DOI: 10.2507/28th.daaam.proceedings.101

CYBER SICKNESS IN VIRTUAL REALITY - LITERATURE REVIEW

Sergo Martirosov, Pavel Kopecek

This Publication has to be referred as: Martirosov, S[ergo] & Kopecek, P[avel] (2017). Cyber Sickness in Virtual Reality - Literature Review, Proceedings of the 28th DAAAM International Symposium, pp.0718-0726, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-11-2, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/28th.daaam.proceedings.101

Abstract

In this paper, we present a review of the major issue of Virtual Reality - Cyber Sickness. As Virtual Reality becomes more and more popular and advanced technology, it is being used in a variety of areas, such as military, surgery, schools, etc. for training and education. Although at this point, Virtual Reality technology has multiple problems to overcome, Cyber Sickness issue is one of the most difficult ones, as it is closely linked to our physiology and Virtual Reality technology as well. Cyber Sickness symptoms are very similar to those of Motion Sickness, but are caused by Virtual Reality Environments. Due to its potential harm to human health, it is important to know the causes of this issue and possible ways to combat it. In this paper, we will highlight what aspects of Virtual Reality technology cause these symptoms and their outcomes.

Keywords: Virtual Reality; Cyber Sickness; Motion Sickness; Postural Stability

1. Introduction

In the modern time Virtual Reality (VR) technology became very popular and is used in many different areas such as entertainment, military, healthcare, education, engineering etc. Thanks to modern technological advance of computer hardware and software, it became possible to incorporate 3D VR in innovative applications of teaching, training, and learning [1][2][3]. Virtual environment or virtual world is a computer generated 3D representation of real or fictional environments. A user can interact in such an environment independently in the same pace, one would experience events in the real world [4]. VR has the ability to support realistic and immersive simulation and enables transfer of taught skills in VR into real contexts as well as provide multi-user, embodied and interactive active learning [5]. VR is believed to be a promising tool for training and complex problem solving, which requires weighing multiple variables and situational decision making [5][6][7][8]. As an example, VR can be used in ergonomics in order to find out time requirements for specific tasks, as well as help minimize the risks related to physical injuries [9].

Despite many studies in this area, there is still controversy about the real effects of VR on learning and cognition, but preliminary results indicate that the use of VR can increase learning performance [10], facilitate usability and enhance interaction [11], help to reconstruct and navigate through non-existent environments [12], help disabled learners with knowledge accessibility [13], etc. Serious games tend to be used often in formal education and with sufficient support are shown to be highly motivational and effective in learning complex tasks [14][15].

VR Technology can be of great use for emergency service personnel such as police, ambulance, fire fighters and army, as they have to be prepared for various operations at all times, thus continuous training is crucial for their success and security. But training in real environment is sometimes impossible, due to cost or complexity and the good alternative that comes handy is virtual training environment, which allows training for such complex collaborative tasks [16][17]. Thus, if the situation doesn't predispose for real life training practice due to danger, cost or effort, emergency service personnel can profit from virtual training to train for scenarios in real environment [18]. Often VR training is the only option that is possible [19]. And in order to make complex VR applications/simulations, some authors suggest methodologies for designing VR applications [20].

One of the topics that frequently comes up about VR is Cyber Sickness (CS). This is something similar to Motion Sickness (MS), as the symptoms are similar, but one is caused in virtual world, another in the real one. There are various applications and suggestions that try to measure and combat those symptoms of CS as they can potentially affect health in a negative way, which could lead to fatal accidents, such as car crash due to feeling sick. Previous research on this topic helps immensely, as it is important to understand what to expect and find the way to deal with that issue. The symptoms include: headache, nausea, vomiting, fatigue, postural instability, disorientation, etc. This sickness is a natural reaction to an unnatural environment and it happens due to the mismatch between sensory inputs. When those inputs don't agree, that's when you start feeling sick. In traditional MS the mismatch occurs because you feel movement in your muscles and your inner ear, but you don‘t see it, like it happens on the boat. With CS it's the opposite, you see movement on the screen, but you don't feel it.

Most of the experiments on evaluating CS in subjects are carried out in some kind of simulators, such as flying simulator, driving simulator, surgical simulator, etc. Or other variant of such environment is maze. A Simulation is a model of a real world where user has the ability to interact with the environment [21]. Simulations are helpful and useful as they provide realistic context in which individuals can explore, experiment and see immediate results as they create models of their own or try theories on the modeled concept [22]. Depending on the amount of senses simulated in VR, such as vision, hearing, touch, balance, even smell, the immersion level in the artificial world can vary. As every person is susceptible to CS in different ways, various environments and scenarios can cause divergent sickness levels in users as well. Thus, it would be wise to conduct more studies in different VR simulations to establish more precise link between training in that particular sphere and the levels of CS caused by it. Narrowing research to specific areas, would allow better understanding of things.

2. Cyber Sickness – Symptoms, Causes and Outcomes

There are a wide variety of research conducted in the field of VR on simulator sickness: simulator sickness in different types of moving images [23], comparison of one-screened and three-screened display types [24][25], relationship between age and sickness level [26], and gender effect on simulator sickness [27][28]. Research on virtual environments has provided converging evidence that being placed in a virtual environment with an HMD can lead to MS [29]. Previous studies suggest that a twenty-minute exposure to VREs can increase CS symptoms in over 60% of participants [30]. It has been found that exposure to VEs and simulators caused 30% of exposures result in nausea, up to 40% in eyestrain, as well as the experience of numerous other symptoms of MS including headache, dizziness/vertigo, loss of postural stability, drowsiness, salivation and sweating [31]. Numerous factors are related to the susceptibility and severity of visually induced motion sickness (VIMS) [32][33][34], including the sensation of illusory self-motion [35][36][37], gender [38], age [39], or personality factors like neuroticism and anxiety [40]. Due to many factors contributing to the cause of simulator sickness both from technological and individual standpoints, it is very difficult to predict [41]. It has been noted that psychological conditions such as anxiety can significantly increase when simulated motion increases [42]. Based on the theories of sensory conflict [43]and neural storage [44], changes in visual stimulus could cause sensory conflicts between different modalities (vision, touch, etc.) which in turn could evoke different levels of virtually induced MS.

