HoloNote: Exploring Augmented Reality Notifications for Ergonomic Feedback in Laparoscopic Training

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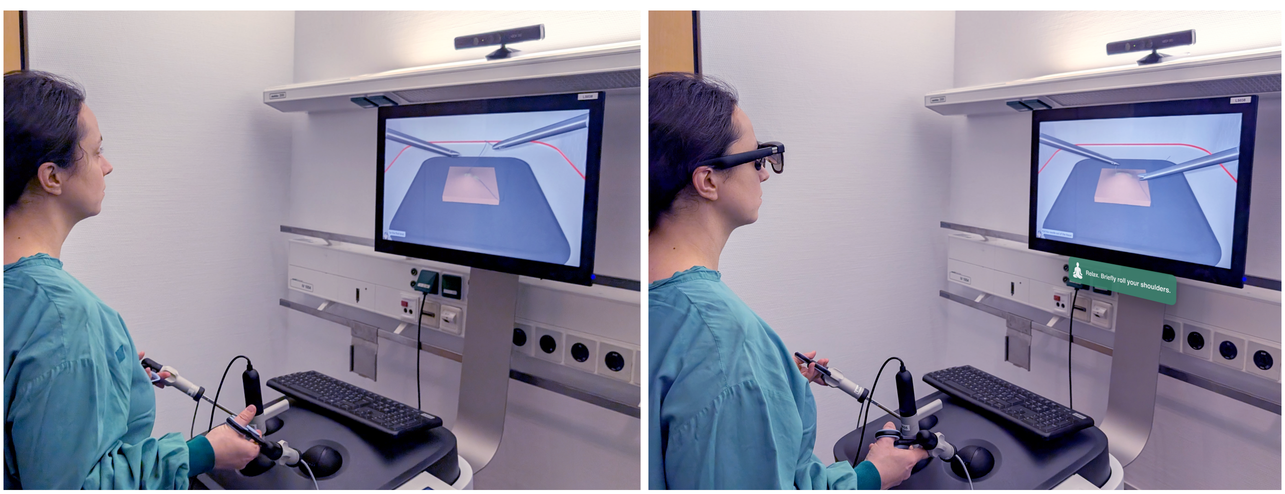

Figure 1: Laparoscopic training scenario without (left) and with (right) AR-based ergonomic notifications.

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Abstract

Laparoscopic surgery is a physically demanding task that can lead to ergonomic strain. While notification-based approaches have been used to support ergonomics in other domains, their application in laparoscopic surgery remains limited. Therefore, an augmented reality (AR) notification concept was implemented using lightweight optical see-through AR glasses, examining their suitability for laparoscopic training. A pilot study with ten surgeons was conducted using a laparoscopic simulator, where participants performed a stitching and knot-tying task with and without AR-based notifications. All participants were able to complete the tasks while wearing the AR glasses. While task completion times were longer in the AR condition, no conclusive differences in perceived workload were observed. User experience and wearing comfort were rated positively, whereas the notifications were perceived as useful but not consistently effective. The findings suggest that lightweight AR glasses are a feasible platform for ergonomic feedback in laparoscopic training and motivate further investigation.

CCS Concepts

• **Human-centered computing** → **Mixed / augmented reality**; **User studies**.

Keywords

medical augmented reality, computer-assisted surgery, notifications

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1 Introduction & Background

Laparoscopic surgery is a physically demanding task requiring sustained precision and constrained postures. Surgeons frequently adopt static or non-neutral body positions, particularly involving the neck, shoulders, and upper body, which are associated with musculoskeletal strain. Accordingly, ergonomics is a well-recognized concern in laparoscopic surgery, with studies reporting a high prevalence of work-related musculoskeletal symptoms [2]. Beyond surgery, prior work has demonstrated that providing feedback can improve ergonomics across a range of tasks, including computer work [1, 3, 21], care activities [4, 9, 17, 28], and industrial workflows [25, 27]. Across these contexts, feedback has been shown to improve posture quality [3, 10, 37], reduce time spent in non-neutral postures [26, 27], and decrease postural stress [1]. Most existing ergonomic feedback systems rely on vibrotactile or auditory cues, but visual feedback has also been explored as an alternative [24]. Across multiple contexts, visual feedback was found to be effective and often perceived as less disruptive and more intuitive than vibrotactile feedback [11, 18, 35]. Visual ergonomic feedback has been implemented using posture visualizations, risk highlighting, and desktop-based pop-up notifications [19, 36, 37].

