Enhancing Ergonomics in Gastrointestinal Endoscopy through the Integration of Head-Mounted Display (with video)

Journal:	*Digestive Endoscopy*
Manuscript ID	JGES-DEN-2024-16161
Wiley - Manuscript type:	Original Article
Date Submitted by the Author:	09-Oct-2024

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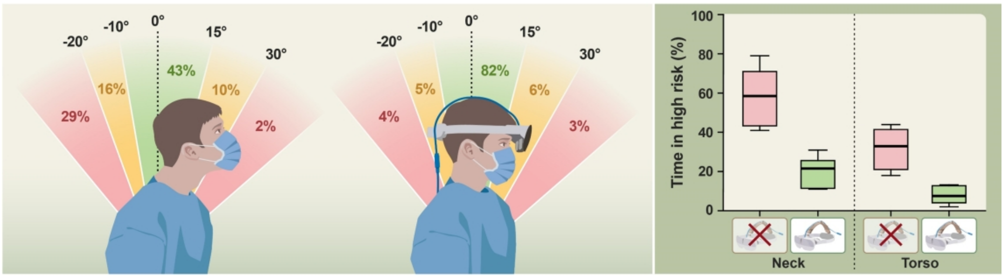
Keyword - Please refer to MESH keyword list. (See above for URL):	Ergonomics, Endoscopy, Smart Glasses
Please choose 1 to 5 categories from the list provided that describes your manuscript. This will aid in finding suitable reviewers for your manuscript.:	Endoscopic instrumentation: Imaging, Endoscopic instrumentation: Education & training



Graphical abstract

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Enhancing Ergonomics in Gastrointestinal Endoscopy through the Integration of Head-Mounted Display (with video)

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Grant support

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (grant no. NRF-2020R1A2C4002621). This study was supported by a grant of the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health and Welfare, Republic of Korea (grant no. HI14C3477).

Conflict of Interest Disclosure

All authors declare no conflict of interest and no financial relationships relevant to this publication.

ABSTRACT

Background and Aims

Endoscopists are at an increased risk of musculoskeletal injuries, which is known to be caused by poor endoscopic postures. There have been limitations to effectively improve endoscopists' ergonomics in a general practice setting. We systematically evaluated the ergonomic advantages offered by medical head-mounted display (HMD) during gastrointestinal endoscopy.

Methods

Upper gastrointestinal endoscopies were conducted both with and without the use of HMD. Experience was subjectively assessed through a NASA-Task Load Index (NASA-TLX). Biomechanical loads during the endoscopic procedures were recorded using electromyography and inertial measurement unit (IMU) sensors. A comparative analysis was performed between the cohort using HMD and the one without, focusing on perceived discomfort, muscle activity, and body posture.

Results

A total of 200 upper gastrointestinal endoscopies were conducted by five endoscopists, with 100 procedures using HMDs and the other 100 without HMDs. Average NASA-TLX scores of participants were lower when using HMD compared to the non-HMD cohort. The HMD cohort demonstrated enhancements in physical demand, effort, and frustration scores in comparison to the non-HMD cohort. Significantly low muscle strain was observed in the HMD cohort, particularly in the sternocleidomastoid and trapezius muscles. IMU analysis revealed a significant reduction in the proportion of high-risk postures of the neck and torso in the HMD cohort.

Conclusions

Utilizing medical HMDs has been shown to significantly improve examiner ergonomics by correcting harmful neck and trunk postures. The incorporation of HMD in gastrointestinal endoscopy is anticipated to enhance the overall ergonomics for endoscopists.

