Standards & Engagement

Leveraging Publicly Available Data on Virtual Reality Headsets for Gender-Responsive Standards Development

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Abstract

Sharing data practices is a primary goal for standards development organizations that are signatories of the United Nations Economic Commission for Europe's Declaration for Gender-Responsive Standards and Standards Development. Here, we present a data-driven approach to selecting an existing voluntary consensus standard to evaluate for gender responsiveness, and we leverage public data to identify potential opportunities for improving its safety impact. We found that UL 8400, the Standard for Safety for Virtual Reality, Augmented Reality and Mixed Reality Technology Equipment was a suitable candidate for the initiative, and we highlight potential safety issues through an analysis of incident data and primary research articles.

Highlights:

- We used a data-driven approach to select UL 8400 for gender-responsiveness.
- Product incident records involving females are more frequently labeled with ambiguous diagnoses.
- Product research studies investigating female user concerns are lacking.
- More initiatives for collecting gender-responsive data are needed.

Introduction

In August 2022, UL Standards & Engagement signed the UNECE Declaration for Gender-Responsive Standards and Standards Development.[1] By signing the declaration, ULSE made a commitment to developing gender-responsive standards and accounting for varying body characteristics across a wider range of users. Gender-responsive standards are developed with consideration of the physical and physiological variation across genders — including grip strength, physical dimensions, skinfold thickness, and body fat percentage — and they feature technical requirements that address these differences.

As a next step in ULSE's commitment to the UNECE Declaration, we developed a pilot project to select, analyze, and propose revisions to an existing UL voluntary consensus standard to account for the unique safety hazards more likely experienced by women and girls, and to promote technical requirements that are equally applicable and effective. Through the pilot project, we developed a methodology for identifying standards that require further review to bolster gender responsiveness. In general, our process involved three parts: 1) assessing anthropometric relevance of the standard using criteria developed by the Center for Industrial Studies,[2] 2) identifying gender disparities in injuries related to applicable products, and 3) identifying further gender safety issues of applicable products in academic research. These steps are the focus of this report and are discussed in more detail below.

In developing this process, our overall findings were that UL 8400 is a suitable candidate for gender-responsive evaluation, and that female users may face unique safety issues with virtual reality headsets that are difficult to account for in incident data or academic research. Standards relevant to this product line, especially those that do not address proper fitting, discomfort, and/or cybersickness in female users, might be more prone to safety gaps. We are currently reviewing proposed modifications to the standard with our standards technical committee.

An important note on the phrase, "gender-responsiveness" – this is generally used across standards development organizations to address coverage gaps in cisgender females. While we recognize this is a limited view of gender, we have maintained that phrase here, and constrict our terminology to "female" and "male" for our SDO readers who are accustomed to discussing standards and research in those terms.

Methods and Results

Part 1: Identifying pilot candidates based on standards content

We began our process by determining which voluntary consensus standards in our portfolio were applicable to review. Following a similar method in the Center for Industrial Studies report on inclusive anthropometrics in European standards, we used computational text-based analyses, guided by feedback from our standards subject experts, to rank standards by relevance to measurements of human physical features. We then used this ranked list to decide, from a handful of standards, which one was most appropriate for subsequent injury and landscape analyses. These are discussed further in parts 2 and 3.

This initial step involved analyzing ULSE's full portfolio of over 1,400 voluntary consensus standards counting anthropometric- and injury-related terms. Anthropometric terms were selected based on general textbook anatomy, and injury terms were selected from internal lists of physiological hazards associated with our standards portfolio. We found 434 standards documents with at least one clause in which one injury and one anthropometric term co-occur. We then ordered documents by total term counts, and eight standards subject matter experts reviewed the top 20 documents to identify pilot candidates. A subset of the top selected standards were run against criteria which allowed us to appraise the anthropometric relevance of the standard.[2]

We then determined UL 8400, the Standard for Safety for Virtual Reality, Augmented Reality, and Mixed Reality Technology Equipment, as the best candidate for our pilot for the following reasons:

1. The relevant anthropometric term counts in the standard was among the top of all UL voluntary consensus standards, and included (but was not limited to) "strain," "injury," "neck size," "eye diameter," "arm," "bone," "muscle strength," "body," "age," "gender," "human," and "skin thickness."

2. Its International Classification of Standards classification (Electronics and Electronic Display Devices) refers to an activity that can overlap with anthropometric concerns.

3. It cites >30 references and documents in the informative annex with titles relevant to anthropometrics.

4. Its scope already mentions some means to reduce physiological hazards, including visually induced motion sickness, skin sensitization, heat exposure to the eye, and biomechanical stress.