Augmented reality (AR) offers a means to present visual feedback and notifications directly within the user's field of view. Prior work on notification modalities in AR suggests that visual notifications are effective and well perceived, offering advantages in ease of use, perceived performance, and quality of experience, as well as improved posture-related outcomes [18, 31]. At the same time, the effectiveness of AR notifications depends on their spatial presentation, with placement influencing noticeability, comprehension, perceived workload, and user preference [7, 22, 29, 33]. In laparoscopic surgery, AR may be particularly beneficial for delivering feedback, as surgeons already operate under high cognitive load and continuous visual demand. Prior work indicates that visual feedback in laparoscopy can improve information perception and be perceived as less disruptive than vibrotactile or multimodal feedback [13, 14]. More broadly, AR has been applied in laparoscopy to support the acquisition of desired behaviors, including access to preoperative imaging, ergonomic assistance, depth perception, and instrument motion analysis [6]. However, while systems exist to measure operator posture during laparoscopic procedures [5], AR-based approaches to ergonomic improvement have largely focused on optimizing the work environment rather than directly supporting the operator's posture. For instance, placing the laparoscopic image within the surgeon's line of sight has been shown to reduce neck strain and perceived workload [23, 39]. AR guidance has been used to reduce unnecessary movements by directing visual attention within the surgical scene [12]. Direct, posture-oriented feedback to the surgeon remains comparatively underexplored.

In this work, we explore the use of AR-based visual notifications to provide posture-related ergonomic feedback during laparoscopic training using a lightweight, optical see-through (OST) AR head-mounted display (HMD). Unlike prior approaches relying on monitors or bulky HMDs, our focus is on assessing whether a slim, glasses-like form factor can feasibly deliver ergonomic feedback without introducing additional physical burden.

Specifically, we address the following research questions: **RQ1:** Is it feasible to use lightweight OST AR glasses during laparoscopic training without substantially increasing perceived workload or preventing task completion? **RQ2:** How does the presence of AR-based ergonomic notifications affect task performance and perceived workload compared to a standard condition? **RQ3:** How are the AR system and the ergonomic notifications perceived in terms of usability, comfort, and usefulness?

To investigate these questions, we designed and evaluated a set of brief, visually integrated notifications intended to raise awareness of non-neutral head and body postures without interrupting the surgical task. An exploratory within-subject study using a laparoscopic simulator was conducted to assess feasibility, performance implications, and subjective perception. The results provide initial insights into the suitability of lightweight AR glasses for ergonomic support in laparoscopy and identify future challenges.

2 Materials & Methods

2.1 Apparatus

The XREAL Air 2 Ultra was selected as the AR HMD (XREAL, China). Prior AR-based approaches in laparoscopy have relied on HMDs with a substantially larger form factor, such as the Microsoft HoloLens [12]. Such devices may be less suitable for prolonged use in ergonomically sensitive tasks [15]. In contrast, the XREAL Air 2 Ultra provides stereoscopic visualization and 6 degrees of freedom (DoF) tracking in a lightweight form factor, allowing AR content to be presented without replacing the primary laparoscopic display or adding considerable physical load. The AR application was executed on an external Android-based compute unit connected to the HMD (XREAL Beam Pro, XREAL, China). An external depth camera

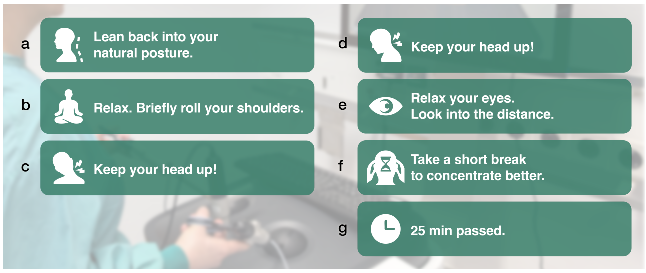

Figure 2: AR-based ergonomic notifications. Notifications a, c and d were triggered by automatic detections of headset movements. All others were time-based. Only notifications a-c were included in the experiment.

was used to record upper-body joint positions (Microsoft Kinect v1, Microsoft, USA). Data recorded with the Kinect were not used to trigger notifications and were not included in the quantitative analysis. The AR system was implemented using Unity (version 6000.0.47f1). The application utilized the HMD's built-in 6DoF tracking to obtain the user's head pose. To spatially align AR content with the laparoscopic display, marker-based tracking provided by the XREAL SDK was employed. A printed marker placed near the simulator screen was detected once at the beginning of each session to establish the screen's position relative to the user. After this initialization step, the marker was removed and notifications were rendered at fixed positions relative to the screen.

