INVESTIGATION OF SCREEN PLACEMENT IN MR TO SUPPORT EXOSCOPE SURGERY

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ABSTRACT

In exoscope surgery, monitor placement for presenting the surgical field has been reported to influence the surgeon's gaze movement and physical workload. To address this issue, mixed reality (MR) technology, which enables interaction with virtual information while perceiving the real world, has attracted attention as a flexible information presentation method in medical applications, particularly in neurosurgical support. This study investigated the effects of monitor placement in an MR-based simulated exoscope surgical environment on task performance and visual burden.

A virtual monitor was presented in an MR environment using a head-mounted display, and participants performed an object transfer task using a laparoscopic surgery training kit. Five monitor placement conditions were examined: front, upper, lower, left, and right. Task completion time, eye-tracking data, and subjective evaluations were collected.

The results showed that the lower and front placements provided higher ratings for ease of viewing and concentration, with lower levels of fatigue and discomfort. In contrast, upper and lateral placements increased gaze movement and subjective burden. These findings suggest that flexible virtual monitor placement using MR technology can effectively support exoscope surgery and reduce surgeon workload.

Keywords: *MR, Medical care, Surgical support*

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1 INTRODUCTION

High-resolution exoscope systems that combine the advantages of microscopes and endoscopes are increasingly used in neurosurgery. Conventional surgical microscopes require surgeons to maintain a fixed posture while viewing the surgical field through eyepieces, often causing physical strain. Modern exoscope systems display magnified images captured by external cameras on large monitors, allowing flexible positioning and image sharing among multiple personnel. This reduces physical burden and may shorten surgical time [1][2]. However, monitor placement in exoscope systems can alter surgeons' posture and gaze movement, potentially causing discomfort and reduced work efficiency depending on the placement [3][4][5]. Therefore, optimization of monitor placement remains an important issue.

This study employs Mixed Reality (MR) technology to construct a simulated surgical task environment. MR enables interaction with virtual information while perceiving the real world and has been applied in various fields, including medicine [6][7]. In neurosurgery, MR has attracted attention for improving visibility and supporting surgical tasks [8][9].

Using a head-mounted display (HMD), this study presents a monitor in an MR environment and investigates how different monitor placements affect task performance and smoothness during hand–eye coordination tasks.

2 EXPERIMENTAL METHOD

2.1 Experimental Overview

Participants transferred an object from one container to another using a laparoscopic surgery training kit (hereafter, "surgical kit") while observing internal images of the kit displayed on a monitor in the MR space (Figure 1). The external appearance of the surgical kit is shown in Figure 2. Task performance and subjective evaluations were compared across different monitor placement conditions.



Figure 1. Example of the internal image of the surgical kit

Twenty-two participants (13 males and 9 females) took part in the experiment. Seventeen participants were aged 20–24 years, and five participants were aged 25 years or older. Seventeen

participants reported normal or good visual acuity (including corrected vision), whereas five reported reduced visual acuity. Nine participants had prior MR experience, whereas thirteen had no prior MR experience. All participants were right-handed and had no prior experience using a laparoscopic surgery training kit. The study was conducted in accordance with ethical guidelines and approved by an institutional ethics review board.