Part 2: Identifying physical injuries associated with VR usage from incident data

Our next step was to determine the prevalence of reported injuries in related products. We focused our analysis on data from the National Electronic Injury Surveillance System[3] because it contains incident data from emergency departments for over the past two decades, allowing us to capture trends starting at times before certain products are widely on the market. The consistency of text narratives captured by medical professionals also enable simple, and reliable text-based analyses. Additionally, NEISS incident records permit a straightforward analysis of sex-related disparities, as patient sex is explicitly reported.

The UL Standards & Engagement Open Data for Safety Incidents[4] portal was queried with the search string (VR OR "virtual reality") to find emergency department visits related to virtual reality headsets in the National Electronic Injury Surveillance System. This resulted in 241 total records between 2001-2023.

The provided statistical weights for each record were summed to estimate total incidents. As the number of incidents did not meet recommended thresholds from the Centers for Disease Control and the Consumer Product Safety Commission, no comparative statistical tests were performed.[5,6]

Counting the number of incidents by diagnosis, we found the top three most frequent diagnoses over the last 10 years were "laceration," "other/not stated," and "fracture," with 1705, 1556, and 1312 estimated incidents, respectively **(figure 1)**. Other diagnoses include concussion, contusions, abrasions, dermatitis/conjunctivitis, internal organ injury, and strain or sprain. Importantly, diagnoses that might encompass symptoms associated with simulator sickness, a commonly measured side-effect of VR use, are not included. As such, to gain more specificity on symptoms, we examined incident narratives.

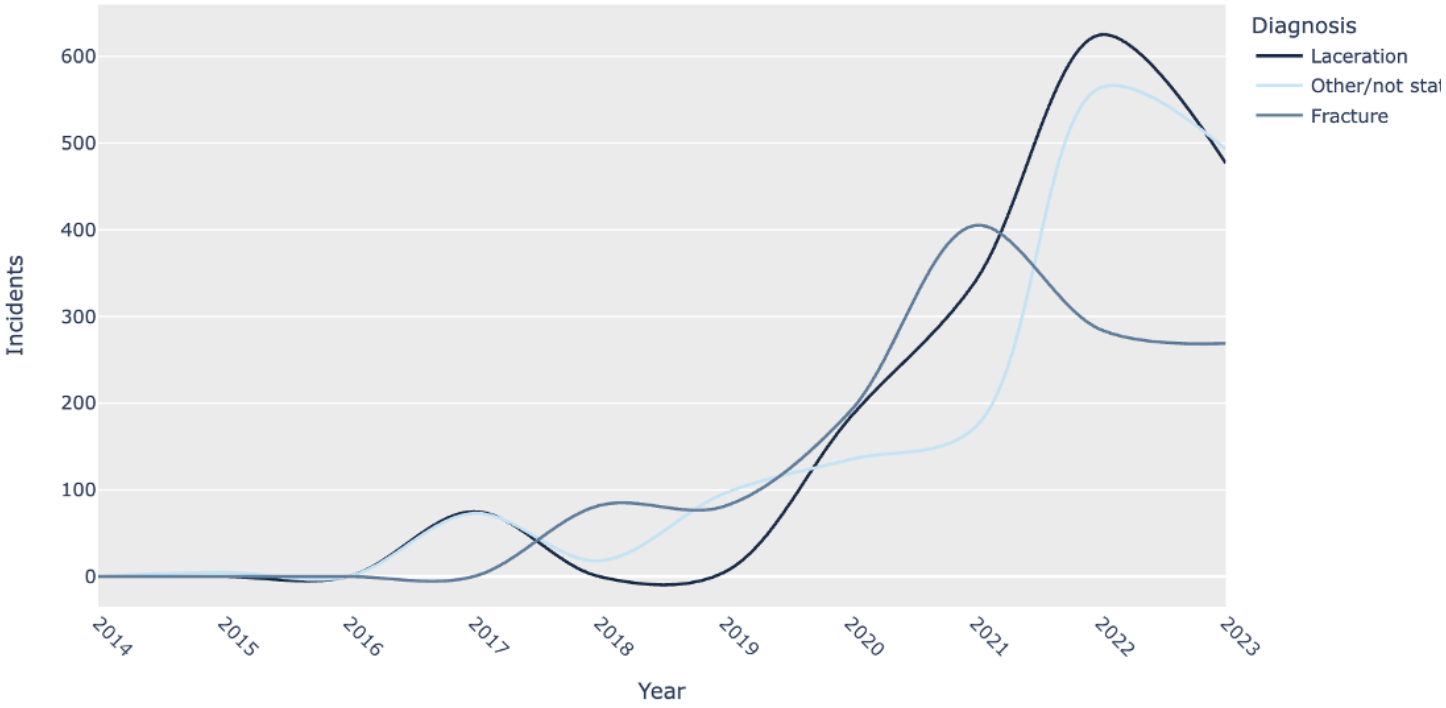

Figure 1: Estimated number of incidents by year. The top three most frequent diagnoses over time are shown. Incident numbers on the y-axis are estimates provided by NEISS.