Little is known on the subject of virtual environment effects on symptoms of CS, thus, a new system describing VE systems, the Virtual Environment Description and Classification System (VEDACS [45]) was proposed. VEDACS describes VEs in terms of 42 variables which are then divided into seven categories: (1) environmental dimensions, (2) visual complexity, (3) the motion of objects, (4) the tasks that users perform, (5) the provision of help/assistance, (6) the provision of sound, and (7) global measures such as the amount of time that each person spent in a VE.

It has been suggested that the size of the monitor and the resulting display angle can also influence the severity of VIMS [46][47]. Often head-mounted devices are used for displaying virtual environments and they are known to cause MS [48][49]. A research conducted to analyze simulator sickness score using a video game in VR with a HMD, notes that sickness occurred in all participants who played the game for a maximum of 50 min [50]. Similar research suggests that sickness occurred both, in users who played a game on a standard TV screen and those with a HMD [51]. One study, targeted at finding out effects of immersion in VRE using a 20 m experiment, concluded that remarkable effects of immersion could not be found under such a short duration condition [52]. Other research suggests that the duration of exposure might be a causal factor in postural disequilibrium and that exposure of less than 3 h would not be sufficient to induce an outstanding detriment in postural steadiness [53]. According to the sensory conflict theory [43][44][54], anything that strengthens the non-veridical visual stimulus should increase MS.

According to various studies, in virtual environments, high-latency that can result from low frame rates can lead to reduced sense of presence [55], impaired task performance, reduced user response [56][57] or simulator sickness [58]. It has been determined by some authors [59] that the critical end-to-end latency is at 17ms, but other authors [60] found this threshold to be even lower. When rotating head in virtual environment with head mounted display on, adaptation to a newly displayed scene has to happen and due to the delay in visual image, during the process of adaptations, some users may develop MS and show postural disequilibrium [61][62].

It is noted that VR environment influences automatic nervous system and equilibrium [63]. Sensory conflict theory states that when there are conflicting visual and vestibular inputs disequilibrium occurs, which results in MS [64]. When sensory conflict happens, the instability of persons standing positions occurs [65] and the influence of this instability may appear in humans walk after the righting reflex occurs [66]. It is a reflex that corrects the orientation of the body when it is taken out of its normal upright position. Various studies note that CS can effect 50-80 % of people, depending on the quality of the digital content and how it’s presented [67]. Also, some studies show that women are more susceptible to MS than men, and those with a history of migraines or concussion also suffer a higher chance of getting motion sick [68]. Also, the older subjects are more susceptible to Simulator Sickness than younger subjects [26][69].

Some authors suggest that major contributor to MS is the duration of motion with visuals [70]. Others argue, that consumer HMDs require ideal frame rates in order to reduce/prevent the discomfort of MS [71]. Various researchers believe that decreasing Field of View (FOV) tends to decrease VR sickness, though at the cost of sense of presence [72]. A few authors came to a conclusion that a wide FOV display can maximize “immersion” in VE, whereas narrow one may hinder sense of presence [73][74]. As a result of increased FOV, users exhibited more postural instability, which has been suggested to be a surrogate measure for simulator sickness [75][76]. Differences in FOV have been related to navigation and memory differences [77][78][79]. Larger FOV can improve spatial awareness as well as increase sense of presence and consequently may help exhibit better memory structure of that VE [80]. Various methods, such as brain wave readings [81], behavioral metrics [82], and self-reported measures [83][84][85], have been employed over the years in order to measure users sense of presence in VEs.

Sense of presence is defined as “a state of consciousness”, the psychological sense of being in the virtual environment [86][87][88][89][90]. A similar concept related to sense of presence is immersion – degree of “the subjective impression that one is participating in a comprehensive, realistic experience” and “the semi-voluntary experience of being transported into an alternate context for an extended duration” [7][91]. Previous research suggests that higher levels of immersion are associated with higher levels of presence [89][92][93]. Furthermore, the psychological perception of being inside a virtual world is known as presence [94]. Among many factors affecting user’s feeling of presence, one is the content of the virtual world [95]. Immersive experience can be created via the sensory and environmental fidelity in 3D virtual environment, engagement with virtual objects and activities, and emotional experience activated through realistic scenarios in virtual world [8].

In some research it is noted that 3D video yields higher discomfort levels than 2D video [96]. There is an interesting conclusion made by some authors, stating that the highest value of sickness occurs during rotation along roll axis and that the results were highly consistent [97]. A study was conducted to analyze Visually Induced Sickness during day-night driving sessions, which showed that sickness level in night sessions was much higher than in morning sessions. In addition to that it was proved that sleep deprivation may strengthen the symptoms [98]. It’s interesting to notice that in traditional MS studies, younger subjects were found to be more prone to sickness than older subjects [43], whereas in others, many older visitors appeared to suffer from effects of CS more than younger subjects [99].