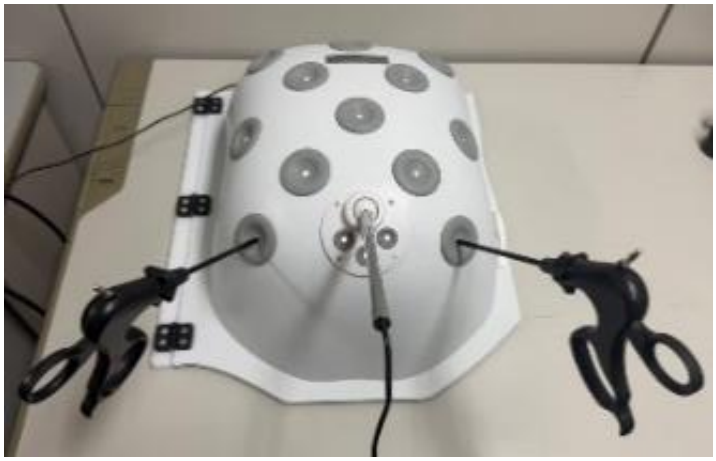

Figure 2. External appearance of the surgical kit

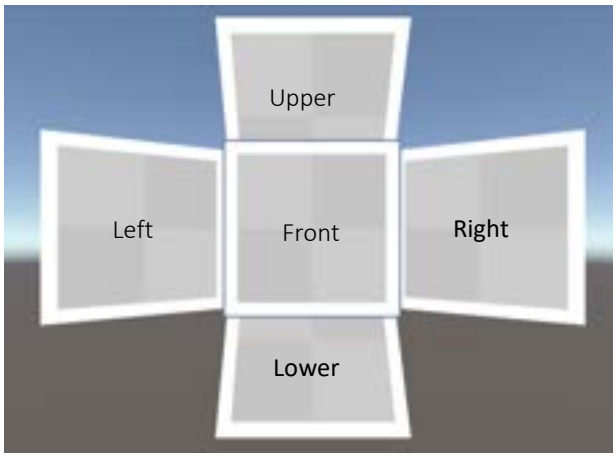

Figure 3. Monitor placement positions

The experimental system was developed in Unity using C# and implemented on a Meta Quest Pro HMD. Real-time internal images of the surgical kit were captured by an external camera, processed using OBS, and streamed via VDO.Ninja, allowing continuous observation during task execution. Five monitor placement conditions were defined: front, upper, lower, right, and left (Figure 3). Based on ergonomic considerations of gaze angle and posture, placements were limited to within ±30° in both vertical and horizontal directions [10]. Eye-tracking data were recorded using the HMD's built-in eye tracker. Gaze data were converted into Unity world coordinates and used to visualize gaze trajectories for qualitative evaluation of gaze behavior under each placement condition.

2.2 Experimental Procedure and Evaluation Items

Participants were informed of the experimental purpose and procedures, provided informed consent, and performed the task while wearing the HMD. To minimize confounding effects of

head movement, participants were instructed to maintain a forward-facing posture, allowing only minimal head motion necessary for task execution. This constraint was intended to isolate the effects of monitor placement on gaze direction and to simulate surgical situations in which gaze and hand positions do not coincide. Under each of the five placement conditions, participants performed the object transfer task while viewing the monitor. Rest periods were provided as needed.

Objective evaluations included task completion time and eye-tracking data. Subjective evaluations were conducted after each condition using a five-point Likert scale assessing ease of viewing (Evaluation 1), ease of concentration (Evaluation 2), fatigue (Evaluation 3), and discomfort (Evaluation 4). For fatigue and discomfort, participants also selected possible causes. After completing all conditions, participants ranked the placements by ease of viewing and task performance, and post-experiment interviews were conducted to collect supplementary comments.

3 RESULTS

One-way ANOVA revealed significant main effects of monitor placement for all subjective evaluation items (Table 1). Multiple comparisons showed that lower placement was rated significantly higher for ease of viewing and concentration than upper and lateral placements, while front placement was rated higher than upper placement. In contrast, upper placement showed significantly higher fatigue and discomfort ratings than lower and front placements (Table 2). No significant differences in task completion time were observed among placement conditions ($p = 0.985$). However, mean task completion times tended to be shorter for front, left, and lower placements and longer for upper and right placements. Gaze trajectory analysis (Figure 4) showed that gaze was concentrated within a narrower area for lower and front placements, whereas upper and lateral placements resulted in wider gaze movement and more frequent gaze shifts.

Table 1. Results of one-way ANOVA for each subjective evaluation item

Evaluation		p-values
Evaluation1	Do you feel that the content on the presented monitor (image) is easy to see?	0.002**
Evaluation2	Does the monitor placement contribute to ease of concentration during the task?	0.000***
Evaluation3	Do you feel fatigue due to the monitor placement?	0.000***
Evaluation4	Do you feel discomfort (unnaturalness or uneasiness) with the monitor placement?	0.000***
	Task completion time	0.985

* $p < .05$, ** $p < .01$, *** $p < .001$

To examine whether the four subjective evaluation items represented independent constructs or reflected common psychological dimensions, Pearson correlation analysis and principal component analysis were conducted using all subjective evaluation data across the five monitor placement conditions. Pearson correlation analysis revealed significant correlations among all four subjective evaluation items (Table 3). Ease of viewing was positively correlated with ease of

concentration (r = 0.724, p < .001) and negatively correlated with fatigue (r = –0.513, p < .001) and discomfort (r = –0.624, p < .001). Fatigue was positively correlated with discomfort (r = 0.580, p < .001). Principal component analysis showed that the four subjective evaluation items reflected a common underlying psychological construct. A single principal component explained 64.8% of the total variance, with high positive loadings for ease of concentration (0.926) and ease of viewing (0.765) and negative loadings for fatigue (–0.667) and discomfort (–0.840) (Table 4).