To identify more granular factors associated with incidents, words from the incident narratives were extracted, and a metric called "term-frequency inverse-document-frequency" was used to identify the most distinguishing terms for each diagnosis. In general, higher scores indicate a term is more characteristic of that kind of incident. The top terms associated with "laceration" and "fracture" diagnoses were "play" and "game." For "other/not stated" diagnoses, the top terms were "pain" and "play" (**table 1).**

Taking into account the reported sex of the injured person, "laceration" was the most common diagnosis for male patients, with a total of 1607 total estimated incidents. These mostly involved the finger, hand, lower arm, and mouth **(figure 2)**. The top diagnosis for female patients, on the other hand, was "Other/ Not Stated" with a total of 759 estimated incidents, involving mostly the knee, finger, trunk, and "more than 50% of the body" **(figure 3**).

Laceration Terms	Score	Other/Not Stated Terms	Score	Fracture Terms	Score
Play	0.517	Pain	0.564	Play	0.447
Game	0.418	Play	0.445	Game	0.343
Hit	0.283	Game	0.348	Close	0.265
Glass	0.260	Chest	0.229	Bone	0.265
Controller	0.154	Seizure	0.155	Wall	0.211

Table 1: Characteristic words of different incident types. Words with the highest term-frequency inverse document frequency scores in incident narratives. Higher scores indicate that word is more characteristic of that type of incident.

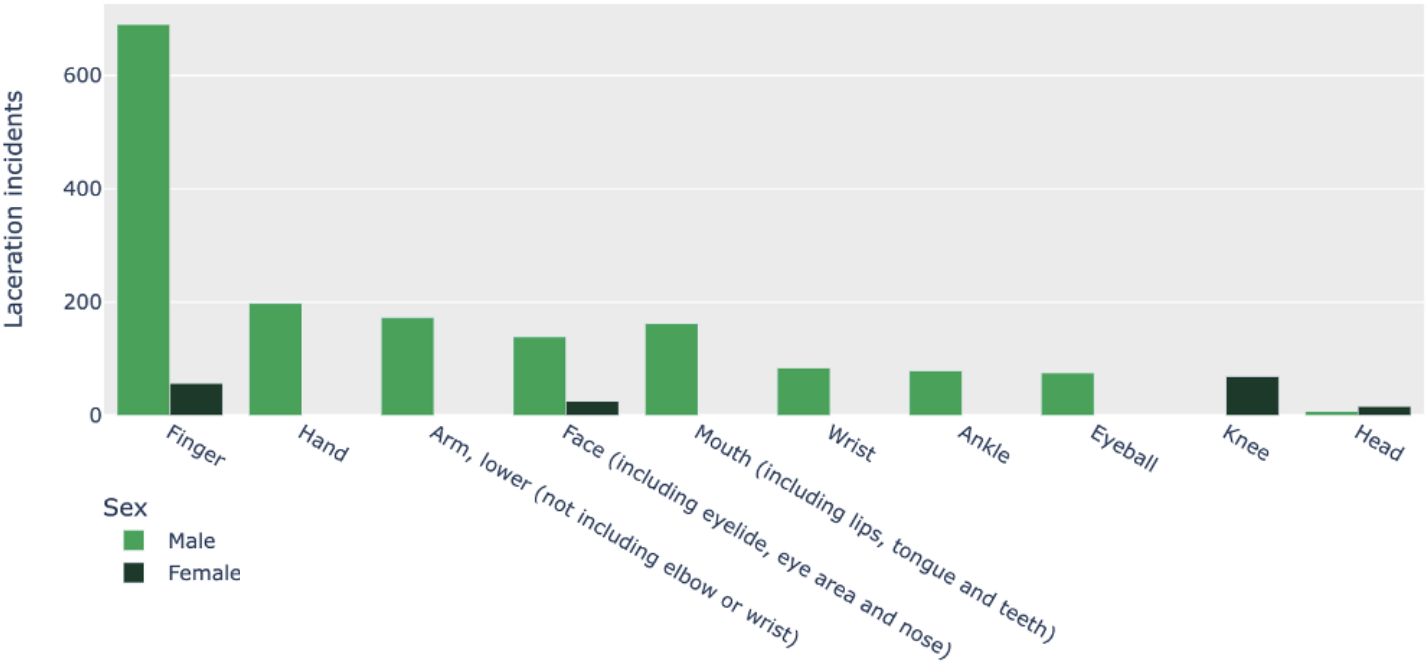

Figure 2: Laceration incidents. Laceration incidents were the most common among male patients. The number of incidents is plotted by body part and reported patient sex.

