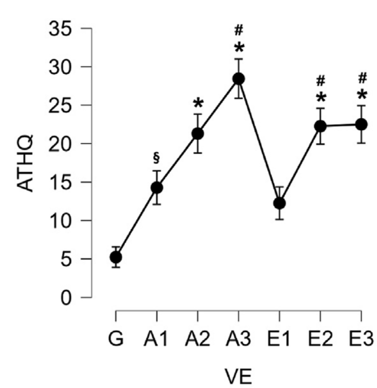

Fig. 5. The Attitude Towards Heights Questionnaire (ATQH) scores differenty in different virtual environments. G: ground level; A1: 2-story level; A2: 4-story level; A3: 6-story level; E1: edge of the 2-story level; E2: edge of the 4-story level; A3: edge of the 6-story level. Bars represent standard errors. * denotes significant differences from G. § denotes significant differences from A3. # denotes significant differences from E1.

Table 1
Mean and standard deviation for the subcategories in the Presence Questionnaire. (Questions 1–19, with questions 14, 17, and 18 concerning reversed items)

Subcategory	Mean ± standard deviation
Involvement	6.22 ± 0.13
Immersion	5.34 ± 0.17
Visual fidelity	5.22 ± 0.19
Interface quality	5.94 ± 0.13

the lowest values in A3 on DAY 1. Simple main effects analysis of the DAY × TASK interaction revealed significant differences in DT and ST during DAY 1 and DAY 2, with high values during DT on DAY 2.

The analysis of mSTAIQ did not yield any significant results. None of the participants exceeded or matched the value of 5 in the SSQ at any point in the study. The descriptive statistics for the subcategories of involvement, immersion, visual fidelity, and interface quality in PQ are shown in Table 1.

4. Discussion

The purpose of this study was to investigate the effects of virtual heights and training on cognitive processing and height-related anxiety among young, healthy adults. It was hypothesized that increasing virtual heights would negatively affect cognitive processing ability and cause height-related anxiety. It was also hypothesized that cognitive processing would improve over the two days of training and that the improvements would be retained after 48 hours of training.

The number of hazards identified in the present study was considered a measure of cognitive processing [23]. The results of the hazard identification revealed a lower number of hazards identified on A3 and E3 VEs than all other VEs. Thus, it could be considered that the participants' cognitive processing was most affected in the A3 and E3 VEs, which are the highest altitudes (six-story (23.69 m/77.72 feet) level) used in the current study. This finding agrees with the authors' original hypothesis, in which cognitive processing was predicted to be affected by increasing virtual heights. Moreover, these results align with previous researchers who have independently shown that virtual heights affect cognitive processing [4,7,9,24]. Newman et al. (2020) exposed young, healthy participants to different virtual heights (ground level, low VR height, and high VR height) while sitting on a chair. The authors used a GO/NOGO task to measure cognitive processing and observed that the participants' cognitive processing (working memory and response inhibition) was significantly affected at virtual heights compared to ground level. The reason for affected cognitive processing at altitudes could be the increased stress-induced cortisol levels upon exposure to heights. At altitude, fear and anxiety develop due to the conflict between visual inputs and the perception of the absence of boundaries, triggering an "unsafe" feeling [25]. The fear, anxiety, stress, and increased sympathetic activity of the body are shown to affect the worker's cognitive performance at altitude [4,7,24].

Regarding training, the number of hazards identified each day was lowest on DAY 1, followed by DAY 2, and then DAY 3. This shows that the participants' cognitive performance improved with training, which was initially hypothesized by the researchers. In the present study, the participants were exposed to the VEs for about 45 minutes over three days, which can be considered short-term training. The number of studies that were conducted on cognition-based training of young individuals at virtual altitudes is extremely scarce in the previous literature. The studies available on the effects of VR-based training on cognition have mainly focused on geriatric or clinical populations [26]. Thus, the duration and frequency of training for young adults are still arbitrary. It may not require prolonged training as in the geriatric or clinical populations [27], which was evident in the present study.

ATHQ yielded significantly lower anxiety values in G, A1, and E1 compared to other VEs, which also agrees with the researchers' original hypothesis. G is the ground, and A1 and E1 were the lowest altitudes (two-story (9.18 m/30.11 feet)) used in the study. Thus, it could be considered that the participants had the lowest acrophobia levels at G, A1, and E1 compared to the other VEs. Although the authors expected to observe significantly increased scores of mSTAIQ at altitudes, this was not evident in the results. Hence, mSTAIQ may not be the best subjective questionnaire to assess anxiety at virtual altitudes.