Table 2. Results of multiple comparisons between monitor placement conditions (p-values)

		Evaluation 1	Evaluation 2	Evaluation 3	Evaluation 4
Front	Upper	0.878	0.006**	0.044*	0.000***
	Lower	0.136	0.793	1.000	1.000
	Right	0.136	0.020*	0.229	0.000***
	Left	0.878	0.020*	0.034*	0.003**
Upper	Lower	0.030*	0.000***	0.003**	0.000***
	Right	0.878	1.000	1.000	1.000
	Left	0.878	1.000	1.000	1.000
Lower	Right	0.000***	0.000***	0.032*	0.000***
	Left	0.009**	0.000***	0.002**	0.000***
Right	Left	0.878	1.000	1.000	1.000

* p < .05, ** p < .01, *** p < .001

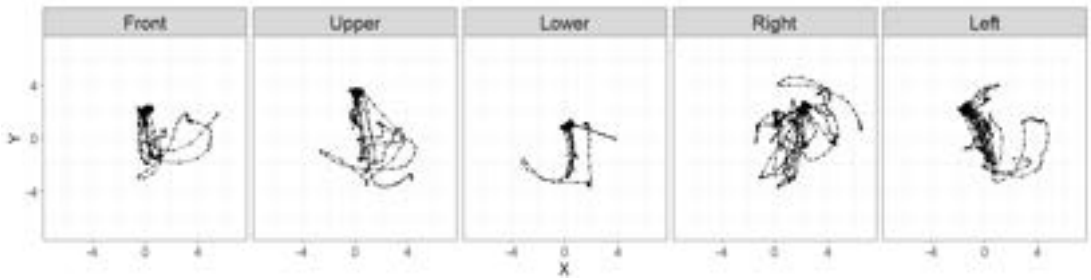

Figure 4. Example of gaze trajectories by monitor placement condition

Table 3. Pearson correlation coefficients among subjective evaluation items

	Viewing	Concentration	Fatigue	Discomfort
Viewing	1.000	0.724***	-0.513***	-0.624***
Concentration		1.000	-0.598***	-0.780***
Fatigue			1.000	0.580***
Discomfort				1.000

*** p < .001.

Additional analyses were conducted according to participant characteristics. Because sex and prior MR experience consisted of two groups, these variables were compared using independent-samples t-tests. In contrast, age and visual acuity were examined descriptively because of the relatively small and unequal subgroup sizes. Independent-samples t-tests revealed no significant

differences according to prior MR experience for any evaluation item or monitor placement condition. Likewise, no significant sex differences were found except for fatigue under the lower placement condition ($p = 0.046$). Descriptive comparisons indicated similar trends across the age and visual acuity groups.

Table 4. Principal component loadings of subjective evaluation items

Item	Factor1
Concentration	0.926
Discomfort	-0.840
Viewing	0.765
Fatigue	-0.667

Eigenvalue = 2.594. Variance explained = 64.8%.

4 DISCUSSION

The results indicate that monitor placement in an MR environment significantly influences visual comfort, concentration, fatigue, and discomfort during task execution. Lower placement provided the highest usability with minimal fatigue and discomfort, likely due to reduced gaze movement and consistency with natural downward viewing during manual tasks. Front placement was also effective but showed slightly increased vertical gaze movement and fatigue. Upper and lateral placements increased gaze travel distance, leading to greater neck and ocular strain, as reflected in higher fatigue and discomfort ratings. The lack of significant differences in task completion time may be attributed to task simplicity and learning effects across trials. Correlation and principal component analyses further indicated that the four subjective evaluation items reflected a common underlying psychological construct rather than independent dimensions. This finding suggests that improvements in monitor placement simultaneously enhance ease of viewing and concentration while reducing fatigue and discomfort, supporting an integrated interpretation of subjective evaluations from a Kansei engineering perspective. Additional analyses according to participant characteristics showed that the effects of monitor placement were generally consistent regardless of sex, age, visual acuity, or prior MR experience. In particular, no significant differences were found between participants with and without prior MR experience for any evaluation item or monitor placement condition. Likewise, no significant sex differences were observed except for fatigue under the lower placement condition. These findings suggest that the observed effects of monitor placement were relatively robust across participants with different backgrounds. However, because the subgroup sizes were limited and not fully balanced, further studies with larger and more diverse participant populations are needed to confirm the generalizability of these findings.

5 CONCLUSION AND FUTURE WORK

This study investigated the effects of monitor placement conditions in an MR environment on work efficiency and task-related burden. The results revealed that the lower and front placements offer superior ease of viewing and concentration with lower levels of fatigue and discomfort. In

contrast, the upper and lateral placements tended to increase gaze movement and subjective burden. Therefore, in support of exoscope surgery, it is desirable to align the surgeon's operation direction with gaze direction as much as possible and to minimize gaze movement through appropriate monitor placement. However, in real surgical environments, it is often difficult to maintain ideal monitor placement due to constraints such as equipment, operating tables, and staff arrangement. In this regard, MR technology enables the construction of virtual environments in which monitors can be flexibly positioned according to the surgeon's stance and operation direction. Consequently, future applications of MR-based surgical support and workload reduction are highly anticipated.

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