Overall, these results show that there were more VR-related safety incidents reported in males than females, but female incidents were most frequently assigned diagnoses with “other/not stated.” This suggests that the nature of these incidents were not as easy to characterize as those involving males, who were most frequently treated for “laceration.” Additionally, “pain” being one of the most characteristic descriptors of the “other/not stated” incidents further suggests this, as clinical pain is commonly difficult to diagnose and treat[7] Regardless, while a statistical analysis between males and females here is not possible due to the overall low number of records, it is clear that safety incidents involving VR headsets are on the rise.

Part 3: Identifying concerns from published academic studies

For a wider analysis of the product safety landscape, we surveyed academic research publications for prevalence and type of safety issues facing female VR headset users. To keep our procedure as accessible to other standards organizations as possible, we focused only on research articles and abstracts that could be obtained through open access. Additionally, while results in the previous section revealed distinct physical injuries like “laceration” were most commonly associated with an emergency department visit after VR use, we focused primarily on research that was more likely to address symptoms related to simulator sickness. We did this because i) simulator sickness is widely studied in head-mounted display technology, and ii) simulator sickness is within the scope of UL 8400.

Abstracts available through PubMed were queried with the PubMed API, using the following search criteria: "('virtual reality' OR 'augmented reality') AND ('motion sickness' OR 'cybersickness' OR ‘dizz*’ OR ‘headache’ OR 'blurred vision' OR 'blurry vision') AND (sex OR gender OR female)," resulting in 210 studies. Notably, we included “female” as part of the search query with the explicit goal of investigating studies that include female participants. We further discarded review studies, and studies in which male and female participant counts could not be ascertained either through the abstract, or through open access to the article. This resulted in 80 studies between years 2003 and 2024 for our final analysis **(figure 4)**.

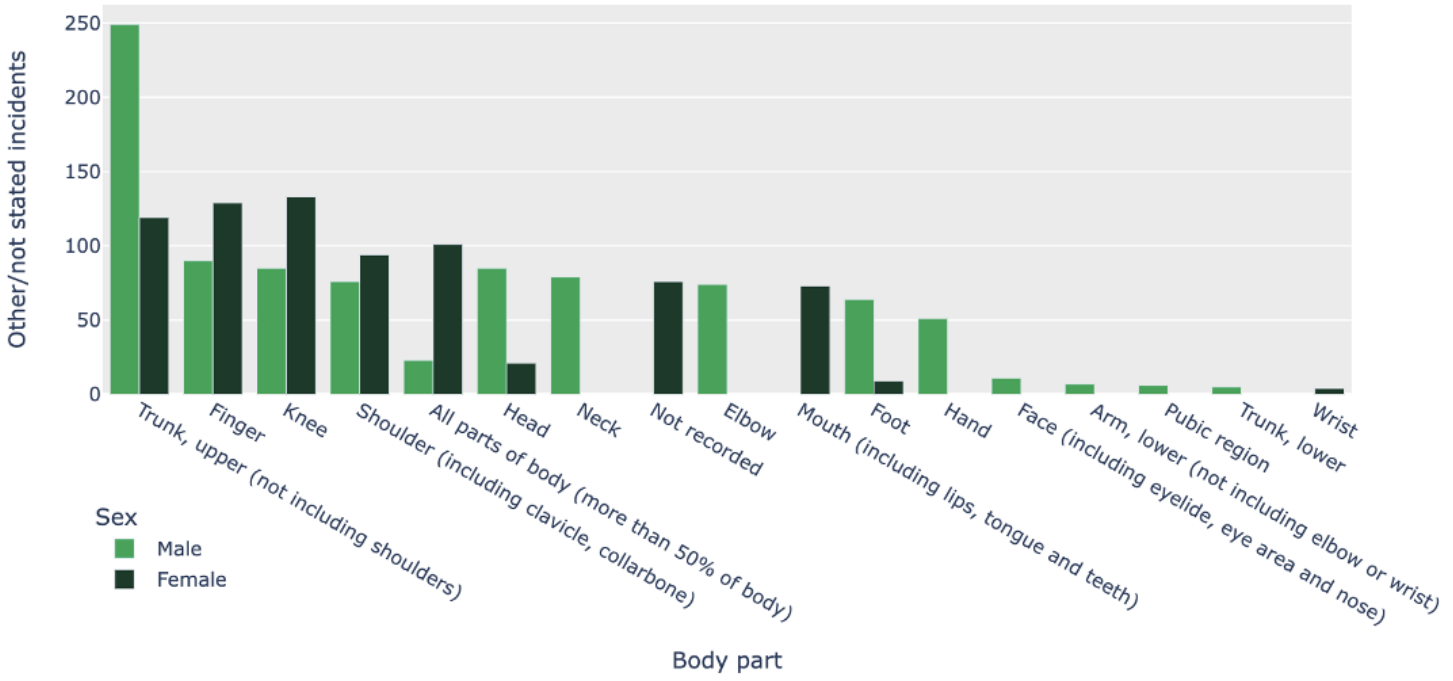

Figure 3: Other/not stated incidents. Incidents with a diagnosis of “other/not stated” were the most common among reported female patients. The number of incidents is plotted by body part and reported patient sex.