It has been noted that some users might exhibit symptoms of CS, both during and after VR experience [100][101]. CS is different from MS in the way that the user is stationary, but has a compelling sense of motion as the visual imagery changes [102][103]. Vection or otherwise illusions of self-motion and sickness can be caused by watching changing moving scenes in VE [104]. Also, it is found that users spending more than 20 min in VE experience progressively more sickness symptoms [105]. Studies suggest that both exposure duration and repeated exposure are significantly linearly related to sickness outcomes [106]. The repetitive watching of the same video image reduced subjective score of MS in 8 of the 14 participants [107]. Some authors found that scene oscillations produce vection and promote CS significantly [108]. Simulation Sickness Questionnaire (SSQ) has been found to be valid and reliable subjective measure tool for both simulator sickness and side effects experienced in VEs [109][110]. It’s interesting to note, that MS after immersion in VRE is much greater when both pre and post questionnaire are given rather than when only post test questionnaire is used [111].

Some previous studies suggest that the discomfort of MS can cause self-control ability decline and lead to serious traffic accident fatalities [43]. And as it was mentioned that the discomfort of all motion related sicknesses may even last for the entire day [112]. This adds some risk to using VR, as many people are very susceptible to VR Sickness and have to cope with that discomfort after their experience with it through the rest of the day, during which fatal accidents may occur and not only during driving a vehicle. For these reasons some studies are conducted to determine a set of MS indicators that would predict the occurrence of a person's MS as soon as possible [113]. Specifically they use electroencephalography (EEG), as among other imaging technologies, it outperforms the other methods in terms of portability and temporal resolution, which refers to the precision of a measurement with respect to time.

Currently there is a debate concerning VR technology and VR sickness. Some argue that the problem of VR sickness is inherent from this technology itself and as long as there is mismatch between what is visually perceived and what is physically sensed, fixing the VR display properties does not address the root cause [114]. Particular study indicates that the weight of the HMD devices themselves play big part in causing VR sickness [114]. The 1994 US Navy study reported that techniques such as biofeedback, relaxation training, and counseling had an estimated 40 to 85 % success rate in helping reduce susceptibility to MS [114]. MS drugs for the most part claim to prevent, not treat, MS [114]. It is suggested that a visible horizon has a mitigating effect on MS [115][116].

Researches were conducted to find out the effect of virtual and real walking in virtual environment and the results seem controversial. A study found that during the task requiring a navigationally complex environment and for a long period of time, it is preferable to use simulated walking [117]. On the other hand, another study reported that natural walking caused less MS than simulated walking in one out of two experiments involving a virtual maze [118]. During a similar research no differences were found in simulator sickness between real walking and several virtual travel techniques in a small virtual room [119]. Furthermore, no differences were found between real walking, gaze-directed and pointing-directed travel techniques in a complex 3D maze [120].

3. Conclusion

In this paper we have showed a multitude of studies conducted on the subject of Cyber Sickness. This issue, which is similar to Motion Sickness, is directly linked to Virtual Reality technology and as research suggests, could potentially harm human health and life. As benefits of Virtual Reality are tremendous, and there is no doubt that it will be used widely in the future, this means that dealing with the issue of Cyber Sickness is inevitable, thus it is important to understand what are the causes of it and what could be done to combat it. Previous research and experiments help with this immensely, as they provide useful information that could be used for future studies. It could be used to allow understanding of what to await while working with Virtual Reality applications and simulations, take every precaution and be prepared for most scenarios.

As every person is susceptible to Cyber Sickness in different ways and every scenario in Virtual Reality is different, in order to have precise knowledge on this topic, it is necessary to produce more research and narrowing the scope to specific areas and scenarios would allow better understanding of this issue.

4. Acknowledgment

This article was created with the subsidy of University of West Bohemia internal grant number SGS-2015-065 titled "Development of a sustainable production system parameters".

5. References

[1] Abulrub, A. G., Attridge, A. N., & Williams, M. A. (2011). Virtual reality in engineering education: the future of creative learning. In Global engineering education conference (EDUCON), 2011 IEEE (pp.751-757). IEEE. DOI:10.1109/EDUCON.2011.5773223

[2] Gregory, S., Gregory, B., Reiners, T., Fardinpour, A., Hillier, M., Lee, M., Basu, A. (2013). Virtual worlds in Australian and New Zealand higher education: remembering the past, understanding the present and imagining the future. In ASCILITE 2013 "Electric dreams", 1-4 december 2013. Sydney, NSW: Macquarie University. ISBN 9781741384031

[3] Jou, M., & Wang, J. (2013). Investigation of effects of virtual reality environments on learning performance of technical skills. Computers in Human Behavior, 29(2), pp.433-438. DOI: 10.1016/j.chb.2012.04.020

[4] Mitchell, P., Parsons, S., & Leonard, A. (2007). Using virtual environments for teaching social understanding to 6 adolescents with autistic spectrum disorders. Journal of autism and developmental disorders, 37(3), pp.589-600. DOI: 10.1007/S10803-006-0189-8

[5] Cheng, Y., & Wang, S. H. (2011). Applying a 3D virtual learning environment to facilitate student's application ability-the case of marketing. Computers in Human Behavior, 27(1), pp.576-584. DOI: 10.1016/j.chb.2010.10.008

[6] Bertram, J., Moskaliuk, J., & Cress, U. (2015). Virtual training: making reality work? Computers in Human Behavior, 43, pp.284-292. DOI: 10.1016/j.chb.2014.10.032

[7] Dede, C. (2005). Millennial learning styles. Educause Quarterly, 28(1), 7-12.

