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Editorial: Cybersickness in Virtual Reality and Augmented Reality

Ben D. Lawson[1]* *and Kay M. Stanney*[2]

[1]*Naval Submarine Medical Research Laboratory, Naval Submarine Base New London, Groton, CT, United States,* [2]*Design Interactive, Inc., Orlando, FL, United States*

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Editorial on the Research Topic

Cybersickness in Virtual Reality and Augmented Reality

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Edited by:
Mel Slater,
University of Barcelona, Spain

Reviewed by:
Joan Llobera,
University of Barcelona, Spain

Correspondence:
Ben D. Lawson
benton.d.lawson.civ@mail.mil

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INTRODUCTION

Early virtual reality (VR) systems introduced abnormal visual-vestibular integration and vergence-accommodation, causing cybersickness (McCauley and Sharkey, 1992) reminiscent of simulator sickness reported by military pilots, e.g., having some shared causes and overlapping (Lawson, 2014a) but distinguishable symptoms (Stanney et al., 1997). Improved processing, head tracking, and graphics were expected to overcome cybersickness (Rheingold, 1991), yet it persists in today's much-improved VR (Stanney et al., 2020a, 2020b). This must be resolved, because VR and Augmented Reality (AR)[1] are proliferating for training for stressful tasks, exposure therapy for post-traumatic stress, remote assistance/control, and operational situation awareness (Hale and Stanney, 2014; Beidel et al., 2019; Stanney et al., 2020b, 2021; NATO Science and Technology Office, 2021).

Experts considered the cybersickness problem recently at a *2019 Cybersickness Workshop*[2] and a 2020 *Visually-Induced Motion Sensations* meeting.[3] Military aspects were discussed during 2019–2021 meetings of a *Cybersickness Specialist Team* (NATO Science and Technology Office, 2021). The *Bárány Society's Classification Committee* just developed relevant international symptom standards for visually-induced motion sickness (VIMS; Cha et al., 2021). Finally, >40 authors produced twelve articles comprising this *Frontiers* Research Topic initiated by Dr. Stanney. Below, we summarize their work and provide recommendations.

COMMENTS ON THE 12 TOPIC ARTICLES

Three Articles Explored The Benefits Of Ambient Or Earth-Referenced Visual Cues

1) Hemmerich et al. found that an Earth-fixed visual horizon (but not a non-horizon cue) significantly reduced cybersickness.[4] 2) Shahnewaz Ferdous et al. posited that Earth-stable cues

[1]AR overlays virtual images on a partial view of the real world. While AR often causes less visual-vestibular conflict, vergence-accommodation problems may persist.

[2]https://s2019.siggraph.org/conference/programs-events/organization-events/frontiers-workshops/cybersickness-causes-and-solutions/

[3]https://ieda.ust.hk/dfaculty/so/VIMS2020/

[4]A VR was used. Our recommendations for futures studies of this type are at the end of this editorial.

introduced into VR or AR (via a partial virtual frame) should improve balance and lessen cybersickness. They discussed two small studies of balance-impaired VR/AR users. Their VR study detected a cueing difference for two balance measures and the Simulator Sickness (SSQ) Disorientation measure[5], while their AR study (which allowed sight of the room) detected a difference in one balance measure but no SSQ measures. Benefits were seen only with balance-impaired subjects. While the findings were mixed, an appropriately-designed Earth-referenced cue should aid orientation. Expanded studies of this type should compare similar VR-versus-AR fields of view. Finally, 3) Cao et al. provided VR users with Earth-stable granulated peripheral cues that allowed some peripheral vision, which improved visual target searching better than restricting field-of-view (FOV), a typical countermeasure. Could this approach also mitigate cybersickness better than FOV restriction?