2.2 AR Notifications

The AR notification system was co-designed in close interdisciplinary collaboration between computer scientists and practicing surgeons (co-authors of this work). Clinical experts contributed domain knowledge regarding typical ergonomic strain patterns, acceptable visual distraction levels, and realistic workflow constraints in laparoscopic training. Their input directly informed the selection of posture-related notification types, threshold definitions for head movement, and wording and iconography of the prompts. Followingly, notifications combined simple iconography with short textual prompts [16] and were intended to be noticeable without interrupting task execution. Seven types of notifications were defined. Three of these were sensing-based and relied on head-pose information obtained from the HMD. The others were triggered based on time intervals. All notifications are shown in Figure 2. *Natural Position* (a) encouraged an upright, neutral posture with relaxed shoulders and was triggered when the user's head position moved outside a $25\,\text{cm} \times 25\,\text{cm} \times 25\,\text{cm}$ volume around a neutral reference position. *Relax Shoulders* (b) served as a periodic reminder to briefly relax shoulder tension. It was triggered every 60 s to ensure repeated exposure within the limited session duration. For future applications, longer time periods should be considered. Two head-orientation notifications addressed neck posture: *Head Tilt Sideways* (c) was triggered when lateral head tilt exceeded $17.5°$, and *Head Tilt Downwards* (d) was triggered when vertical head tilt exceeded predefined thresholds. Both notifications encouraged an upright head position to reduce potential neck strain. *Relax Eyes* (e) aimed to mitigate visual strain by encouraging brief gaze breaks or eye closure and was intended to appear infrequently over longer periods. *Break* (f) was designed as a rare reminder for extended pauses during prolonged activity. *Time* (g) provided information about elapsed task time and could be enabled as needed. To minimize cognitive load in this initial evaluation and due to limited simulator time, only notifications (a)–(c) were active during the study. This decision was based on suitability to the chosen simulator task.

All notifications were displayed using a consistent visual design. Messages were presented on a dark background with white text and icons, using a billboard size of $30\,cm \times 6\,cm$ and a font size of 30 to ensure readability. This design choice was informed by prior findings indicating that dark backgrounds with high-contrast text are suitable for indoor AR applications across devices and environments [8]. Notifications were world-stabilized and positioned below the laparoscopic display at the bottom center, as prior work has found bottom placement to be desirable [7, 22] and has suggested advantages of body- or world-anchored feedback over notifications anchored within the HMD display [20, 29]. In addition to visual cues, a short auditory signal was played when a notification appeared to support detection without requiring continuous visual attention. Notifications were blended in over 0.25 s and blended out over 0.25 s, and automatically disappeared after 4.5 s. When multiple notifications were present, they were vertically stacked, with the most recent notification displayed at the top.

2.3 Task and Simulator

The study was conducted using a commercial laparoscopic simulator (LapSim, Surgical Science, Sweden). Participants completed the *Stitch & Surgeon's Knot* lesson from the *Suturing and Anastomosis* module. The simulator provides a virtual surgical environment with integrated haptic feedback through laparoscopic instrument controllers. The task was performed on a virtual skin pad. At the start of each trial, two target positions were marked on it. Participants were instructed to insert a curved needle with an attached suture thread into the first marked position. Upon successful insertion, the target changed color. The needle then had to exit through the second marked position, which similarly changed color when successfully reached. After pulling the needle through the puncture site, participants were required to tie a laparoscopic surgeon's knot, followed by a second knot in the opposite direction to secure the suture.

2.4 Participants

Ten surgeons (7 female, 3 male) participated in the pilot study. Participants had a median age of 35. Nine participants were right-handed. Professional qualification ranged from first-year residents to specialist physicians, with seven participants holding specialist qualifications. Prior experience with virtual simulators and laparoscopic knot tying was assessed on five-point Likert items ranging from 1 (very low) to 5 (very high). Median self-reported experience was 2 for virtual reality and 2.5 for knot tying.