[8] Dede, C. (2009). Immersive interfaces for engagement and learning. Science, 323(5910), pp.66-69. DOI: 10.1126/science.1167311
[9] Bures, M. (2016). Time Demands of Virtual Ergonomic Modelling – Experimental Study, Proceedings of the 26th DAAAM International Symposium, pp.0286-0291, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-07-5, ISSN 1726-9679, Vienna, Austria, DOI:10.2507/26th.daaam.proceedings.039
[10] Carpenter T. & Anderson L. (1996). Using virtual reality technology for learning design skills, Proceedings of ED-MEDIA 96, Boston, USA, pp.752
[11] Mikropoulos T. & Nikolou E. (1996). A virtual hand with tactile feedback for virtual learning environments,Proceedings of ED-MEDIA 96, Boston, USA, pp.792
[12] Littman M.(1996). Enhancing instruction through virtual reality, Proceedings of ICTE, New Orleans, USA,pp.31-33
[13] Lumbreras M., Sánchez J., Barcia M. (1996), A 3D sound hypermedial system for the blind. In Proceedings of the First European Conference on Disability, Virtual Reality and Associated Technologies, pp.187-191, Maidenhead, UK. DOI: 10.1145/302979.303101
[14] Chatti, Mohamed Amine, et al. (2012). "A reference model for learning analytics." International Journal of Technology Enhanced Learning 4.5- 6: pp.318-331. DOI: 10.1504/IJTEL.2012.051815
[15] Eseryel, D., Law, V., Ifenthaler, D., Ge, X., & Miller, R. (2014). An investigation of the interrelationships between motivation, engagement, and complex problem solving in game-based learning. Journal of Educational Technology & Society, 17(1), pp.42-53.
[16] Moskaliuk, Bertram & Cress (2013a). Impact of virtual training environments on the acquisition and transfer of knowledge. Cyberpsychology, Behavior, and Social Networking, 16(3), pp.210–214. DOI: 10.1089/cyber.2012.0416
[17] Moskaliuk, Bertram & Cress (2013b). Training in virtual environments: Putting theory into practice. Ergonomics, 56(2), pp.195–204. DOI: 10.1080/00140139.2012.745623
[18] Rose, F. D., Attree, E. A., Brooks, B. M., Parslow, D. M., Penn, P. R., & Amibihaipahan, N. (2000). Training in virtual environments: Transfer to real world tasks and equivalence to real task training. Ergonomics, 43(4), pp.494–511. DOI: 10.1080/001401300184378
[19] Romano, D. M., & Brna, P. (2001). Presence and reflection in training: Support for learning to improve quality decision-making skills under time limitations. CyberPsychology & Behavior, 4(2), pp.265–277. DOI: 10.1089/109493101300117947
[20] Polcar, J, Gregor M, Horejsi P, Kopecek P. (2016). Methodology for Designing Virtual Reality Applications, Proceedings of the 26th DAAAM International Symposium, pp.0768-0774, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-07-5, ISSN 1726-9679, Vienna, Austria, DOI:10.2507/26th.daaam.proceedings.107
[21] Thurman, R. A. (1993). Instructional simulation from a cognitive psychology viewpoint. Educational technology research and development, 41(4), pp.75-89. DOI: 10.1007/BF02297513
[22] Rieber, L.P. (1992). Computer-based microworlds: a bridge between constructivism and direct instruction. Educational Technology Research and Development, 40(1), pp.93-106. DOI: 10.1007/BF02296709
[23] Kuze, J. and Ukai, K. (2008) : “Evaluation of Visual Fatigue Caused by Motion Images”, Elsevier, Display, Vol.29, pp.159-166. DOI: 10.1016/j.displa.2007.09.007
[24] Seay A.F., Krum, D.M., Hodges, L. and Ribarsky, W., (2001). “Simulator Sickness and Presence in a High FOV Virtual Environment,” IEEE Virtual Reality Conference 2001 (VR2001), Japan, March 13-17, pp.299-300. DOI: 10.1109/VR.2001.913806
[25] Chompoonuch J. and Kazuhiko H., (2011) “Study on Parallax Affect on Simulator Sickness in One-Screen and Three-screen Immersive Virtual Environment”, Proceeding of The School of Information and Telecommunication Engineering, Tokai University, Vol.4, No.1, pp.34-39.
[26] Laura L. Arns and Melinda M. Cerney (2005). “The Relationship Between Age and Incidence of Cyber sickness Among Immersive Environment Users”, Proceedings of the IEEE Virtual Reality, pp.267-268. DOI: 10.1109/VR.2005.1492788
[27] Thomas D. Parsons, Peter Larson, Kris Kratz, Marcus Thiebaux, Brendon Bluestein, J. Galen Buckwalter, and Albert A. Rizzo (2004): “Sex Differences in Mental Rotation and Spatial Rotation in a Virtual Environment”, Elsevier Ltd., Neuropsychologia 42, pp.555-562. DOI: 10.1016/j.neuropsychologia.2003.08.014
[28] Evan A. Suma, Samantha L. Finkelstein, Seth Clark, Paula Goolkasian, and Larry F. Hodges (2010). “Effects of Travel Technique and Gender on a Divided Attention Task in a Virtual Environment”, IEEE Symposium on 3D User Interface, March 20-21, USA, pp.27-34. DOI: 10.1109/3DUI.2010.5444726
[29] DiZio, P. and Lackner, J.R. (1998). “Alleviation of motion sickness and postural instability during and after virtual environment exposure” (Technical Report). Prepared for Naval Air Warfare Center Training Systems Division, Orlando, FL.
[30] Regan, E. and Price, K. (1994). “The Frequency and Occurrence and Severity of Side-Effects of Immersion in Virtual Reality,”. Aviation Space and Environmental Medicine, vol. 65, pp. 527-530.
[31] Kennedy, R. S., Fowlkes, J. E. and Lilienthal, M. G., (1993). “Postural and performance changes in Navy and Marine Corps pilots following flight simulators,” Aviation, Space, and Environmental Medicine, Vol. 64, pp.912-920, 1993.

