Bridging Subjective and Physiological Measures of Cognitive Load in Imaging-Guided Environments

[1] Yun Wu, and [1] Bin Zheng
[1] Department of Surgery, University of Alberta, Edmonton, AB T6G 2S2, Canada
Email: bin.zheng@ualberta.ca

INTRODUCTION

Operators in demanding environments such as surgery often face challenging moments with significant cognitive loads. This issue is particularly evident in imaging-guided tasks, such as visual tracking and endoscopic surgery, where operators must process complex visual information while making decisions or performing precise manual actions. Accurately measuring operators' workload is essential for enhancing safety and efficiency. As the multimodal approach that combines subjective assessments with objective data gains popularity, understanding the correlation between these methods becomes increasingly important

This study aims to advance the understanding of workload assessment and make several key contributions: i) Reveal a direct correlation between subjective workload measures (NASA-TLX) and objective indicators (pupillary responses) across two different imaging-guided tasks. This will validate pupil responses as a reliable measure of workload applicable to different task types; ii) Reveal how tasks requiring both visual and motor coordination differ from those involving only visual tracking in terms of workload, as evidenced by both subjective and objective measures; iii) Reveal the influence of repeated task exposure on workload, as evidenced by both subjective and objective measures [1].

MATERIALS AND METHODS

Participants performed either a visual tracking or laparoscopic visuomotor task, with eye movements recorded by a Tobii Pro Nano eye tracker.

In the visual tracking task, participants watched an arrow move within an 8×8 grid (2 cm² cells) at one cell per second. Task complexity increased with more directional changes (3-11) and longer paths across five difficulty levels, each shown twice to evaluate repetition effects on workload. After each task, they completed a NASA-TLX and had pupil data recorded. Sessions included five-minute breaks and lasted about 30 minutes.

The laparoscopic visuomotor task required eye–hand coordination in a simulation enviroment. Participants used graspers to insert a surgical needle through a silicone pad without knotting. Three difficulty levels, including easy (1 cm strip, stable platform), medium (0.5 cm, movable platform), and hard (0.25 cm, shaky platform), all at 6 cm height. Each 15-minute session spanned three days; each task difficulty repeated twice. Eye-tracking was calibrated before sessions, and NASA-TLX assessments were completed after, with 10–20-minute rests between sessions.

Statistical analyses were performed using R and RStudio. For the first hypothesis, pupil size was correlated with NASA-TLX scores using Pearson's correlation and linear regression, visualized with GGally scatter plots. For the second and third hypotheses, t-tests compared outcome variables between tasks, and paired t-tests compared variables between repeated trials..

RESULTS AND DISCUSSION

15 participants participated in the visual tracking task (5 males and 10 females), with a mean age of 28 ± 7 years. 22 participants completed the laparoscopic surgery task (10 males and 12 females), with a mean age of 22.8 ± 4.6 years. The results showed a moderate positive correlation between pupil size and NASA-TLX scores ($r = 0.513$, $p < 0.001$). The laparoscopic surgery task, which requires visuomotor coordination, resulted in significantly higher NASA-TLX scores ($t = 6.23$, $p < 0.001$), larger original pupil sizes ($t = 22.57$, $p < 0.001$), and more adjusted pupil sizes ($t = 22.57$, $p < 0.001$) than the purely visual task. Additionally, task repetition led to a significant reduction in the NASA-TLX scores ($t = 2.86$, $p = 0.005$), the original mean pupil size ($t = 5.50$, $p < 0.001$), and the adjusted pupil size ($t = 6.34$, $p < 0.001$).

CONCLUSIONS

This study contributed to a better understanding of how subjective and objective measures of workload relate to each other in complex imaging-guided task environments. The main research finding revealed a significant, moderate correlation between NASA-TLX scores and pupil size measurements, supporting the use of eye tracking as an objective tool for assessing workload. Furthermore, this study clarifies how tasks involving eye–hand coordination differs from purely visual tasks in their impact on both subjective and objective workload indicators, and how repetition practice influences these measures.

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REFERENCES

[1] Yun W et al. *Applied Sciences, 14(24), 11975..*