2.5 Study Design and Measures

The study followed a within-subjects design. Each participant completed the task in two conditions: the AR condition with ergonomic notifications and a standard condition without AR support. The order of conditions was alternated across participants. Task performance was recorded using the metrics provided by the laparoscopic simulator. For each condition, we collected task completion time and the simulator's overall performance score. The performance score is a composite metric calculated by the system and incorporates multiple task-related parameters, including instrument path length, angular movement, error events, and task completion time. Because completion time contributes to the composite score, the two measures are not independent. We therefore report both metrics separately for transparency and interpret the overall performance score with caution, acknowledging that differences in completion time may partially drive differences in the composite performance measure. Perceived workload was assessed for both conditions using the Surgery Task Load Index (SURG-TLX) [38], which measures multiple dimensions of surgical workload, including mental demand, physical demand, temporal demand, task complexity, situational stress, and distractions. Participants additionally completed the short version of the User Experience Questionnaire (UEQ) to assess pragmatic and hedonic quality of the AR system [34]. Furthermore, a set of custom AR-specific questionnaire items was administered to capture perceptions related to the AR system and the ergonomic notifications. These items addressed wearing comfort, perceived restriction of the field of view, perceived brightness restrictions, perceived usefulness of the notifications, and self-reported effectiveness regarding compliance with the provided instructions. All custom questionnaire items used five-point Likert items. For analysis and visualization, responses were mapped to a symmetric scale ranging from -2 (strong disagreement / rejection) to $+2$ (strong agreement / approval), with positive values consistently indicating more favorable evaluations.

2.6 Procedure

No formal institutional review board approval was required according to local institutional guidelines, as the study involved simulator-based tasks with professional participants and no patient data. Nevertheless, the study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. As such, upon arrival, participants were informed about the study procedure, and written informed consent was obtained. All data was handled anonymously. Participants then received a brief introduction to the AR prototype and an explanation of the laparoscopic simulation. The AR system was set up by a technical experimenter before being handed to the participant. Participants then performed the suturing task once for both conditions in alternating order. After each trial, they filled out the corresponding questionnaires. After completing both conditions, participants were given the opportunity to provide comments. Two experimenters were present throughout the study: one with clinical expertise to provide guidance related to the laparoscopic task and one responsible for technical setup and support of the AR system.

3 Results

No inferential statistics were performed due to the small number of subjects. Instead, the data were evaluated descriptively. Regarding performance, mean completion time was 438.63 ± 229.60 s in the AR condition and 209.99 ± 93.40 s in the standard condition. Individual differences were observed, but the trend toward longer task durations with AR was consistent across most participants. Similarly, overall performance scores were lower in the AR condition than in the standard condition. Mean scores were 38.44 ± 38.08 in the AR condition and 78.00 ± 18.24 in the standard condition. This pattern suggests reduced task efficiency when the AR HMD was worn. Given the small sample size and the pilot nature of the study, these differences should be interpreted with caution. Participants varied in their prior experience with laparoscopic simulation, and several reported limited familiarity with the simulator itself, which may have influenced performance outcomes. In general, the first performed trial also reliably showed worse performance, indicating strong learning effects.

Average SURG-TLX scores were comparable between conditions, with a mean of 47.70 ± 18.86 for the AR condition and 41.70 ± 17.90 for the standard condition. Across individual SURG-TLX subscales, no consistent pattern of increased workload attributable to the AR condition was observed (see Figure 3 top). Both pragmatic and hedonic quality scores of the UEQ were generally positive, with median ratings above the neutral midpoint. This suggests acceptable but improvable UX (see Figure 3 bottom left). Custom questionnaire items further indicated that participants rated wearing comfort, field of view, and brightness of the AR system positively (see Figure 3 bottom right). Perceived usefulness of the notifications showed mixed responses, with ratings spanning the full scale. Self-reported compliance with the notifications was similarly varied, indicating that while participants noticed and understood the notifications, they did not consistently act upon them during task execution.

In unstructured post-study feedback, experienced surgeons reported mixed reactions to the ergonomic notifications. Several noted that they already perform posture corrections automatically and therefore chose not to comply with some notifications, while others described the reminders as helpful for increasing ergonomic awareness. The bottom-centered placement of notifications was generally perceived as unobtrusive, but in some cases resulted in notifications being noticed acoustically rather than visually. Feedback on the AR glasses was largely positive: participants reported that the device was comfortable, not perceived as heavy, and compatible with prescription glasses, although minor adjustments were required in one case to secure the fit. Comments on the simulator highlighted limitations in haptic feedback and procedural realism, particularly among more experienced participants, suggesting that simulator fidelity may influence both task performance and perceived relevance of ergonomic feedback.