[32] Golding, J.F. (2006). Predicting individual differences in motion sickness susceptibility by questionnaire, Personality and Individual Differences 41 (2), pp. 237– 248. DOI: 10.1016/j.paid.2006.01.012
[33] Shupak, A. and Gordon, C.R. (2006). Motion sickness: advances in pathogenesis, prediction, prevention, and treatment, Aviation Space and Environmental Medicine 77 (12), pp.1213–1223.
[34] Stanney, K.M, Hale, K.S., Nahmens, I., Kennedy, R.S. (2003). What to expect from immersive virtual environment exposure: Influences of gender, body mass index, and past experience, Human Factors 45 (3), pp.504–520. DOI: 10.1518/hfes.45.3.504.27254
[35] Flanagan, M.B., May, J.G. and Dobie, T.G. (2004). The role of vection eye movements and postural instability in the etiology of motion sickness, Journal of Vestibular Research-Equilibrium and Orientation 14 (4), pp.335–346.
[36] Hettinger, L.J., Berbaum, K.S., Kennedy, R.S., Dunlap, W.P. and Nolan, M.D. (1990). Vection and simulator sickness, Military Psychology 2 (3), pp.171–181. DOI: 10.1207/s15327876mp0203_4
[37] Smart, L.J., Stoffregen, T.A. and Bardy, B.G. (2002). Visually induced motion sickness predicted by postural instability, Human Factors 44 (3), pp.451–465. DOI: 10.1518/0018720024497745
[38] Flanagan, M.B., May, J.G. and Dobie, T.G. (2005). Sex differences in tolerance to visuallyinduced motion sickness, Aviation Space and Environmental Medicine 76 (7), pp.642–646.
[39] Turner, M. and Griffin, M.J. (1999). Motion sickness in public road transport: passenger behavior and susceptibility, Ergonomics 42 (3), pp.444–461. DOI: 10.1080/001401399185586
[40] Bick, P.A. (1983). Physiological and psychological correlates of motion sickness, The British Journal of Medical Psychology 56 (Pt 2), pp.189–196. DOI: 10.1111/j.2044-8341.1983.tb01546.x
[41] LaViola Jr., J.J. (2000). “A Discussion of Cybersickness in Virtual Environment”, SIGCHI Bulletin, Vol.32, No.1, pp.47-56. DOI: 10.1145/333329.333344
[42] Bruck, S. and Watters, P.A. (2009). “Cybersickness and Anxiety During Simulated Motion: Implications for VRET.” Annual Review of CyberTherapy and Telemedicine (ARCTT). in press. DOI: 10.3233/978-1-60750-017-9-169
[43] Reason, J.T. and Brand, J.J. (1975). Motion Sickness, Academic Press, London. ISBN-13: 978-0125840507
[44] Reason, J.T. (1978). Motion sickness adaptation: a neural mismatch model, J. R. Soc. Med. 71 (11), pp.819.
[45] Nichols, S., Ramsey, A.D., Cobb, S., Neale, H., D’Cruz, M. and Wilson, J.R. (2000). Incidence of virtual reality induced symptoms and effects (VRISE) in desktop and projection screen displays, HSE Books: Sudbury, Suffolk, UK. ISBN 0 7176 1810 2
[46] Duh, H.B.L., Parker, D.E. and Furness, T.E. (2004). An independent visual background reduced simulator sickness in a driving simulator, Presenence: Teleoperators and Virtual Environments 13 (5), pp.578–588. DOI: 10.1162/1054746042545283
[47] Emoto, M., Sugawara, M., and Nojiri, Y. (2008). Viewing angle dependency of visuallyinduced motion sickness in viewing wide-field images by subjective and autonomic nervous indices, Displays 29 (2), pp.90–99. DOI: 10.1016/j.displa.2007.09.010
[48] Mon-Williams, M., Wann, J.P. and Rushton, S. (1993). Binocular vision in a virtual world: visual deficits following the wearing of a head-mounted display, Ophthalmic & Physiological Optics 13 (4), pp.387–391. DOI: 10.1111/j.1475-1313.1993.tb00496.x
[49] Patterson, R., Winterbottom, M.D. and Pierce, B.J. (2006). Perceptual issues in the use of head-mounted visual displays, Human Factors 48 (3), pp.555–573. DOI: 10.1518/001872006778606877
[50] Merhi, O., Faugloire, E., Flanagan, M. and Stoffregen, T.A. (2007). Motion sickness, console videogames, and head-mounted displays,Human Factors 49 (5), pp.920–934. DOI: 10.1518/001872007X230262
[51] Stoffregen, T.A., Faugloire, E., Yoshida, K., Flanagan, M.B. and Merhi, O. (2008). Motion sickness and postural sway in console video games, Human Factors 50 (2), pp.322–331. DOI: 10.1518/001872008X250755
[52] Cobb, S.V.G. (1999). "Measurement of postural stability before and after immersion in a virtual environmlent," Applied Ergonomics, vo1.30, pp.45-57. DOI: 10.1016/S0003-6870(98)00038-6
[53] Kennedy, R.S. and Lilienthal, M.G. (1995). "Implications of balance disturbances following exposure to virtual reality systems," Proceedings of Virtual Reality Annual Intemational Symposium'gfi, IEEE Computer Society Press, Los Alamitos : CA, pp.35-39. DOI: 10.1109/VRAIS.1995.512477
[54] Oman, C.M. (1990). Motion sickness: a synthesis and evaluation of the sensory conflict theory, Canadian Journal of Physiology and Pharmacology 68 (2), pp.294– 303. DOI: 10.1139/y90-044
[55] Slater, M., Lotto, B., Arnold, M.M. and Sanchez-Vives, M.V. (2009). How we experience immersive virtual environments: the concept of presence and its measurement. Anuario de Psicolog´ıa, 40(2): pp.193–210.
[56] Ellis, S.R., Adelstein, B.D., Baumeler, S., Jense, G.J. and Jacoby, R.H. (1999). Sensor Spatial Distortion, Visual Latency, and Update Rate Effects on 3D Tracking in Virtual Environments. In Proceedings of IEEE Virtual Reality, pp.218–221. DOI: 10.1109/VR.1999.756954
[57] MacKenzie I.S. and Ware, C. (1993). Lag As a Determinant of Human Performance in Interactive Systems. In Proceedings of the INTERACT ’93 and CHI ’93 Conference on Human Factors in Computing Systems, pp.488–493. DOI: 10.1145/169059.169431
[58] Buker, T.J., Vincenzi, D.A. and Deaton, J.E. (2012). The Effect of Apparent Latency on Simulator Sickness While Using a See-Through HelmetMounted Display: Reducing Apparent Latency With Predictive Compensation. Human Factors, 54(2): pp.235–249. DOI: 10.1177/0018720811428734