To illustrate the extent to which female participants were included in our search, we counted the number of total females and males reported in the studies and calculated their percentages. Overall, participant pool size ranged from 1 to 1615, with a median of 37 (46). Additionally, the percentage of female participants across all studies ranged from 0% to 100%, with a median of 52% (29%) **(figure 5)**. Note, despite our search query including "female", we still obtained 2 studies which did not include female participants. We did not perform a query for studies that are not restricted by the presence of "female", and the absence of reporting on participant sex in VR studies has been found in other meta-analyses[8,9]. Thus it is likely that the median we report does not accurately reflect female participation in VR research at large.

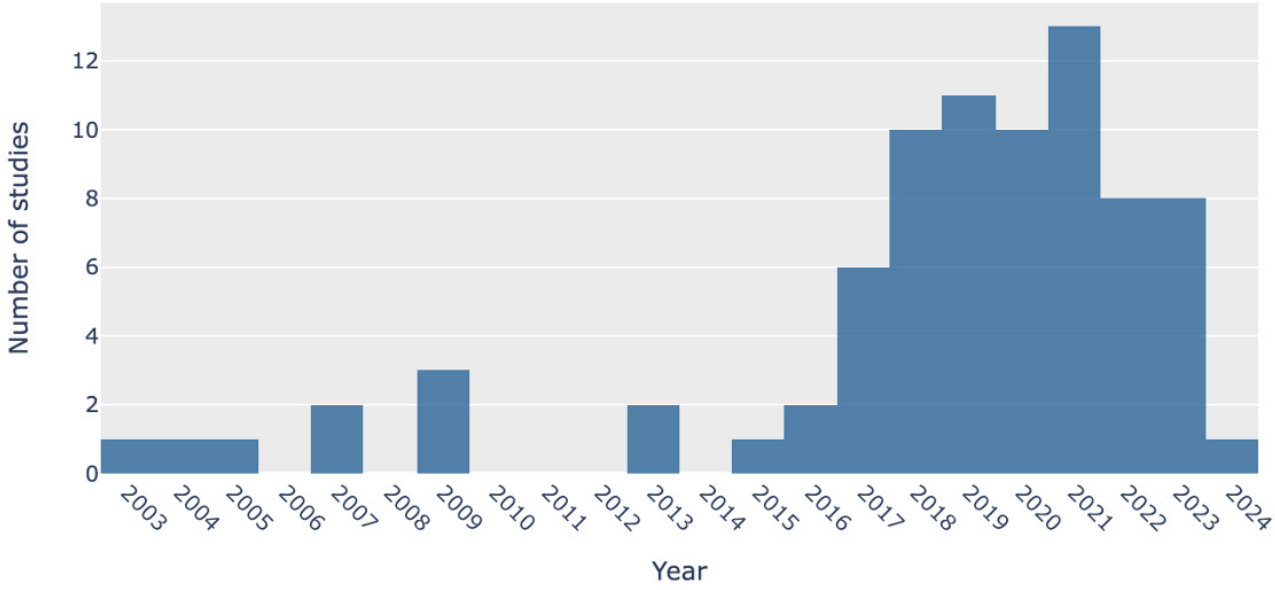

Figure 4: Total study counts by year. The plot indicates the number of studies included in the final analysis, counted by year of publication.