4 Discussion and Conclusion

This work presents an exploratory investigation of ergonomic notifications delivered via lightweight OST AR glasses in laparoscopic simulator training. Our findings indicate that such devices can be worn during a demanding surgical task without substantially increasing perceived workload, and that participants were generally able to complete the procedure while using the AR system. Subjective feedback further suggests that the glasses themselves were usable and comfortable, supporting the feasibility of the tested HMD as a platform for ergonomic support. These findings directly address **RQ1**, indicating that lightweight OST AR glasses can be

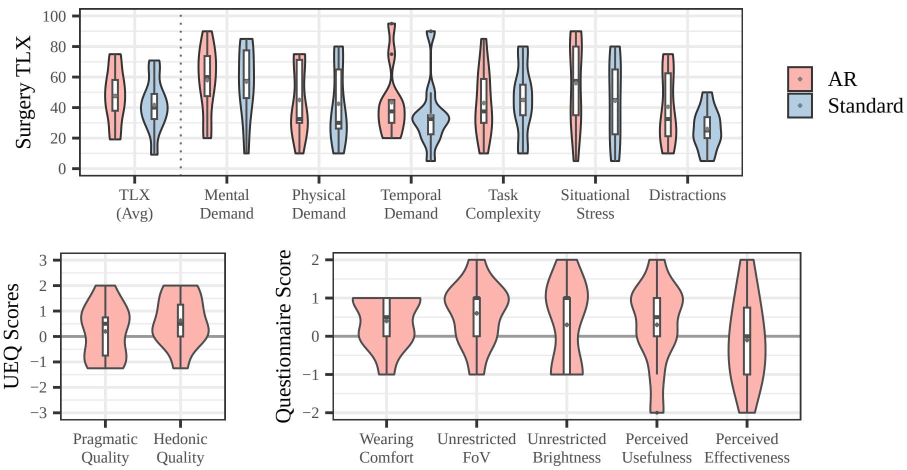

Figure 3: Subjective evaluation results. Top: SURG-TLX overall score and subscales comparing AR and standard conditions. Bottom left: UEQ subscale scores. Bottom right: Post-interview question ratings.

used during laparoscopic training without substantially increasing perceived workload or preventing task completion.

At the same time, task performance was lower in the AR condition, and this study could not demonstrate that the notifications were effective in improving ergonomics. In relation to **RQ2**, these findings suggest that although AR-based notifications did not increase perceived workload, their integration into the task may have introduced additional interaction or attentional demands that affected efficiency. Notably, the observed increase in completion time represents a substantial performance difference that would constitute a serious barrier in real surgical settings. Several factors may have contributed to this effect. Participants were unfamiliar with the AR device, and the additional visual layer may have required adaptation time. In addition, repeated notifications could have led to momentary attentional shifts particularly in a visually demanding task. Moreover, even though the visualization was described as unobtrusive, partial visual occlusion or increased visual complexity cannot be excluded. Future studies should therefore systematically investigate adaptation effects, notification frequency, and alternative placement strategies to disentangle performance costs from training and novelty effects.

Notification impact was assessed only through self-reported usefulness and compliance, which yielded mixed responses. Several experienced surgeons reported that they already self-correct posture and therefore chose not to follow the prompts, while others described the reminders as helpful. This indicates that the perceived value of ergonomic notifications may depend strongly on user expertise and task context, addressing **RQ3** by showing that while the system was generally perceived as usable and comfortable, the practical usefulness of the notifications varied across participants and situations. Consistent with findings from longer-term studies of notifications on smartglasses [30], notifications were noticeable but could still be deprioritized when users were highly engaged in a primary task. Additionally, although the visualization placement was described as unobtrusive, some participants reported relying more on the audio cues, suggesting that the visual cue may not have been sufficiently visible. Therefore, future work could investigate alternative feedback placements, such as anchoring feedback to the body rather than the environment [20, 32], or directly integrating feedback into the laparoscopic display.

Exploratory posture logging using a Microsoft Kinect was conducted to assess whether objective behavioral responses to notifications could be captured in this setting. In practice, the close proximity of the simulator and frequent occlusions led to missing or unreliable tracking data, limiting the interpretability of the recordings. Moreover, strong task engagement further reduced observable posture changes that could be meaningfully attributed to notifications. While isolated instances suggested potential value in combining AR notifications with external posture sensing, these findings primarily highlight the challenges of measuring ergonomic effects in realistic laparoscopic training setups.

Overall, the contribution of this work lies in demonstrating the feasibility of lightweight OST AR glasses for delivering ergonomic notifications in laparoscopic training and in identifying practical and methodological challenges related to notification design, performance trade-offs, and posture measurement. This study provides a foundation for future work with larger samples, improved sensing setups, and study designs tailored to specific expertise levels.