[59] Adelstein, B.D., Lee, T.G. and Ellis, S.R. (2003). Head Tracking Latency in Virtual Environments: Psychophysics and a Model. In Proceedings of the Human Factor Ergonomics Society, pp.2083–2087. DOI: 10.1177/154193120304702001

[60] Jerald, J.J. (2010). Scene-Motion- and Latency-Perception Thresholds for HeadMounted Displays. PhD thesis, University of North Carolina at Chapel Hill.

[61] Kolasinski, E.M. and Gilson, R.D. (1999) Ataxia following exposure to a virtual environment, Aviat. Space Environ. Med. 70, pp.264–269.

[62] Regan, E.C. and Price, K.R. (1994). The frequency of occurrence and severity of side-effects of immersion virtual reality, Aviat. Space Environ. Med. 65, pp.527–530.

[63] Nakagawa, C., Ohsuga, M., Takeda, T., (2000). Basic study toward VE-sickness assesment, The Japanese Journal of Ergonomics,vo1.36(3), pp.130-138. DOI: 10.5100/jje.36.131

[64] Money KE (1970) Motion Sickness. Am. Psychol. Soc. 50: pp.1–39

[65] Murata. A. and Miyoshi, Y., (2000). Effects of Duration of Immersion in a Virtual Environment on Postual Stability, Proc of IEEE-SMC2000, pp.961- 966. DOI: 10.1109/ICSMC.2000.885974

[66] Hreljac, A. and Marshall, N., (2000). Algorithms to determine event timing during normal waking using kinematic data, Journal of Biomechanics,Vol.33, pp.783-786. DOI: 10.1016/S0021-9290(00)00014-2

[67] Chang, C., Pan, W., Tseng, L. et al. Experimental Brain Research (2012) 217: pp.299-309. DOI: 10.1007/s00221-011-2993-4

[68] Koslucher, F., Haaland, E., TA Stoffregen. (2016). Experimental Brain Besearch 234 (1), pp.313-322. DOI: 10.1007/s00221-015-4462-y

[69] Johnell O. Brooks, Richard R. Goodenough, Matthew C. Crisler, Nathan D. Klein, Rebecca L. Alley, Beatrice L. Koon, William C. Logan Jr., Jennifer H. Ogle, Richard A. Tyrrell and Rebekkah F. Wills, (2010). “Simulator Sickness during Driving Simulation Studies,” Elsevier Accident Analysis and Prevention 42, pp.788-796. DOI: 10.1016/j.aap.2009.04.013

[70] Mohsen, S., Nika, Z., Kristina, M., (2013). Abdominal Muscle Behavior and Motion Sickness During Paired Visual Input with Roll Motion, Poland. DOI: 10.1109/HSI.2013.6577831

[71] Edward, P., Christoff, L., Burkhard, W., (2013). More for Less: Fast Image Warping for Improving the Appearance of Head Tracking on HMDs, 28th Intern ational Conference on Image and Vision Computing, New Zealand. DOI: 10.1109/IVCNZ.2013.6726990

[72] Ajoy, F., Steven, F., (2016). Combating VR Sickness through Subtle Dynamic Field-Of-View Modification. DOI: 10.1109/3DUI.2016.7460053

[73] Prothero, J.D. and Hoffman, H.D. (1995). “Widening the field-ofview increase the sense of presence within immersive virtual environments”, Human Interface Technology Laboratory Tech. Rep. R-95-4, Seattle: University of Washington.

[74] Stanney, K. and Salvendy, G. (1998). “Aftereffects and sense of presence in virtual environments: formulation of a research and development agenda”, International Journal of Human- Computer Interaction, 10(2), pp.135-187. DOI: 10.1207/s15327590ijhc1002_3

[75] Duh, H.B.L., Lin, J.J.W., Kenyon, R.V., Parker, D.E. and Furness, T.A. (2001). "Effects of field of view on balance in an immersive environment", Proceedings of IEEE Virtual Reality 2001, Yokohama, Japan. DOI: 10.1109/VR.2001.913791

[76] Duh, H.B.L., Lin, J.J.W., Kenyon, R.V., Parker, D.E. and Furness, T.A. (2002). "Effects of characteristics of image quality on balance in an immersive environment", Presence: Teleoperators and Virtual Environments. DOI: 10.1162/105474602317473259

[77] Alfano, P. and Michel, G. (1990). “Restricting the field-of-view: perceptual and performance effects”, Perceptual and Motor Skills, 70, pp.35-45. DOI: 10.2466/pms.1990.70.1.35

[78] McCreary, F.A. and Williges, R.C. (1998). “Effects of age and field-of-view on spatial learning in an immersive virtual environment”, Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting, 1998, pp. 1491-1495.