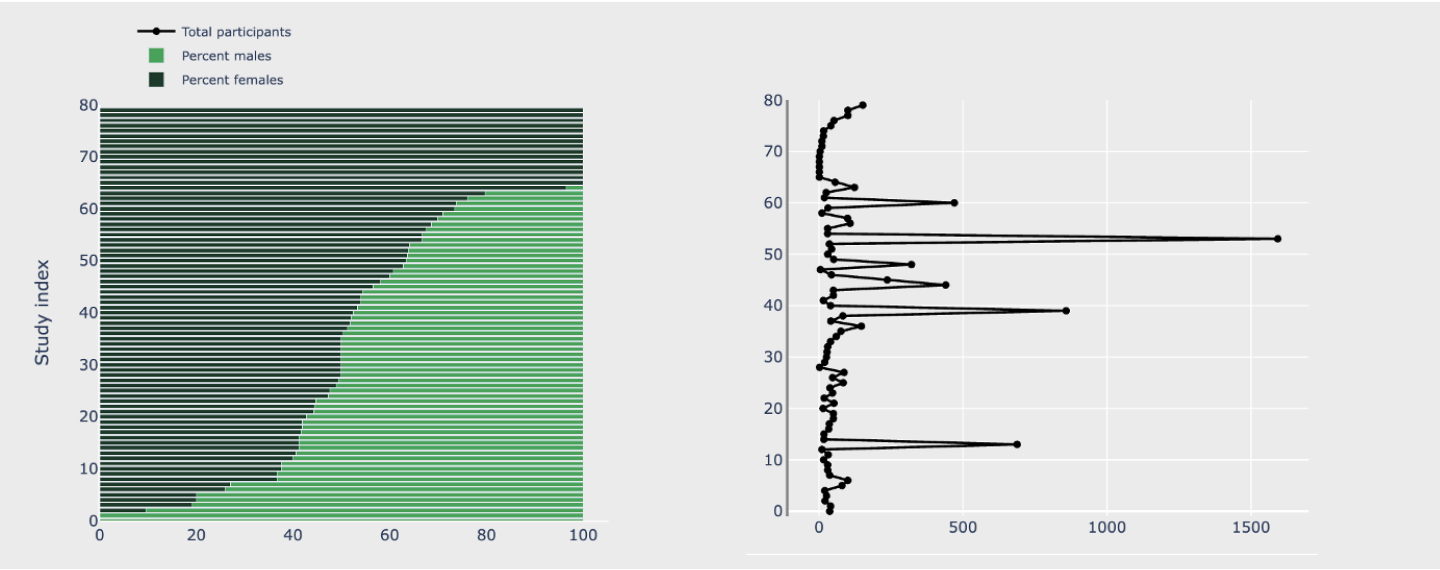

Figure 5: Female / male distributions and total participant counts. The left plot indicates the percentage of reported males and females in each study. The corresponding right plot shows each study's total participants.

We determined that 17 of the 80 studies were not applicable to a group difference analysis because participants were indicated as either all male or female. We were also unable to ascertain whether an analysis had been performed in nine studies due to paywalls and an absence of reporting in the abstract. Of the remaining 54 articles, 35 of them did not report whether a group analysis had been performed at all. One reason for this is likely due to small sample sizes — 12 of the 13 studies with less than 30 participants did not mention testing for group differences. However, larger studies with at least 30 participants also frequently refrained from reporting group analysis, totaling 23 of 41 **(figure 6)**.

Overall, 12 studies indicated no significant differences between males and females, with measurements including susceptibility to motion sickness,[10] cybersickness,[11–13] and patient experience ratings.[14] Seven studies reported positive comparisons, including greater motion sickness susceptibility,[15] greater motion sickness,[16–18] greater discomfort,[15,19] and lower likelihood of achieving a good fit in females.[20] Interestingly, a large-scale social media analysis of public perception of VR-reported female comments were associated with higher valence scores than males.[21] If we include articles that were originally discarded due to inaccessible or unreported participant counts, 27 total studies indicated some comparison between males and females, with 13 of them reporting significant differences. Most of these indicate greater levels of discomfort, cybersickness, or motion sickness in female participants **(table 2)**.