Introduction

Endoscopists face a heightened risk of musculoskeletal injuries (MSI), with reported prevalence ranging 39–89% [1, 2]. Various factors contribute to these injuries in the context of endoscopy, with the primary factor being the frequent performance of endoscopic procedures, leading to overuse and repetitive movements [3]. Additional risk factors include incorrect positioning during endoscopy procedures and specific maneuvers such as torquing during colonoscopy [4]. Research indicates that the most frequently reported areas of pain among endoscopists are the neck, upper back, hands, fingers, shoulders, and elbows [5, 6]. Despite the recent focus on providing ergonomics training that includes incorporating microbreaks and improving the endoscopy room environment [7], the practical application of these measures in a clinical setting presents certain difficulties. Endoscopists often sustain a prolonged, fixed posture while maintaining high concentration and exerting significant hand strength, especially when closely observing a stationary monitor. Engaging in complex endoscopic procedures like endoscopic submucosal dissection or polypectomy increases the likelihood of MSI [8]. Practitioners often adopt unfavorable postures, such as leaning their neck towards the monitor or standing lopsidedly, to carefully observe minor alterations on the endoscope screen. The use of a medical head-mounted display (HMD) provides the benefit of freeing surgeons from the constraint of observing a stationary monitor, thereby improving their ergonomic posture [9]. HMDs allow surgeons to practice in a more ergonomic and neutral position, which has been reported to result in less MSI. Until now, the ergonomic efficacy of HMD in the field of endoscopy has not been studied.

We conducted an experiment to evaluate whether the use of HMD provided ergonomic benefits for a group of endoscopists who were experiencing neck and shoulder pain during endoscopic procedures. Participants' ergonomic experience was subjectively assessed using a questionnaire based on the NASA-Task Load Index (NASA-TLX), while objective measures of biomechanical loads during the procedures were captured through electromyography (EMG) and the use of inertial measurement unit (IMU) sensors.

Materials and methods

Participants

Five gastroenterology fellows performed screening upper gastrointestinal endoscopy procedures using the HMD device. All participants possessed considerable experience, with each having completed more than 500 screening endoscopy procedures. Participants were not explicitly informed about the purpose of the experiment before it began. The experiment was conducted over 4 days for each participant. On the first day, participants completed 10 gastroscopy procedures using the HMD. After a 1-week interval, the same participants conducted another set of 10 gastroscopy procedures without the HMD, using the traditional monitor. The endoscopies were performed one week apart, alternating between the HMD-assisted method and the conventional approach. Biomechanical loads during the endoscopic procedures were measured using EMG and IMU sensors. A comparative analysis was conducted between the cohort using HMDs and those not using HMDs, focusing on perceived discomfort, muscle activity, and body posture. The endoscopic procedures were video recorded and subsequently reviewed by a physiatrist. Informed consent was obtained from the participants. The study was reviewed and approved by our institutional review board (2023AN0142, Approval date: April 10, 2023).

Head-mounted display

The medical HMD system SCOPEYE (MediThinQ, Seoul, Korea) consisted of a semi-transparent wearable glasses module and a wired image-transmitting main module (Fig. 1a). The wearable glasses module comprised two microdisplays with a screen resolution of 1920 × 1080 for each eye. The field of view was 40°, and the glasses weighed 410 g. Latency duration was no more than 30 ms. The SCOPEYE module consisted of a cable connected with a wired image-transmitting main module (Fig. 1a). The output signals of the endoscopy systems (Olympus, Tokyo, Japan) were transferred to the original medical monitor through the HMD transmitting module. Participants put on the HMD before endoscopy and conducted the procedure (Fig. 1b).

NASA-TLX

The workloads of participants were subjectively assessed using the online NASA-TLX scale [10]. Following the completion of endoscopy procedures, participants evaluated the difficulty of the procedure using the NASA-TLX, a quantifiable scoring system developed and validated by NASA to assess the workload in a procedure. The NASA-TLX encompasses six factors: mental, physical, and temporal demands; performance; effort; and frustration. The NASA-TLX questionnaire was administered four times to each participant, specifically after completing 10 gastroscopies.

Muscle activation analysis by EMG

Surface electromyography (sEMG) equipment was used to collect EMG signals using LXM 3208-RF (WEMG-8, LAXTHA Inc., Daejeon, Korea). Nine electrodes were affixed to the participant's body for the entirety of the procedures, enabling continuous measurement of EMG throughout the experimental processes. Measurement electrodes were attached to the right (R) and left (L) sides of the sternocleidomastoid (SCM), R and L trapezius pars descendens (TPZ), R and L brachioradialis, and R and L erector spinae longissimus. These sensors were calibrated by capturing each endoscopist's maximal voluntary contraction (MVC) before their initial observation. MVC is the voltage generated by a specific muscle group during a maximal contraction, which is indicative of the level of muscle activity. To allow for comparison across participants, %MVC is used. This is determined by dividing the sEMG measurement for a given task by the MVC for the corresponding muscle group of the individual. The primary outcome variable in this study was the %MVC [11]. Continuous sEMG data were collected from each muscle group as the participant performed each procedure. We calculated the overall average %MVC for each muscle group with and without HMD, and those values were compared using two-sided paired student's t-tests.