[79] Witmer, B.G., Bailey, J.H. and Knerr, B.W. (1994). “Training dismounted soldiers in virtual environments: Route learning and transfer”, ARI Technical Report 1022, Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. From http://www.dtic.mil/get-tr-doc/pdf?AD=ADA292900

[80] Usoh, M., Catena, E., Arman, S. and Slater, M. (2000). “Using Presence Questionnaires in Reality”, Presence: Teleoperators and Virtual Environment, 9(5), pp.497-503. DOI: 10.1162/105474600566989

[81] Pugnetti, L., Mendozzi, L., Cattaneo, A.M., Guzzetti, S., Mezzetti, C., Cglati, C., Brancotti, A. and Venanzi, D. (1995). “Psychophysiological activity during virtual reality (VR) testing”, Journal of Psychophysiology, Vol. 8, No. 4, pp.361-362.

[82] Usoh, M., Arthur, K., Whitton, M., Bastos, R., Steed, A., Slater, M. and Brooks, F. (1999). “Walking > Walking-in-Place > Flying in Virtual Environments”, Proc. of ACM SIGGRAPH 99, pp.359-364. DOI: 10.1145/311535.311589

[83] Kennedy, R., Lane, N., Berbaum, K. and Lilienthal, M. (1993). “A Simulator Sickness Questionnaire (SSQ): A New Method for Quantifying Simulator Sickness”, International Journal of Aviation Psychology, Vol. 3, No. 3, pp.203-220. DOI: 10.1207/s15327108ijap0303_3

[84] Slater, M. and Steed, A. (2000). “A Virtual Presence Counter”, Presence, Vol. 9, No. 5, pp.413-434. DOI: 10.1162/105474600566925
[85] Slater, M., Usoh, M. and Steed, A. (1994). “Depth of Presence in Virtual Environments”, Presence, Vol. 3, No. 2, pp. 145-157. DOI: 10.1162/pres.1994.3.2.130
[86] Barfield, W., & Hendrix, C. (1995). The effect of update rate on the sense of presence within virtual environments. Virtual Reality, 1(1), 3-15. DOI: 10.1007/BF02009709
[87] Heeter, C. (1992). Being there: the subjective experience of presence. Presence: Teleoperators and virtual environments, 1(2), pp.262-271. DOI: 10.1162/pres.1992.1.2.262
[88] Lee, K. M. (2004). Presence, explicated. Communication theory, 14(1), pp.27-50. DOI: 10.1111/j.1468-2885.2004.tb00302.x
[89] Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): speculations on the role of presence in virtual environments. Presence: Teleoperators and Virtual Environments, 6(6), pp.603-616. DOI: 10.1162/pres.1997.6.6.603
[90] Witmer, B. G. B. G., Jerome, C., & Singer, M. (2005). The factor structure of the presence questionnaire. Presence, 14(3), pp.298-312. DOI: 10.1162/105474605323384654
[91] Buchanan, K. (2006). Beyond attention-getters: Designing for deep engagement (Unpublished doctoral dissertation). Michigan: Michigan State University. Retrieved from http://education.uwsp.edu/publications/buchanan_2006_beyond_attention.pdf
[92] Bystrom, K. E., Barfield,W., & Hendrix, C. (1999). A conceptual model of the sense of presence in virtual environments. Presence: Teleoperators and Virtual Environments, 8(2), pp.241-244. DOI: 10.1162/105474699566107
[93] Faiola, A., Newlon, C., Pfaff, M., & Smyslova, O. (2013). Correlating the effects of flow and telepresence in virtual worlds: enhancing our understanding of user behavior in game-based learning. Computers in Human Behavior, 29(3), pp.1113-1121. DOI: 10.1016/j.chb.2012.10.003
[94] Witmer B. and Singer, M. (2000). “Measuring presence in virtual environments: A presence questionnaire”. Presence: Teleoperators and Virtual Environments, vol. 9, issue 5, 2000, pp.497-503. DOI: 10.1162/105474698565686
[95] Ijsselsteijn, W.A., H. de Ridder, Freeman., J. and Avons, S.E. (2000). “Presence: Concept, determinants and measurement”, Proceedings of the SPIE, Human Vision and Electronic Imaging V, San Jose, CA,3959-3976. ISBN 0-8194-3577-5
[96] Naoki, K., Hiroki, Y., Masahiro, I., Yutetsu, M., (2015). Effects of Visual Induced Motion Sickness of Stereoscopic 3D Interactive Video, IEEE 4th Global Conference on Consumer Electronics (GCCE). DOI: 10.1109/GCCE.2015.7398678
[97] Ujike, H., Yokoi, T. and Saida, S. (2004). Effects of Virtual Body Motion on Visually-Induced Motion Sickness, Proceedings of the 26th Annual International Conference of the IEEE EMBS. DOI: 10.1109/IEMBS.2004.1403694
[98] Sunu, W., Titis, W., Hanung, A., Muhhamad, B., Mumtaz, N., (2015). Quantifying visual attention and visually induced motion sickness during day-night driving and sleep deprivation, International Conference on Data and Software Engineering. DOI: 10.1109/ICODSE.2015.7436996
[99] Pausch, R., Crea, T., & Conway, M. (1992). A literature survey for virtual environments: Military Flight Simulators Visual Systems and Simulator Sickness. Presence,1(3): pp.344-363. DOI: 10.1162/pres.1992.1.3.344
[100] Bowman, D., Kruijff, E., LaViola J.J. and Poupyrev, I. (2001). “An introduction to 3-D user interface design,” Teleoperators and Virtual Environments, 2001, vol. 10, pp. 96-108. DOI: 10.1162/105474601750182342
[101] Rich, C.J. and Braun, C.C. “Assessing the impact of control and sensory compatibility on sickness in virtual environments,” Proceedings of Human Factors and Ergonomics Society 40th Annual Meeting 1996, 2-6 September, Philadelphia, USA. DOI: 10.1177/154193129604002203
[102] Hale, K.S., Stanney, K.M. (2002). Handbook of Virtual Environments, New York: Earlbaum. ISBN 9780805832709
[103] Lathan, R. (2001). “Tutorial: a brief introduction to simulation sickness and motion programming,” Real Time Graphics, vol. 9, pp.3-5.
[104] So, H.Y., Lo, W.T. and Ho, T.K. (2001). “Effects of navigation speed on motion sickness caused by an immersive virtual environment,” Human Factors, 2001, vol. 43, pp.452-461. DOI: 10.1518/001872001775898223
[105] Regan, C. (1995). “An investigation into nausea and other side-effects of headcoupled immersive virtual reality,” Virtual Reality, 1995, vol. 1, pp.17- 32. DOI: 10.1007/BF02009710
[106] Kennedy, R. S., Stanney, K. M. and Dunlap, W. (2000). “Duration and exposure to virtual environments: sickness curves during and across sessions,” Presence: Teleoperators and Virtual Environments, vol. 9, pp.463-472. DOI: 10.1162/105474600566952
[107] Norihiro Sugita, Makoto Yoshizawa and Makoto Abe, (2007). “Evaluation of Adaptation to Visually Induced Motion Sickness by Using Physiological Index Associated with Baroreflex Function,” in Proceedings of the 29th Annual International Conference of the IEEE EMBS, France, pp.303-306, , 23-26 August. DOI: 10.1109/IEMBS.2007.4352284
[108] Lo, W. T. and So, R.-H. Y. (2001). “Cybersickness in the presence of scene rotational movements along different axes,” Applied Ergonomics, vol. 32, pp.1-14. DOI: 10.1016/S0003-6870(00)00059-4