Regarding the percentage increase in RHR, the authors expected to observe a lower percentage increase in RHR at lower virtual heights after training and during ST. However, according to the results, the percentage increase in HR was lowest on A3, DAY 1, and during ST. Thus, the participants were the least anxious on A3, on DAY 1, and while performing ST. Due to the requirement of performing two tasks (standing on the platform and identifying occupational hazards/signs), a greater increase in RHR was expected during DT trials. However, the lower percentage increase in RHR at A3 and on DAY 1 contradicts the authors' hypothesis. Nonetheless, similar findings were observed by previous authors such as Simeonov et al. (2005), who conducted a study on a young, healthy sample in which they were exposed to 0 m, 3 m, and 9 m real and matched virtual heights. The researchers assessed some physiological parameters, including HR, to measure anxiety. Although a direct relationship between HR and real heights has been previously noted, that was not observed in the VEs [28]. This absence of anxiety in VEs could probably be due to the knowledge of the absence of physical danger in the VEs and the use of a young, healthy population without acrophobia. In a clinical or geriatric population, the findings might be different.

In PQ, the questions are ranked on a scale of 0–7, with 4 considered the "neutral" score [29]. In the present study, all four categories (involvement, immersion, visual fidelity, and interface quality) had a score higher than 4 (Table 1), suggesting that the participants experienced a closer-to-realistic experience with a high level of involvement, interface quality, and immersion [29]. This indicates that the VE was engaging, reliable regarding depth perception and visual clarity, responded realistically, and was easy to use [21,29]. Furthermore, in the present study, the participants completed the SSQ four times during data collection, and none of the participants developed simulator sickness. According to these, it could be suggested that VR could be a convenient, safe, and cost-effective training tool with great simulation capability.

There were certain limitations to the study. The participants were young and healthy adults who may have had experience with VR. This could have affected the results, especially the findings related to HR. In addition, the participants were collegiate students with zero experience in the construction or roofing industries. Thus, the results could only be applied to young, healthy, novice workers with zero experience at altitude. Recruiting experienced workers, individuals with acrophobia, and individuals with zero previous VR exposure could yield interesting findings. In addition, a different method/questionnaire to assess anxiety at virtual heights could be suggested.

5. Conclusion

The results of the present study indicate that cognitive processing is negatively affected by virtual altitudes, while it improves with short-term training. Thus, VR could be a suitable training tool to address this affected cognition. While the acrophobia levels assessed through a subjective questionnaire (ATHQ) showed lower levels of acrophobia at lower altitudes, the increase in HR may not be the best way to assess virtual height-related anxiety in young, healthy adults. Moreover, VR shows promising features, such as higher involvement, engagement, and reliability, which makes it a more convenient training tool to be considered in ergonomic settings. The findings of this study will provide insights into cognitive DT at altitude and its challenges, which will eventually aid in minimizing injuries at the workplace. However, more research is warranted to assess the improvement of cognition with VR-based training among young, healthy adults.

Conflicts of interest

All authors have no conflicts of interest to declare.