Objective posture measurement by IMU

A validated IMU system (TEA Captiv, Nancy, France) was used for the objective assessment of the endoscopist's posture throughout each procedure. The IMU sensors were placed on various body parts, including the head, chest, waist, left and right biceps, left and right wrists, and left and right hands, for motion tracking and to track body angulations. Postural angles of the neck, torso, and both shoulders were computed from the IMU data using a customized program in MATLAB (R2016b, MathWorks Inc., Natick, MA, USA). The IMU sensors calculate body posture angles by integrating data from an accelerometer, magnetometer, and gyroscope embedded within each sensor [12]. Ergonomic risk was assessed by calculating the percentage of time spent in a specified range of risk categories for each anatomical segment. The reference posture angles for our study were determined based on the reference angle values provided by the modified rapid upper limb assessment (RULA) tool and the IMU systems. RULA is a well-known assessment scale used to analyze upper limb–related MSI through evaluation of body posture, force, and repetition [12-14]. The IMU system's reference angles are based on exposure-response analyses from occupational ergonomic research, demonstrating clinically significant musculoskeletal disorders linked to exposure in the high-risk categories for neck, torso, and arm postures [15, 16]. Low risk posture (green colored zone) refers to conditions suitable for ergonomically performing endoscopy, intermediate risk posture (orange zone) signals a need for consideration and adjustment in activity, and high-risk posture (red zone) indicates inappropriate activity that needs an immediate correction [17]. We analyzed the angles of the neck and torso during endoscopy with an IMU.

Statistical analysis

Continuous variables were reported using mean ± standard deviation. Categorical variables were reported using proportion (%). Outcomes between the 2 groups were compared using a Student t test for continuous variables and a χ^2 test for categorical variables. Differences with $P < .05$ were considered significant. Statistical analyses were performed using SAS (SAS Institute, Cary, NC, USA).

Results

The experiment was conducted with five gastroenterology fellows as the participants, including three males and two females. Three participants were in their first year of fellowship and two participants were in their second year of fellowship. Participants were a median age of 32 years (range, 28-35). Median height was 170cm with range of height from 155cm to 178cm. Median weight was 62kg with a range of 54kg to 85kg. All participants reported being right-handed. The median number of colonoscopies of these participants per week was 19 (range, 12-26) and a median number of upper endoscopies per week was 28 (range, 24-34). No difference was observed in the mean total procedure time between the HMD and non-HMD cohorts (4.6 vs. 4.4 min, $P > 0.05$).

NASA-TLX

The NASA-TLX scores for endoscopic procedures with a conventional monitor and HMD are summarized in Table 1. The total NASA-TLX scores were significantly lower in the HMD cohort than those in the non-HMD cohort (31.9 ± 6.2 vs. 45.5 ± 9.8, $P < 0.05$). When the score was subdivided into individual components, it was significantly lower in the HMD cohort that that in the non-HMD cohort with regard to physical demand (5.8 ± 1.4 vs. 8.8 ± 1.6, $P < 0.05$), effort (6.1 ± 1.7 vs. 8.8 ± 3.1, $P < 0.05$), and frustration (4.4 ± 2.2 vs. 9.1 ± 1.8, $P < 0.05$) (Table 1). Several participants expressed concerns regarding the HMD device. One participant noted that the HMD felt slightly burdensome, but did not cause significant discomfort. Another participant mentioned that the screen dimensions of the HMD seemed somewhat small.

EMG during endoscopy

The HMD cohort had lower %MVC for most muscle groups near the neck including SCM and TPZ muscles. Muscle activation of both TPZ muscles was significantly lower in the HMD cohort compared with that in the non-HMD cohort (TPZR [6.8 ± 0.86 vs. 8.3 ± 1.26, $P < 0.05$]; TPZL [5.4 ± 0.86 vs. 6.6 ± 1.26, $P < 0.05$]) (Fig. 2). Muscle activation of the right SCM was also significantly lower in the HMD cohort compared with the non-HMD cohort (SCMR (5.1 ± 1.16 vs. 6.4 ± 1.86, $P < 0.05$) (Fig. 2). No significant difference in muscle activation was observed in the non-HMD cohort for other muscles compared with the HMD cohort.