[109] Kiryu, T. and So, R. H. Y. (2007). “Sensation of presence and cybersickness in applications of virtual reality for advanced rehabilitation,” Journal of NeuroEngineering and Rehabilitation, vol. 4, pp.34. DOI: 10.1186/1743-0003-4-34

[110] Hale K.S. and Stanney, K.M. (2006).“Effects of low stereo acuity on performance, presence and sickness within a virtual environment,” Applied Ergonomics, vol. 37, pp.329-339. DOI: 10.1016/j.apergo.2005.06.009

[111] Sean D. Y., Bernard D. A. and Stephen R. E., (2006). “Demand Characteristics of a Questionnaire Used to Assess Motion Sickness in a Virtual Environment,” in Proceeding of the IEEE Virtual Reality Conference, pp.97-102, 25-29. DOI: 10.1109/VR.2006.44

[112] Gower, D.W. and Fowlkes, J.E. (1989). “Simulator Sickness in the UH-60 (Black Hawk) Flight Simulator”, U.S. Army Aeromedical Research Laboratory, September.

[113] Chin-Teng, L., Shu-Fang, T., Li-Wei, K., (2013). EEG-Based Learning System for Online Motion Sickness Level Estimation in a Dynamic Vehicle Environment, IEEE Trans. on Neural Networks and Learning Systems, Vol. 24, no. 10. DOI: 10.1109/TNNLS.2013.2275003

[114] Michael, P., (1998). Motion Sick in Cyberspace, IEEE Computer Graphics and Applications. DOI: 10.1109/38.637264

[115] Steele, J.E., (1961). Motion Sickness and Spatial Perception. A Theoretical Study. from http://www.dtic.mil/get-tr-doc/pdf?AD=AD0273602

[116] Tal, D., Wiener, G. and Shupak, A. (2014). Mal de debarquement, motion sickness and the effect of an artificial horizon, J. Vestibular Res.: Equilibr. Orient. 24 (1), pp.17–23, DOI: 10.3233/VES-130505.

[117] Evan A. Suma, Samantha L. Finkelstein, Myra Reid, Amy Ulinski and Larry F. Hodges, (2009). “Real Walking Increases Simulator Sickness in Navigationally Complex Virtual Environments, ” in IEEE Virtual Reality, Louisiana, USA, pp.245-246. DOI: 10.1109/VR.2009.4811037

[118] Chance, S.S., Gaunet, F., Beall, A.C and Loomis, J.M. (1998). Locomotion mode affects the updating of objects encountered during travel: The contribution of vestibular and proprioceptive inputs to path integration. Presence, 7(2): pp.168–178. DOI: 10.1162/105474698565659

[119] Zanbaka, C.A., Lok, B.C., Babu, S.V., Ulinski, A.C. and Hodges, L.F. (2005). Comparison of path visualizations and cognitive measures relative to travel technique in a virtual environment. IEEE TVCG, 11(6): pp.694–705. DOI: 10.1109/TVCG.2005.92

[120] Suma, E.A., Babu, S. and Hodges, L.F. (2007). Comparison of travel techniques in a complex, multi-level 3d environment. In IEEE Symposium on 3D User Interfaces, pp.147–153. DOI: 10.1109/3DUI.2007.340788