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References

[1] Ravi Charan Ailneni, Kartheek Reddy Syamala, In-Sop Kim, and Jaejin Hwang. 2019. Influence of the wearable posture correction sensor on head and neck posture: Sitting and standing workstations. *WORK* 62, 1 (Jan. 2019), 27–35. doi:10.3233/WOR-182839

[2] Chantal C. J. Alleblas, Anne Marie de Man, Lukas van den Haak, Mark E. Vierhout, Frank Willem Jansen, and Theodoor E. Nieboer. 2017. Prevalence of Musculoskeletal Disorders Among Surgeons Performing Minimally Invasive

Surgery: A Systematic Review. *Annals of Surgery* 266, 6 (Dec. 2017), 905–920. doi:10.1097/sla.0000000000002223

[3] Ahmad Bazazan, Iman Dianat, Nafiseh Feizollahi, Zohreh Mombeini, Alireza Mohammad Shirazi, and Héctor Ignacio Castellucci. 2019. Effect of a posture correction–based intervention on musculoskeletal symptoms and fatigue among control room operators. *Appl. Ergon.* 76 (April 2019), 12–19. doi:10.1016/j.apergo.2018.11.008

[4] Rik Bootsman, Panos Markopoulos, Qi Qi, Qi Wang, and Annick A. A. Timmermans. 2019. Wearable technology for posture monitoring at the workplace. *Int. J. Hum. Comput. Stud.* 132 (Dec. 2019), 99–111. doi:10.1016/j.ijhcs.2019.08.003

[5] Nicola Carbonaro, Gabriele Mascherini, Ilenia Bartolini, Maria Novella Ringressi, Antonio Taddei, Alessandro Tognetti, and Nicola Vanello. 2021. A Wearable Sensor-Based Platform for Surgeon Posture Monitoring: A Tool to Prevent Musculoskeletal Disorders. *Int. J. Environ. Res. Public Health* 18, 7 (April 2021), 3734. doi:10.3390/ijerph18073734

[6] Francisco Javier Celdrán, Javier Jiménez-Ruescas, Carlos Lobato, Lucía Salazar, Juan Alberto Sánchez-Margallo, Francisco M. Sánchez-Margallo, and Pascual González. 2025. Use of Augmented Reality for Training Assistance in Laparoscopic Surgery: Scoping Literature Review. *J. Med. Internet Res.* 27, 1 (Jan. 2025), e58108. doi:10.2196/58108

[7] Soon Hau Chua, Simon T. Perrault, Denys J. C. Matthies, and Shengdong Zhao. 2016. Positioning Glass: Investigating Display Positions of Monocular Optical See-Through Head-Mounted Display. In *ACM Other conferences*. 1–6. doi:10.1145/2948708.2948713

[8] Saverio Debernardis, Michele Fiorentino, Michele Gattullo, Giuseppe Monno, and Antonio Emmanuele Uva. 2014. Text Readability in Head-Worn Displays: Color and Style Optimization in Video versus Optical See-Through Devices. *IEEE Transactions on Visualization and Computer Graphics* 20, 1 (Jan. 2014), 125–139. doi:10.1109/tvcg.2013.86

[9] Ramez Doss, Jonathan Robathan, Daniel Abdel-Malek, and Michael W. R. Holmes. 2018. Posture Coaching and Feedback during Patient Handling in a Student Nurse Population. *IISE Transactions on Occupational Ergonomics and Human Factors* (Oct. 2018). https://www.tandfonline.com/doi/full/10.1080/24725838.2018.1428838

[10] Rhonda Epstein, Sean Colford, Ethan Epstein, Brandon Loye, and Michael Walsh. 2012. The effects of feedback on computer workstation posture habits. *WORK* 41, 1 (Jan. 2012), 73–79. doi:10.3233/WOR-2012-1287

[11] Michael Haller, Christoph Richter, Peter Brandl, Sabine Gross, Gerold Schossleitner, Andreas Schrempf, Hideaki Nii, Maki Sugimoto, and Masahiko Inami. 2011. Finding the Right Way for Interrupting People Improving Their Sitting Posture. In *Human-Computer Interaction – INTERACT 2011*. Springer, Berlin, Germany, 1–17. doi:10.1007/978-3-642-23771-3_1

[12] Florian Heinrich, Florentine Huettl, Gerd Schmidt, Markus Paschold, Werner Kneist, Tobias Huber, and Christian Hansen. 2021. HoloPointer: a virtual augmented reality pointer for laparoscopic surgery training. *Int. J. CARS* 16, 1 (Jan. 2021), 161–168. doi:10.1007/s11548-020-02272-2