Work postures assessment by IMU

During the assessment of work posture, five fellow endoscopists had their movements continuously monitored using an IMU recording device. The non-HMD cohort spent a substantial 57% of their procedure time in high-risk neck positions, as indicated by the orange and red zones in Figure 3a. In contrast, the HMD cohort spent only 18% of their procedure time in these high-risk neck positions. In the non-HMD cohort, high-risk extensions exceeding 20° were recorded for 29% of the total examination duration, while extensions ranging from 10° to 20° were noted during 16% of the procedure. In the HMD cohort, a marked improvement in the proportion of high-risk angles during endoscopy was observed. High-risk extensions of 20° or more were reduced to an average of 4% of the total examination time, and extensions between 10° and 20° decreased to 5% (Fig. 3a). The postural correction effect of the HMD was further confirmed through an analysis of the torso angle using IMU sensors. In the non-HMD cohort, torso flexion was predominantly observed, with high-risk flexion ranging from 20° to 45° occurring in 28% of the total examination time. However, this percentage significantly decreased to 5% in the HMD cohort (Fig. 3b). The HMD cohort had a significantly shorter percentage of procedural time in poor postures (orange and red zones as shown in Fig. 3) compared with those of non-HMD cohort for the neck (median [interquartile range, IQR]: 58.5 [45–71] % vs. 21.5 [12–24] %, $P < 0.05$) and torso (median [IQR]: 33 [21–40] % vs. 7.5 [4–12] %, $P < 0.05$) (Fig. 4).

Work postures assessment by physiatrist

The experiment was video recorded and analyzed by a physiatrist to identify characteristic postures exhibited by the endoscopists. Varying degrees of forward head posture (FHP) were observed in all participants who did not use the HMD (Fig. 5a). Additionally, poor postures such as thoracic kyphosis, continuous lateral cervical tilt, and trunk flexion (forward lean) were observed in more than three participants. In contrast, most participants in the HMD cohort showed significant improvements in FHP (Fig. 5b). They demonstrated a reduced tendency to lean toward the monitor, exhibited lower degrees of thoracic kyphosis, and maintained a neutral posture for longer periods (Video 1).

Discussion

MSI have been recognized as a significant challenge in the field of gastrointestinal endoscopy, with growing concerns about such injuries among gastrointestinal endoscopists. In a 2021 investigation, Pawa and colleagues conducted an electronic survey among 1,698 members of the American College of Gastroenterology to evaluate the prevalence of self-reported endoscopy-related injuries (ERI) [6]. The study revealed that 75% of the participants reported experiencing ERIs. The most frequently reported areas of injury were the thumb (63.3%), neck (59%), hand/finger (56.5%), and lower back (52.6%). Other studies have found that the neck and shoulder are the most common sites for ERIs [5, 18]. While the upper extremities and the thumb are mainly strained by handling the endoscope, neck and back are affected by awkward positions during endoscopic procedures and by focusing the video monitor [19]. Repetitive, high-force loading, especially in nonneutral postures, can overcome the internal tissue tolerances of the muscles, tendons, and nerves and lead to chronic tissue inflammation [8]. The importance of maintaining a neutral position of the neck and back in terms of endoscopic ergonomics has been well studied. American Society for Gastrointestinal Endoscopy (ASGE)'s 2023 endoscopic ergonomics guidelines also recommend adjusting monitor height to maintain a neutral neck and back position [7]. Recent statistics show that only 23.8% of endoscopists actually actively adjust the monitor height before procedures [19].