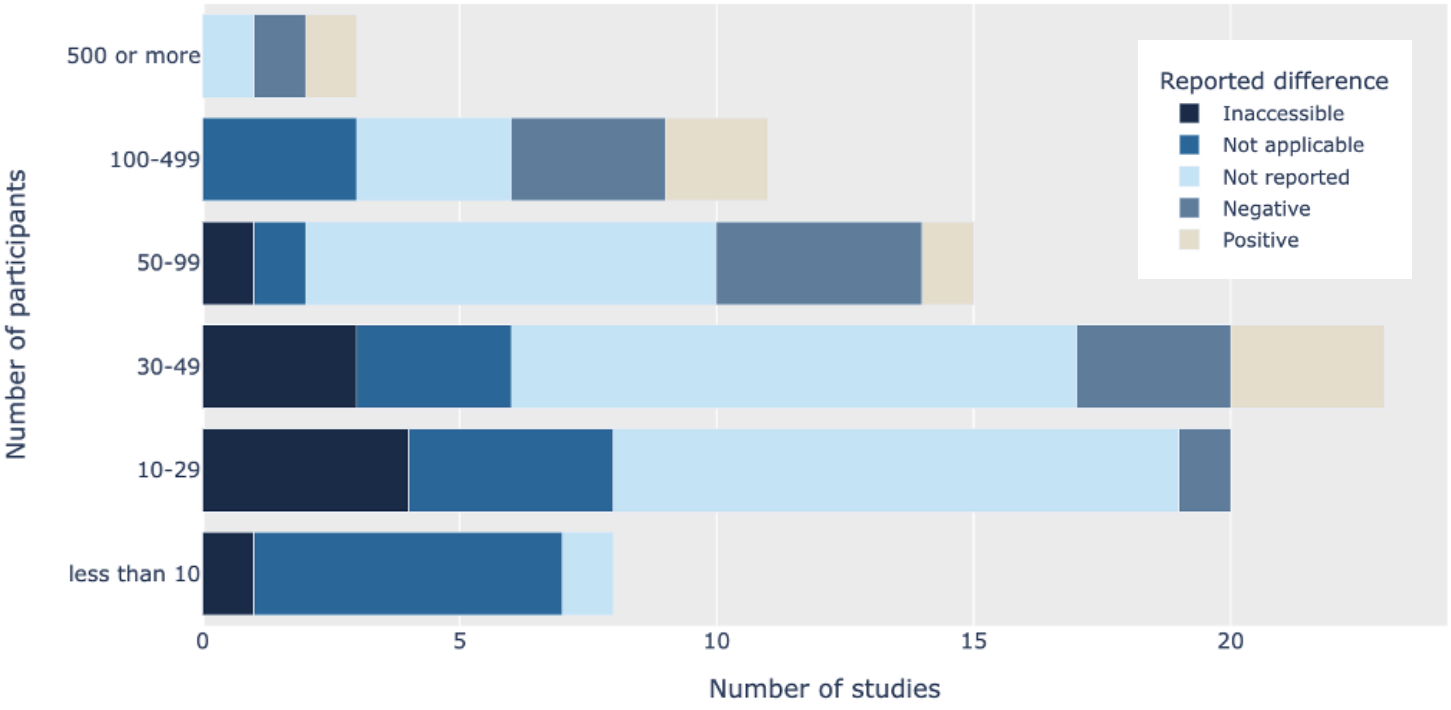

Figure 6: Distribution of reported findings, grouped by participant pool size. The number of studies reporting differences between males and females are shown according to participant pool sizes. “Inaccessible” indicates that the article did not report findings in the abstract, or that the article was not available to view open-source. “Not applicable” was assigned to studies in which participants were reported as all female or male. “Not reported” indicates the article did not report a differential analysis between females and males. “Negative” indicates that statistical tests between males and females were reported as not significant, while “positive” indicates tests were significant.

Study	Females	Participants	Measurement	Difference
MS Keller et al., 2017 [21]	1021	1614	comment valence	females > males
R Pot-Kolder et al., 2018 [22]	inaccessible	170	cybersickness	females > males
S Weech et al., 2018 [17]	19	30	cybersickness	females > males
GM Bannigan et al., 2024 [19]	20	30	discomfort	females > males
D Odell & N Dorbala, 2023 [23]	inaccessible	16	discomfort	females > males
B Keshavarz et al., 2021 [15]	195	321	dizziness, headache, fatigue, eye strain, motion sickness susceptibility	females > males
S D'Amour et al., 2017 [24]	inaccessible	82	fast motion sickness	females > males
K Stanney et al., 2021 [20]	74	147	inability to achieve fit	females > males
L Tychsen & P Foeller, 2019 [16]	21	50	motion sickness	females > males
TA Stoffregen et al., 2017 [18]	20	40	motion sickness	females > males
NA Matas et al., 2015 [25]	inaccessible	88	simulator dropout	females > males
J Munafo et al., 2016 [26]	inaccessible	inaccessible	motion sickness	females > males
RS Kennedy et al., 1996 [27]	inaccessible	inaccessible	motion sickness	males > females
AA Alharbi et al., 2021 [28]	inaccessible	60	anxiety	none
J Roettl & R Terlutter, 2018 [29]	134	237	cognitive load	none
P Larson et al., 1999 [30]	inaccessible	inaccessible	cognitive performance	none
P Pavilionis et al., 2023 [31]	279	688	concussion symptom provocation	none
R Hernandez et al., 2021 [13]	4	20	cybersickness, presence, usability	none
AP Garcia et al., 2013 [32]	28	44	dizziness	none
I Lukacova et al., 2023 [10]	239	440	motion sickness susceptibility	none
M Guenther et al., 2022 [14]	21	40	patient experience	none
S Cesaroni et al., 2019 [33]	54	56	postural control	none
AA Alharbi et al., 2017 [34]	30	60	postural stability	none
H Kim et al., 2021 [12]	43	83	simulator sickness, fast motion sickness	none
B Keshavarz et al., 2022 [35]	25	43	simulator sickness, fast motion sickness, visually induced motion sickness	none
S Gopalakrishnan et al., 2020 [36]	26	100	visual acuity	none
Y Sawada et al., 2020 [11]	16	80	visually induced motion sickness	none

Table 2: Overview of studies reporting female/male group comparisons. The number of female participants, total participants, behavioral measurement, and the measurement difference is shown for each study that reported a comparison between males and females. Note, studies in which the female participant count was inaccessible were not included in the previous analyses on participant counts.

Overall, our analysis shows that distribution of male and female participants in our collection of studies was relatively balanced. Additionally, the studies that did report group comparisons exhibited a mix of results, with just under half showing females experienced greater unpleasant effects. Of note, an overwhelming majority of studies in our sample did not report performing any comparisons between males and females, and this is not limited to studies with small participant samples. Additionally, the large number of studies that we had to exclude from our analyses due to a lack of reporting participant sex or gender is not uncommon to those reported previously[8,9]. On the whole, our results highlight a lack of reporting male/female comparisons, while those that do report comparisons tend to show either no difference, or greater unpleasant experiences for females.