Two Articles Discussed Aspects Of Tracking Latency As A Cybersickness Contributor

4) Stauffert et al. explored cybersickness implications of latency between the movement of a tracked object and its movement on a head-worn display. They provided information to assist in assessing latency, and stressed the need for comparable assessments. 5) Palmisano et al. posited that a key (and readily quantifiable) contributor to cybersickness is a large, temporally inconsistent difference between actual and virtual head position. Their findings are relevant to Moss et al. (2011), who found that varying head tracking latency was sickening. As many studies have observed that visually-moving fields elicit symptoms even when the head is still (e.g., Webb and Griffin, 2002), however, the contribution of visual field motion versus head position/motion conflict should be studied.

Three Articles Explored Additional Effects Of Head Motion, Head Orientation, Or Head-Mounting Of Displays

6) Kim et al. posited that linear head oscillations increase sensory conflict in VR devices that only track angular motion. While they failed to detect device-related differences in perceived scene stability, spatial presence, or cybersickness, this was a creative pilot study exploring implications of different tracking devices. 7) Wang et al. confirmed that vection (the illusion of self-motion) elicited by viewing a rotating dot pattern was stronger when concordant with expected graviceptive cues. VR/AR designers should know that when vection is desired, its direction should not contradict somatosensory/vestibular cues that would be present during real motion. Also, specific motion/orientation perceptions will tend to be altered to minimize sensory conflict (Young et al., 1975; Lackner and Teixeira, 1977; Dizio and Lackner, 1986; Howard et al., 1987; Golding, 1996; Tanahashi et al., 2012). The notion that vection can reduce sickening conflict is better supported than vection as a cause of sickness (Lawson, 2014a; Stanney et al., 2020b). Finally, 8) Hughes et al. evaluated head-worn versus tablet-based AR during tactical combat casualty training. They observed greater sickness with head-worn AR, but symptoms for both devices were mostly limited to the Oculomotor cluster of the SSQ, with little Nausea. Moreover, while subjects in the head-worn condition completed fewer training scenarios in the time allotted, they had more correct responses in completed scenarios. AR could be a less-sickening training approach, and solutions to mitigate oculomotor disturbances would make it even better.

Three Articles Explored The Role Of Active Sensorimotor Engagement Or Maintenance Of Postural Equilibrium

9) Curry et al. evaluated participants in a head-worn racing game. They did not detect main differences in cybersickness between active drivers versus passengers. The reasons for this should be explored, as a difference has been observed in other contexts (Rolnick and Lubow, 1991; Stanney and Hash, 1998; Seay et al., 2002; Sharples et al., 2008). 10) Weech et al. found a correlation between visually-influenced body sway (reflected by the center-of- pressure [COP] ratio)[6] and SSQ Disorientation and Oculomotor sub-scores in a VR. It makes sense for the Disorientation score to be related to sway; expanded studies should determine if COP ratio correlates with SSQ Total Sickness or Nausea scores, as these are likely to predict quitting a training session. Finally, 11) Jasper et al. evaluated the efficacy of different cybersickness recovery strategies. Their study elicited sufficient cybersickness (Stanney et al., 2003). Greatest recovery was observed for resting with the VR off (real natural decay), while doing a virtual hand-eye task yielded the least recovery. We agree with the authors' implication that administration of the SSQ during VR/AR should be explored further.

Three Studies Addressed The Role Of Individual Cybersickness Susceptibility (Two Of Which Were Mentioned Immediately Above)

12) Golding et al. found that sickness severity in a moving visual surround is predicted by history of susceptibility to motion sickness, migraine, and fainting. They did not detect a relationship between sickness and vection, adding to the

[5]Four measures are yielded by SSQ (Total Sickness Score, Disorientation score, Nausea Score, and Oculomotor score) (Kennedy et al., 1993). Five within-device balance-related measures were tried (two sway measures, one sway-driven dodgeball task, and one questionnaire).

[6]Defined as the amount of sway associated with visual scene oscillation, where a high ratio implies an inability to down-weigh visual information and is a hypothesized cybersickness contributor.

TABLE 1 | Twelve Research Topic Publications (by Number), and their Links to Etiological Hypotheses.