Our study showed promising results that introducing HMDs to gastrointestinal endoscopy can significantly improve endoscopists' ergonomics. One of the key benefits observed in this study is the correction of poor postures of the neck and torso during endoscopy. First, we objectively analyzed how poorly the endoscopists are postured when performing endoscopy. To our knowledge, this is the first attempt to objectively analyze endoscopists' neck and trunk motion using an IMU. When analyzing IMU data of endoscopic postures for fellows with neck and shoulder pain, a high-risk position of the neck was observed more than half of the procedure time. The HMD mitigated the risk of MSI by aligning the examiner's body in a more natural and comfortable way (Fig. 5b) (Video 1). The reduction in muscle strain by HMD is also noteworthy, as it indicates a less physically demanding experience for endoscopists, potentially contributing to improved overall job satisfaction and well-being. The examination of muscle activation patterns through EMG sensors revealed significant reductions in SCM and TPZ muscle activities in the HMD cohort. The ability of HMD to minimize muscle strain is crucial for preventing chronic conditions and injuries that may arise from prolonged periods of poor posture during endoscopic procedures. The participants did not express significant complaints regarding the functional drawbacks of HMDs in comparison to conventional monitors. The weight of the HMD was also not a major inconvenience. Because of the gap at the bottom of the HMD device, no problems were faced in operating the endoscopic instruments or monitoring patient vital signs.

A significant finding from this research indicates a potentially strong correlation between FHP and neck pain among endoscopists. A study by Markwell et al.[20] analyzed the postures of eight endoscopists and found that six had FHP, and neck pain was the most common complaint of the endoscopists in the study. Our research revealed similar results. In our study, participants without HMD exhibited FHP while simultaneously flexing their trunks forward and extending their necks backward. It is well-known that excessive neck extension, especially in FHP, significantly increases strain in the TPZ and SCM muscles [21]. In this experiment, we observed that the use of an HMD resulted in the correction of FHP in endoscopists.

This study had several limitations. The potential for HMDs to correct posture may be overemphasized, as the research was carried out with fellows who possessed limited understanding of ergonomic posture. Gastroenterology fellows are a group with a poor understanding of endoscopy ergonomics and are known to have a high incidence of MSI due to poor posture [22]. HMD may be less effective for experts or those with less neck pain. Second, the experiment was conducted with a small number of participants; therefore, it may not be representative of the general posture adapted by endoscopists. This study focused on the effectiveness of HMDs in correcting endoscopists' posture; long-term results will be needed to confirm a direct link to pain improvement. Assessing the efficacy of HMDs during more advanced, and thus, longer, endoscopic procedures such as endoscopic polypectomy or endoscopic submucosal dissection is imperative.

The HMD assisted endoscopists in adopting more neutral postures during the procedure and reduced surgical workload and muscular fatigue of the neck and shoulder. HMDs offer ergonomic benefits compared to conventional monitors and could present a novel alternative for endoscopists experiencing neck discomfort.

Author Contributions

Sang Hyun Kim: Conceptualization; Data Curation; Project Administration; Writing – Original Draft Preparation

Hyuk Soon Choi: Conceptualization; Methodology; Writing – Review & Editing

Han Jo Jeon: Validation, Supervision, Software

Jae Min Lee: Project Administration; Visualization

Eun Sun Kim: Funding Acquisition

Bora Keum: Formal Analysis; Resources

Yoon Tae Jeen: Investigation; Resources

Hong Sik Lee: Conceptualization; Methodology

Hoon Jai Chun: Supervision; Methodology

Bo Ryun Kim: Validation

Ethics Statement

- The study was reviewed and approved by our institutional review board (2023AN0142, Approval date: April 10, 2023).

- Informed Consent: N/A.

- Registry and the Registration No. of the study/trial: N/A.

- Animal Studies: N/A.

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Figure legends

Fig. 1 (a) Wearable medical head-mounted display (HMD) system SCOPEYE (MediThinQ, Seoul, Korea). (b) An endoscopist wearing HMD.

Fig. 2 %MVC data of individual muscles were compared between non-HMD and HMD settings. *$p < 0.05$ SCM, sternocleidomastoid; TPZ, trapezius pars descendens; ES, erector spinae longissimus; BR, brachioradialis; R, right; L, left

Fig. 3 The work postures for the neck (a) and torso (b) measured by IMU, comparing non-HMD (Left) and HMD cohort (Right). For each anatomical segment, the percentage of time spent in a particular risk category was overlaid on a semicircle representing the risk category. Low risk posture (green colored zone), intermediate risk posture (orange zone), high-risk posture (red zone)

Fig. 4 Percentage of procedural time in ergonomically poor postures for the neck and torso, measured by IMU, comparing non-HMD and HMD cohort. The central line in each boxplot represents the median, the edges of the box are the 25th and 75th percentiles, and the error bars extend to ± 1.5 of the interquartile range

Fig. 5 (a) Posture of an endoscopist using a conventional stationary monitor. (b) An endoscopist wearing HMD during upper gastrointestinal endoscopy.

