with the previously observed results indicating *eye strain* resulting from vergence-accommodation conflict. It is important to note that in our setup the objects did not present extreme negative or positive parallax. This could be one of the reasons as to why other symptoms were not reported. Our results are in line with Shibata et al.'s [36] findings. We can conclude that for the 2D-3D condition, if we limit extreme parallax we gain on accuracy with lesser fatigue.

2D-VO condition.

The outcomes of the experiment suggest that 2D-VO condition fares worst in terms of accuracy and average task time. Even if we only consider the *hard difficulty level*, we see that the results are just marginally better than the 2D-2D condition for accuracy and still worse for average task time. From the NTLX scores for *mental demand*, we find that it has higher values than the other two conditions. These results are unexpected. We assumed that a more realistic representation of objects would help recover more information and hence help accuracy.

4.2 Implications

A general and direct implication of these results is that an MDE consisting of a spatial 3D display and a 2D display should be avoided for spanned tasks involving high cognitive load. This was contrary to our initial expectation that 2D-VO condition would be significantly better than the rest. However, as pointed out by Grossman and Balakrishnan [13], there are a few mitigating factors for poor performance of a spatial 3D display. Even as of today, the display quality of such devices is not at par with that of 2D and stereo-3D displays. There are artefacts in the display (for e.g. the central spine of the display cannot show any information and colour quality) which can influence the results. However, it is also important to note that in our case, the experimental setup was designed such that these effects were minimized. The visual size of the output of all three displays was matched and there were no extra visual cues provided by the shapes shown on the 2D display or the stereo-3D display.

When compared to the 2D-2D condition, it is possible that there are other focus based factors affecting the performance for 2D-VO condition. For the side-by-side 2D displays, the user has a fixed reference to a focal point on the plane of the display. However with a spatial 3D display, there is no central plane and thus no central point of focus. This can add to mental load when there is switching between the displays.

Also as the visualization of the shape in true 3D makes it look more real, it is possible that the switching process becomes one where the user has to switch contexts (from virtual world to real world) and they potentially do not view the two displays as a part of the same system. Such a situation also arises when the user has to switch focus between a physical object and a virtual object. Surprisingly, we could not find any research that investigates performance effects while comparing a purely virtual context to one with mixed context. The closest work is in the tangible literature by Marshall et al. [27] where they cautiously suggest that in a single user instance, a tangible interface is not necessarily better. Thus further investigation in this regard is warranted.

It is also possible that users find it difficult to compare a true 3D shape with a 2D shape that the first display shows. We refrained from using perspective correction on the 2D shape for the 2D-VO condition as the static 2D served as a common control shape to all three experimental conditions.

Lastly, as a recommendation for selection of 3D display elements for MDEs, we feel that there is a possible benefit of amalgamation of the 2D-2D and 2D-3D condition. The 2D-2D condition allowed perspective corrected views and motion parallax for the second shape. Comparing its accuracy results with 2D-3D, the overall results for symptoms and NTLX we can argue that this may be an ideal configuration for prolonged use tasks. With the availability of low cost desktop based head tracking systems, it might be beneficial to have a stereo-3D display which is operated mainly in 2D mode but allow perspective corrected views for presenting 3D. Only when the task involves high density of 3D elements, the device can switch to stereoscopic mode thus adding binocular disparity as another cue.

4.3 Future Work

We do not believe that a spatial 3D display is unsuitable for MDE setups. For tasks similar to our experimental task, our results hold true. However there may be other tasks with minimal cross-device contexts wherein a spatial 3D display may prove to be more beneficial. Future work could be used to explore the impact which the task has on our results. Furthermore, effects like aesthenopia and nausea were not a major factor in any of our conditions. However, with prolonged use, the effects may become most prevalent in the 2D-3D condition. Another factor of our tested MDE setups is that they all contained only 2 displays. In the future, it may be interesting to understand the impact of having a greater number of displays, or including displays with larger form factors and with arrangements that favor the type of 3D display used.

5 Conclusion

We have investigated the performance cost of repetitive switching between a 3D (stereo or spatial) display and a standard 2D display in context of a MDE. The experimental results prove that there is a cost involved with the scenarios involving a 2DD and a spatial 3D display which is higher than other scenarios. The results should provide a guideline for the design of MDEs utilizing either spatial 3D or stereo-3D elements.

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