[13] Thomas Howard and Jérôme Szewczyk. 2016. Assisting Control of Forces in Laparoscopy Using Tactile and Visual Sensory Substitution. In *New Trends in Medical and Service Robots*. Springer, Cham, Switzerland, 151–164. doi:10.1007/978-3-319-30674-2_12

[14] Thomas Howard and Jérôme Szewczyk. 2016. Improving Precision in Navigating Laparoscopic Surgery Instruments toward a Planar Target Using Haptic and Visual Feedback. *Front. Rob. AI* 3 (June 2016), 198921. doi:10.3389/frobt.2016.00037

[15] Florentine Huettl, Florian Heinrich, Christian Boedecker, Lukas Vradelis, Annekatrin Ludt, Werner Kneist, Hauke Lang, Christian Hansen, and Tobias Huber. 2023. Real-Time Augmented Reality Annotation for Surgical Education during Laparoscopic Surgery: Results from a Single-Center Randomized Controlled Trial and Future Aspects. *Journal of the American College of Surgeons* 237, 2 (2023), 292–300. doi:10.1097/xcs.0000000000000712

[16] Nuwan Nanayakkarawasam Peru Kandage Janaka, Shengdong Zhao, and Shardul Sapkota. 2023. Can Icons Outperform Text? Understanding the Role of Pictograms in OHMD Notifications. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. ACM, 1–23. doi:10.1145/3544548.3580891

[17] Megan Kamachi, Mohammadhasan Owlia, and Tilak Dutta. 2021. Evaluating a wearable biofeedback device for reducing end-range sagittal lumbar spine flexion among home caregivers. *Appl. Ergon.* 97 (Nov. 2021), 103547. doi:10.1016/j.apergo.2021.103547

[18] Mehakdeep Kaur, Hyeongil Nam, Ryan Kang, Dongyun Han, DongHoon Kim, and Isaac Cho. [n. d.]. When Senses Collide: Investigating Modality Congruence and Interference Between Task and Notification in Augmented Reality. In *2025 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, 08–12. doi:10.1109/ISMAR67309.2025.00117

[19] Joohee Kim, Na Hyeon Lee, Byung-Chull Bae, and Jun Dong Cho. 2016. A Feedback System for the Prevention of Forward Head Posture in Sedentary Work Environments. In *ACM Conferences*. 161–164. doi:10.1145/2908805.2909414

[20] Elisa Maria Klose, Nils Adrian Mack, Jens Hegenberg, and Ludger Schmidt. 2019. Text Presentation for Augmented Reality Applications in Dual-Task Situations. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 636–644. doi:10.1109/vr.2019.8797992

[21] Yi-Liang Kuo, Kuo-Yuan Huang, Chieh-Yu Kao, and Yi-Ju Tsai. 2021. Sitting Posture during Prolonged Computer Typing with and without a Wearable Biofeedback Sensor. *Int. J. Environ. Res. Public Health* 18, 10 (May 2021), 5430. doi:10.3390/ijerph18105430

[22] Hyunjin Lee, Sunyoung Bang, and Woontack Woo. 2022. Effects of coordinate system and position of AR notification while walking. *Virtual Reality* 27, 2 (2022), 829–848. doi:10.1007/s10055-022-00693-9

[23] Ae Kyeong Lim, Junsun Ryu, Hong Man Yoon, Hee Chul Yang, and Seok-ki Kim. 2022. Ergonomic effects of medical augmented reality glasses in video-assisted surgery. *Surg. Endosc.* 36, 2 (Feb. 2022), 988–998. doi:10.1007/s00464-021-08363-8

[24] Carl M. Lind. 2024. A Rapid Review on the Effectiveness and Use of Wearable Biofeedback Motion Capture Systems in Ergonomics to Mitigate Adverse Postures and Movements of the Upper Body. *Sensors* 24, 11 (May 2024), 3345. doi:10.3390/s24113345

[25] Carl Mikael Lind, Bart De Clercq, Mikael Forsman, Alain Grootaers, Mathieu Verbrugghe, Lieve Van Dyck, and Liyun Yang. 2023. Effectiveness and usability of real-time vibrotactile feedback training to reduce postural exposure in real manual sorting work. *Ergonomics* (Feb. 2023). doi:10.1080/00140139.2022.2069869