Video 1. Comparison of endoscopist's posture during upper gastrointestinal endoscopy between conventional monitor and HMD settings.

Figure 1a

120x155mm (300 x 300 DPI)

Figure 1b

181x161mm (300 x 300 DPI)

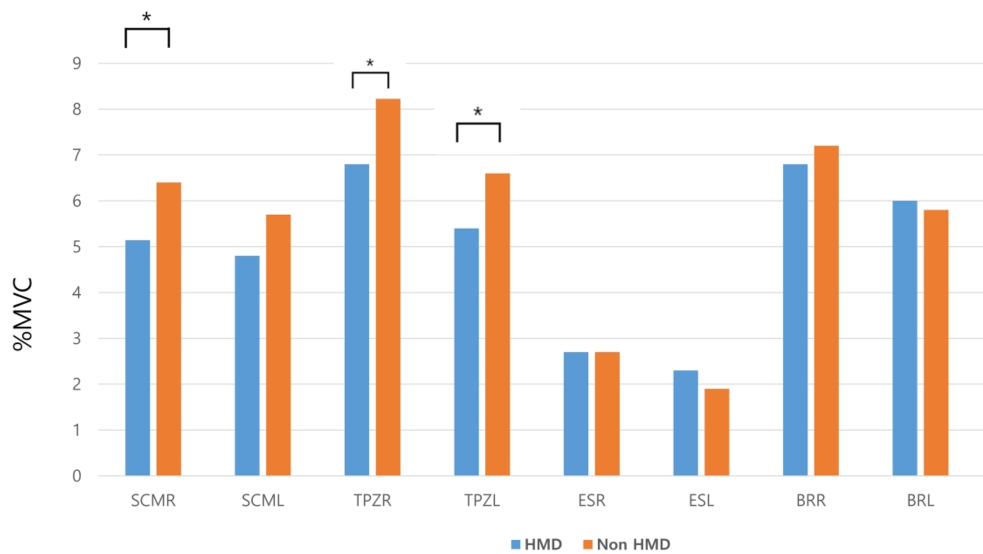

Figure 2

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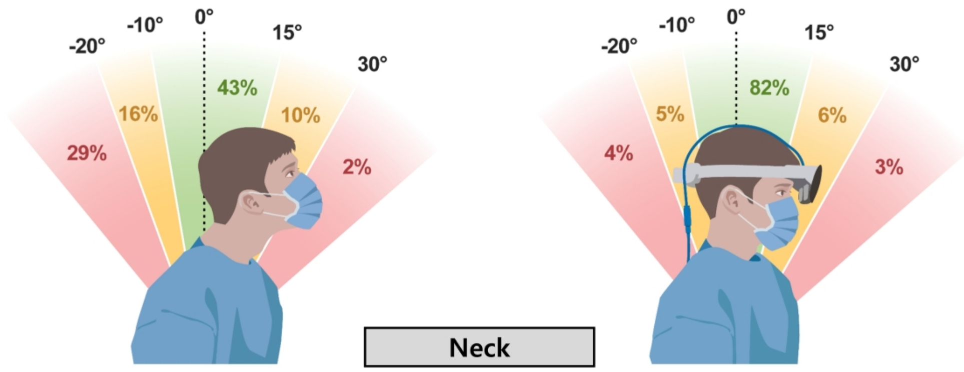