Hypotheses	I. Sensory conflict (and variants)	II. Postural instability	III. Eye movement	IV. Evolutionary (and variants)
Publication	#1–5; 7; 9–11	#7, 9–10	#6–8; 10	#9, 11, 12
Comment	Relevant variants: frame-of-reference (#1–3), neural mismatch (#4–5[9]; 7, 11), reweighting/ development (#9–10)	Possible or direct relevance	Possible relevance during certain self/ scene motions, oculomotor reactions	Possible relevance for individual differences; partially related to evolution

many studies failing to find this relation (Lawson, 2014a; Stanney et al., 2021).[7] Consistent with the literature (Lawson, 2014a; Stanney et al., 2020a), the aforementioned article #11 by Jasper et al. and #9 by Curry et al. observed mixed findings concerning sex as a factor in cybersickness susceptibility. Jasper et al. observed that women reported more cybersickness, but this was confounded by women having less experience with video games. The sex difference detected in Curry et al. was solely among the subset of subjects who discontinued participation early, wherein women quit earlier when driving, but not when passengers. Future studies of individual cybersickness differences should estimate variance accounted for by experience with motion sickness, driving, video games, and head-worn displays.

CAUSAL HYPOTHESES RELEVANT TO THE 12 TOPIC ARTICLES

While the explanatory capabilities of a complete motion/ simulator/cybersickness theory have been described (Lawson, 2014a), there is no universally accepted theory. Six hypotheses were discussed by Stanney et al. (2021) and ten by Keshavarz et al. (2014). Most of these can be grouped into four established categories (Table 26.1, Keshavarz et al.), which in **Table 1** are linked to the 12 articles in this Research Topic. This taxonomy may aid further literature inquiries concerning theoretical implications.[8]

CONCLUDING RECOMMENDATIONS TO THE RESEARCH COMMUNITY

We thank the authors for contributing many provocative studies. As is common in research, as many questions were raised as were answered. Answering the key cybersickness questions requires controlled, labor-intensive research entailing:

1. Assessment of relevant stimulus experiences (Jasper et al.) and past susceptibility (Golding et al.): This is vital to interpretation and such measures can be used as covariates to improve analyses.
2. Larger samples (e.g., Moss and Muth, 2011) than have commonly been employed (e.g., Kim et al.; Shahnewaz Ferdous et al.), in order to deal with high individual variability in susceptibility (Lawson, 2014a).
3. Stimuli that elicit functionally relevant cybersickness (Stanney et al., 2014[10]), to avoid basement effects or detection of statistical differences lacking clear functional significance (e.g., Hemmerich et al.).
4. Managing sessions and session intervals to reduce carry-over effects which may confound studies with many cybersickness sessions held closely together (e.g., Hemmerich et al.; Kim et al.). Sickening VR or simulator studies should ideally limit the number of sessions to three (Lawson et al., 2009[11]) and allow 1 week of recovery between sessions, to reduce visual-vestibular and vergence-accommodation carry-over effects due to adaptation (Dai et al., 2011) or sensitization (Dizio and Lackner, 2000), as well as learning, fatigue, classical conditioning, subject attrition, and ultradian variation (Lawson et al., 2009; Lawson, 2014a) (Comparable session guidelines need to be established for AR studies.)
5. Careful establishment of measures, e.g., whenever "objective" indicators of cybersickness are considered (Stauffert et al.; Shahnewaz Ferdous et al.; Hemmerich et al.); researchers should realize that specificity needs more emphasis (Bos and Lawson, 2021), and an established symptom scale is required for validation (Lawson, 2014b).

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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[7]Curry et al. (#9) also posit that their findings are (indirectly) inconsistent with a causal cybersickness role for vection.

[8]Stanney et al. and Keshavarz et al. provide (and evaluate) the source materials.

[9]Palmisano et al. (#5) hypothesize a new conflict between virtual versus physical head pose.

[10]Moderate-to-medium cybersickness severity occurs at 20–28 SSQ points (Table 31.3), and 20 points is where some subjects would quit (personal communication, Dr. Stanney, 1 May 2020).

[11]See p. 16–17.

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