Discussion

We carried out a three-part process for identifying standards that could benefit from a fuller account of safety for females. This involved a survey of our standards for anthropometric requirements that might differentially affect male and female users, examining safety incident records on related products, and investigating research articles for differential sex effects. We view this work as a modified process put forth by CSIL[2], further augmented by incident data and research evidence. Our hope is to offer a way for other SDOs to incorporate data-driven practices into their own efforts towards gender-responsive standards.

The data we leveraged are open-access and freely available. Barriers toward employing this approach, therefore, we hope are minimal. However, drawing definitive results regarding differential effects between males and females was not without challenge. For example, our examination of emergency department visits involving VR headsets revealed that female users more frequently experience injuries that are given ambiguous diagnoses. And our landscape analysis of academic research demonstrated some contention as to whether female users are more susceptible to cybersickness and discomfort from VR headset use. At the same time, similar to a previous review of VR studies[9], we found that most studies we examined did not investigate effects in females and males separately, despite having sample sizes that could have supported such analyses. These findings suggest female VR users might face safety issues that would be difficult to pinpoint in a scalable manner given this lack of standardized data and testing. This is likely to be a non-trivial challenge in scaling this method for other SDOs.

Moreover, underrepresentation of females in medical research studies is a well-known problem [37–40], and lack of appropriate data could continue to be a central challenge towards developing gender-responsive standards. Anecdotally, we have witnessed this as a point of frustration – in the 2023 World Trade Organization Youth Summit on Trade and Gender, presenters commonly expressed that a roadblock for measuring impact was a lack of sex-disaggregated data.[41] Likewise, standards technical committees in our own organization have communicated challenges to rationalize updating technical standards for gender-responsiveness without the data to support such efforts.

To that end, concurrent with the incident and literature analysis, we conducted a survey of 412 VR users across the U.S., Canada, India, and ASEAN countries to collect data on headset usage, practices, and bodily effects. We found significant differences between males and females, including the Total Simulator Sickness Score[42], with female respondents experiencing “concerning” or “bad” symptoms[43] during use 17% of the time, compared to 8% in males. Additionally, we found within the first ten minutes of use 52% of female respondents report experiencing stomach awareness, 48% report nausea, and 47% report vertigo and general discomfort – also significantly higher rates than those reported by males. Moreover, 14% of females report experiencing headaches every session compared to 6% of males.

And while typical VR sessions last an hour or less for all users, 29% of males, compared to only 20% of females, reported sessions lasting 1-2 hours, indicating differences in overall exposure. These survey results not only align with the above findings, but also provide a user-centric perspective indicating a need to mitigate early onset of discomfort and ultimately better protect female users.

While the survey addresses some concerning gaps in sex-disaggregated VR usage data, it is part of a separate effort at ULSE and is not crucial to the standard selection method we have otherwise outlined. Regardless, we hope the above analyses demonstrate how other SDOs might draw gender-related insights from freely available sources, and helps those seeking to develop gender-responsive standards.

Limitations

Our method was subject to limitations which would ideally be overcome by SDOs who wish to consider their own standards for gender responsiveness. First, the CSIL guidance for assessing anthropometric adequacy in standards included additional information we did not consider, such as the area of expertise of a technical committee. While our approach paralleled their analyses of text and references, information pertaining to the anthropometrics expertise of technical committee members may further clarify the anthropometric relevance of a standard. Second, we were unable to perform statistical testing on VR headset incidents due to their low amount, and as such our results on incident rates are best interpreted as observational trends only. Over time, as more VR headsets enter the market and data is collected through NEISS, more robust statistical testing should be available. Third, our query for research articles was limited to Pubmed abstracts and open-access papers. While this hindered our ability to fully assess the research landscape on VR user experiences, we believe paywalls will not be an uncommon challenge faced by other SDOs, and as such our method demonstrates what can still be performed given restricted resources to research.

Next Steps

For next steps in the pilot project, we are continuing to review UL 8400 for gender responsiveness and have sought out external experts in human factors engineering and kinesiology to help analyze and provide input on the technical requirements through a gender lens. Input by these external experts will be used to develop and submit proposals to the standards technical committee in line with ULSE's standards development process. Throughout the process of selecting UL 8400 and leveraging public data to identify potential opportunities for improving its safety impact, we prioritized engaging with the standards technical committee to promote awareness on the importance of considering gender in standards development. By conducting the pilot project, we developed a methodology for identifying standards that require further review to bolster gender responsiveness, and developed proposals for a more gender-responsive voluntary consensus standard with UL 8400.

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