Figure 3a

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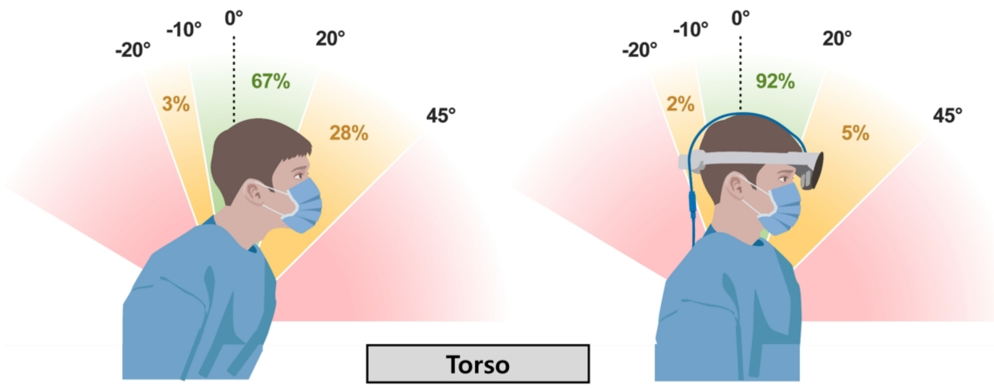

Figure 3b

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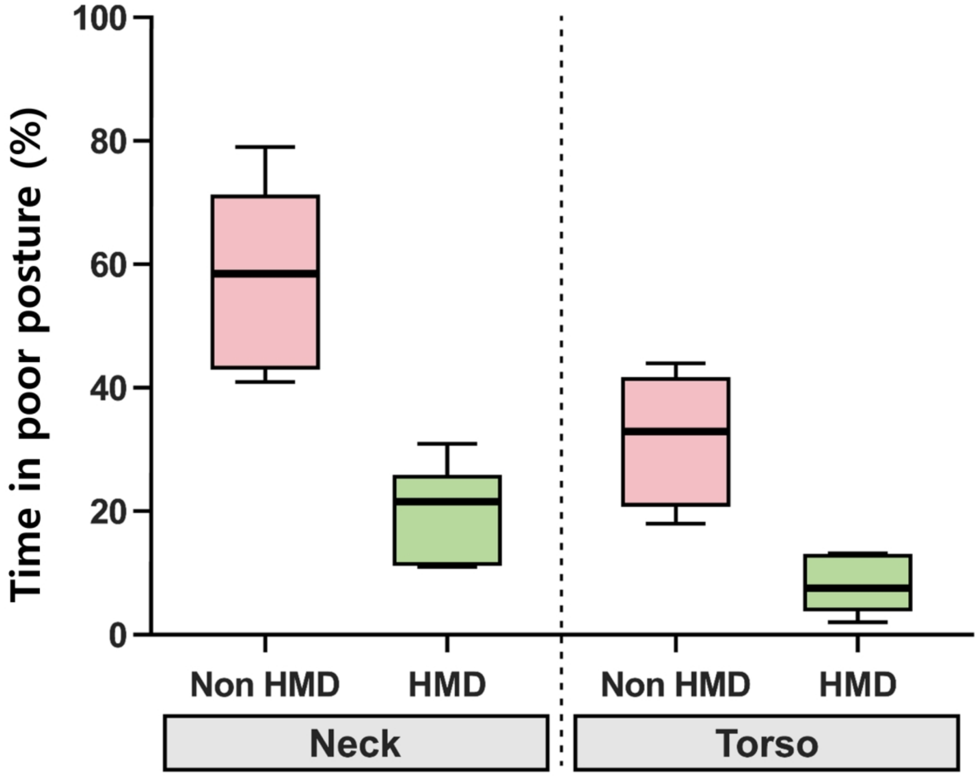

Figure 4

154x130mm (300 x 300 DPI)

Figure 5a

155x134mm (300 x 300 DPI)

Figure 5b

163x128mm (300 x 300 DPI)

Tables

Table 1. Comparison of NASA-TLX scores between HMD and Non-HMD cohort.

	Non-HMD	HMD	P value
NASA-TLX	45.5 ± 9.8	31.9 ± 6.2	<.05
Mental demand	7.7 ± 1.8	7.2 ± 2.3	.53
Physical demand	8.8 ± 1.6	5.8 ± 1.4	<.05
Temporal demand	6.3 ± 2.1	5.3 ± 2.8	.49
Performance	6.6 ± 2.9	4.1 ± 2.2	.32
Effort	8.8 ± 3.1	6.1 ± 1.7	<.05
Frustration	9.1 ± 1.8	4.4 ± 2.2	<.05

Values are mean ± standard deviation.

Authorship and COI form

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2. Drafting the work or revising it critically for important intellectual content;
3. Final approval of the version to be published;
4. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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