[26] Carl Mikael Lind, Jose Antonio Diaz-Olivares, Kaj Lindecrantz, and Jörgen Eklund. 2020. A Wearable Sensor System for Physical Ergonomics Interventions Using Haptic Feedback. *Sensors* 20, 21 (Oct. 2020), 6010. doi:10.3390/s20216010

[27] Carl Mikael Lind, Liyun Yang, Farhad Abtahi, Lars Hanson, Kaj Lindecrantz, Ke Lu, Mikael Forsman, and Jörgen Eklund. 2020. Reducing postural load in order picking through a smart workwear system using real-time vibrotactile feedback. *Appl. Ergon.* 89 (Nov. 2020), 103188. doi:10.1016/j.apergo.2020.103188

[28] Mohammadhasan Owlia, Megan Kamachi, and Tilak Dutta. 2020. Reducing lumbar spine flexion using real-time biofeedback during patient handling tasks. *WORK* 66, 1 (May 2020), 41–51. doi:10.3233/WOR-203149

[29] Lucas Plabst, Sebastian Oberdörfer, Francisco Raul Ortega, and Florian Niebling. 2022. Push the Red Button: Comparing Notification Placement with Augmented and Non-Augmented Tasks in AR. In *ACM Conferences*. 1–11. doi:10.1145/3565970.3567701

[30] Lucas Plabst, Lena Plabst, Florian Niebling, and Francisco R. Ortega. 2025. Five-day research-in-the-wild observation of notifications on smartglasses: A double edged sword. In *Proceedings of the 2025 31st ACM Symposium on Virtual Reality Software and Technology (VRST '25)*. ACM, 1–10. doi:10.1145/3756884.3765976

[31] Thiago Braga Rodrigues, Ciarán Ó. Catháin, Noel E. O'Connor, and Niall Murray. 2020. A Quality of Experience assessment of haptic and augmented reality feedback modalities in a gait analysis system. *PLoS One* 15, 3 (March 2020), e0230570. doi:10.1371/journal.pone.0230570

[32] Rufat Rzayev, Sven Mayer, Christian Krauter, and Niels Henze. 2019. Notification in VR: The Effect of Notification Placement, Task and Environment. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '19)*. ACM, 199–211. doi:10.1145/3311350.3347190

[33] Rufat Rzayev, Paweł W. Woźniak, Tilman Dingler, and Niels Henze. 2018. Reading on Smart Glasses: The Effect of Text Position, Presentation Type and Walking *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–9. doi:10.1145/3173574.3173619

[34] Martin Schrepp, Andreas Hinderks, and Jörg Thomaschewski. 2017. Design and Evaluation of a Short Version of the User Experience Questionnaire (UEQ-S). *International Journal of Interactive Multimedia and Artificial Intelligence* 4, 6 (2017), 103. doi:10.9781/ijimai.2017.09.001

[35] Francesco Scotto di Luzio, Clemente Lauretti, Francesca Cordella, Francesco Draicchio, and Loredana Zollo. 2020. Visual vs vibrotactile feedback for posture assessment during upper-limb robot-aided rehabilitation. *Appl. Ergon.* 82 (Jan. 2020), 102950. doi:10.1016/j.apergo.2019.102950

[36] Diego Vicente, Mario Schwarz, and Gerrit Meixner. 2023. Improving Ergonomic Training Using Augmented Reality Feedback. In *Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management*. Springer, Cham, Switzerland, 256–275. doi:10.1007/978-3-031-35741-1_20

[37] Nicolas Vignais, Markus Miezal, Gabriele Bleser, Katharina Mura, Dominic Gorecky, and Frédéric Marin. 2013. Innovative system for real-time ergonomic feedback in industrial manufacturing. *Appl. Ergon.* 44, 4 (July 2013), 566–574. doi:10.1016/j.apergo.2012.11.008

[38] Mark R. Wilson, Jamie M. Poolton, Neha Malhotra, Karen Ngo, Elizabeth Bright, and Rich S. W. Masters. 2011. Development and Validation of a Surgical Workload Measure: The Surgery Task Load Index (SURG-TLX). *World Journal of Surgery* 35, 9 (May 2011), 1961–1969. doi:10.1007/s00268-011-1141-4

[39] Ezequiel Roberto Zorzal, José Miguel Campos Gomes, Maurício Sousa, Pedro Belchior, Pedro Garcia da Silva, Nuno Figueiredo, Daniel Simões Lopes, and Joaquim Jorge. 2020. Laparoscopy with augmented reality adaptations. *J. Biomed. Inf.* 107 (July 2020), 103463. doi:10.1016/j.jbi.2020.103463