References

[1] Bureau of Labor Statistics. A look at work injuries, illnesses, and fatalities; 2020 [Online]. Available: https://www.bls.gov/opub/ted/2020/a-look-at-work-injuries-illnesses-and-fatalities-on-workers-memorial-day.htm. [Accessed 6 May 2021].
[2] Incidence rates of nonfatal occupational injuries and illness by industry and case types. Bureau of Labor Statistics, US Department of Labor. 2017. Available from: https://www.bls.gov/.
[3] Huppert D, Wuehr M, Brandt T. Acrophobia and visual height intolerance: advances in epidemiology and mechanisms. J Neurol 2020;267(1):231–40.
[4] Cleworth TW, Horslen BC, Carpenter MG. Influence of real and virtual heights on standing balance. Gait Post 2012;36(2):172–6.
[5] American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 4th ed.; 1994. Washington, DC.
[6] Diemer J, Lohkamp N, Mühlberger A, Zwanzger P. Fear and physiological arousal during a virtual height challenge – effects in patients with acrophobia and healthy controls. J Anxiety Disord 2016;37:30–9.
[7] Fadeev KA, Smirnov AS, Zhigalova OP, Bazhina PS, V Tumialis A, Golokhvast KS. Too real to be virtual: autonomic and EEG responses to extreme stress scenarios in virtual reality. Behav Neurol 2020;2020:5758038.
[8] Arnsten AFT. Stress signalling pathways that impair prefrontal cortex structure and function. Nat Rev Neurosci Jun. 2009;10(6):410–22.
[9] Newman VE, Liddell BJ, Beesley T, Most SB. Failures of executive function when at a height: negative height-related appraisals are associated with poor executive function during a virtual height stressor. Acta Psychol 2020;203:102984.
[10] Peterson S, Furuichi E, Ferris D. Effects of virtual reality high heights exposure during beam-walking on physiological stress and cognitive loading. PLoS One Jul. 2018;13:e0200306.
[11] Wang H, Wang Q, Hu F. Are you afraid of heights and suitable for working at height? Biomed Signal Process Contr 2019;52:23–31.
[12] Wang Q, Wang H, Hu F. Combining EEG and VR technology to assess fear of heights. In: 2018 9th International Conference on Information Technology in Medicine and Education (ITME) 2018. p. 110–4.
[13] Fu Q, Hou H, Jiang D, Liu Z. The design of immersion acrophobia adjuvant therapy system (IAATS); 2019. p. 447–55.
[14] Emmelkamp P, Bruynzeel M, Drost L, Mast C. Virtual reality treatment in acrophobia: a comparison with exposure in vivo. Cyberpsychol Behav Jul. 2001;4:335–9.
[15] Lavender SA, Polivka BJ, Darragh AR, Sommerich CM, Stredney DL, Wills CE. Evaluating home healthcare workers' safety hazard detection ability using virtual simulation. Home Healthc Now 2019;37(5):265–72.
[16] Ferguson B. ACSM's guidelines for exercise testing and prescription 9th Ed. J Can Chiropr Assoc 2014;58(3):328. Sep. 2014.
[17] Shojaei A, Rokooei S, Mahdavian A. Immersive video capture technology for construction management education VIDEO CAPTURE TECHNOLOGY; 2020. September.
[18] Kennedy R, Lane N, Berbaum K, Lilienthal M. Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness. Int J Aviat Psychol Jul. 1993;3:203–20.
[19] Abelson JL, Curtis GC. Cardiac and neuroendocrine responses to exposure therapy in height phobics: desynchrony within the 'physiological response system. Behav Res Ther 1989;27(5):561–7.
[20] Gjoreski M. "Continuous stress monitoring using a wrist device and a smartphone; 2016. 86 p.
[21] Witmer B, Singer M. Measuring presence in virtual environments: a presence questionnaire. Pres Teleoper Virtual Environ 1998;7(Jul).
[22] Chander H, Shojaei A, Deb S, Kodithuwakku Arachchige SNK, Hudson C, Knight AC, et al. Impact of virtual reality–generated construction environments at different heights on postural stability and fall risk. Workplace Health Saf; Aug. 2020. 2165079920934000.
[23] Harvey P. Domains of cognition and their assessment. Dialog Clin Neurosci 2019;21(3):227–37.
[24] Kaur R, Sun R, Ziegelman L, Sowers R, Hernandez M. Using virtual reality to examine the neural and physiological anxiety-related responses to balance-demanding target-reaching leaning tasks; 2019.
[25] Huppert D, Grill E, Brandt T. Down on heights? One in three has visual height intolerance. J Neurol Oct. 2012;260.
[26] Liao Y-Y, Yang Y-R, Cheng S-J, Wu Y-R, Fuh J-L, Wang R-Y. Virtual reality–based training to improve obstacle-crossing performance and dynamic balance in patients with Parkinson's disease. Neurorehabil Neural Repair Dec. 2014;29(7):658–67.
[27] Elion O, Sela I, Bahat Y, Siev-Ner I, (Tamar) Weiss PL, Karni A. Balance maintenance as an acquired motor skill: delayed gains and robust retention after a single session of training in a virtual environment. Brain Res 2015;1609:54–62.
[28] Simeonov PI, Hsiao H, DotsonM BW, Ammons DE. Height effects in real and virtual environments. Hum Factor. Jun. 2005;47(2):430–8.
[29] Witmer Bob, Jerome C, Michael S. The factor structure of the presence questionnaire; 2005.