Intra-operative 3D Hologram Support with Mixed Reality Techniques in Liver Surgery

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Running title: Intraoperative 3D hologram in liver surgery

Mini-Abstract:

An intra-operative 3D hologram with mixed reality techniques contributed to "last-minute simulation", not for "navigation" in liver surgery. This intra-operative hologram might be a new next-generation operation-supportive tool in terms of spatial awareness, sharing, and simplicity.

Structured Abstract:

Objective

The aim of this study was to investigate the potential of an intra-operative 3D hologram, which was a computer graphics (CG) model liver, with mixed reality (MR) techniques in liver surgery.

Summary Background Data

The merits for the application of a hologram for surgical support are: 1) no sterilized display monitor; 2) better spatial awareness; and 3) 3D images shared by all the surgeons.

Methods

3D polygon data using pre-operative computed tomography (CT) data was installed into head mount displays, HoloLens (Microsoft Corporation, Redmond, WA).

Results

In a Wi-Fi-enabled operative room, several surgeons wearing HoloLens succeeded in sharing the same hologram and moving that hologram from respective operators' angles by means of easy gesture-handling without any monitors. The intra-operative hologram contributed to better imagination of tumor locations, and for determining the parenchymal dissection line in the hepatectomy for the patients with more than twenty

(20) multiple colo-rectal liver metastases (CRLMs). In another case, the hologram enabled a safe Gliisonean pedicle approach for hepato-cellular carcinoma (HCC) with a hilar anatomical anomaly. Surgeons could easily compare the real patient's anatomy and that of the hologram just before the hepatic hilar procedure.

Conclusions

This initial experience suggested that an intra-operative hologram with MR techniques contributed to "last-minute simulation", not for "navigation". The intra-operative hologram might be a new next-generation operation-supportive tool in terms of spatial awareness, sharing, and simplicity.

Abbreviations:

intraoperative ultrasound; IOUS

mixed reality; MR

head mount displays; HMDs

three dimensional; 3D

computer graphics; CG

multi-detector computed tomography; MDCT

colorectal liver metastasis; CRLM

hepatocellular carcinoma; HCC

Introduction:

In liver surgery, there are several steps other than parenchymal dissection such as: liver mobilization; hepatic hilar procedure with Glissonean pedicle or intra-fascial approaches; and intraoperative ultrasound (IOUS) for recognizing tumor location or vascular anatomy. Operators and assistants performed those operative steps imagining the pre-operative simulation in their mind. If their simulation imagination is intra-operatively embodied, such an intra-operative support system should be useful to relieve the stress for the surgeons in terms of "last-minute simulation" other than "navigation". Mixed reality (MR) is the result of blending the physical world with the digital world [1, 2]. Head mount displays (HMDs) intrinsically provide the user with an egocentric viewpoint and they allow the user to work hands free [3), 4)]. Using those HMDs, surgeons can see three-dimensional (3D) computer graphics (CG) with MR techniques intra-operatively. The merits for the application of MR techniques for surgical support are: 1) no sterilized display monitor; 2) better spatial awareness; and 3) 3D images shared by all the surgeons [5)]. In the present study, the authors reported an initial experience of an intra-operative 3D hologram, which was a CG model liver, with MR techniques in several steps of liver surgery for last-minute simulation, and investigated the potential of a 3D hologram as an intra-operative support tool.

Methods:

3D-reconstruction from pre-operative CT images

3D-reconstruction of the hepatic vasculature was made using data from a contrast enhanced multi-detector computed tomography (MDCT) and SYNAPSE VINCENT software (Fuji Film Medical Co. Ltd., Tokyo, Japan). The whole liver, portal vein, hepatic artery, and hepatic vein were extracted from MDCT scans. After obtaining the image of the liver, the hepatic volume was calculated automatically. Then the portal vein, hepatic artery and hepatic vein were traced, and 3D images were integrated.

Hologram making

Polygon (STL) files were exported from SYNAPSE VINCENT, and these were uploaded into the HoloeyesXR system (Holoeyes Inc., Tokyo, Japan). After uploading the data, 3D images were automatically converted as a case-specific CG for MR, which is called a hologram. It takes a total of about fifteen (15) minutes from the upload of the data until the generation of an application.

Installation of the hologram into HMDs (HoloLens)

HoloLens (Microsoft Corporation, Redmond, WA) is an optical see-trough (OST) HMD, which enables optical superposition of virtual content onto the user's direct view of the physical world [6)]. The HoloLens weigh 579 grams. The data of the hologram can be download onto HoloLens.

Questionnaires of intraoperative hologram support

To evaluate the workload of our intraoperative hologram support, questionnaires with NASA-Task load index (NASA Human Performance Research Group, 1987) were performed in ten surgeons, who experienced this hologram support, in our department. Intraoperative hologram support was compared with usual intraoperative 2D support using printed papers or iPad with preoperative 3D simulation data.

Results:

New intra-operative 3D hologram support

In the Wi-Fi-enabled operative room, several surgeons in HoloLens succeeded in sharing the same hologram. They could also view and move that hologram from the respective operator's angles by means of easy gesture-handling without any monitors.

Case 1: Better imagination of multiple liver tumors

This was a conversion hepatectomy case for more than twenty (20) multiple colorectal liver metastases (CRLMs) after systemic chemotherapy. The hologram contributed to the better imagination of tumor locations, especially tumors located in deeper area and for determining the parenchymal dissection lines. All the surgeons finally could decide on all the tumor locations and the dissection lines for all the tumors just before parenchymal dissection. This final confirmation between pre-operative imagination in mind and the intra-operative 3D hologram might lead to safer and more accurate operations. Extended Segment 3 and Segment 4 resection and several partial resections were performed during the exercise (Figure 1A).

Case 2: A safe hilar approach when an anatomical anomaly is present

This was an anatomical liver resection for hepato-cellular carcinoma (HCC) located in the posterior Segment with a hilar anatomical anomaly. The ventral branch of the anterior Glissonean pedicle which originated from the left main Glissonean pedicle, and the dorsal branch of the anterior Glissonean pedicle was formed from the posterior Glissonean pedicle. When a Glisonean pedicle approach was performed, it was important whether the posterior Glissonean pedicle without the ventral branch of the anterior Glissonean pedicle could be safely encircled or not. The anatomy of the hepatic hilum was carefully checked just before the hilar procedure using the 3D hologram. The surgeons could easily switch the real patient's anatomy with that of the hologram (Figure 1B). As a result, the posterior Glissonean pedicle was certainly revealed at the hepatic hilum and the Glissonean pedicle approach with the anatomical anomaly was safely performed.

NASA-Task load index

Hologram scored significant higher “physical demand”, and “effort” than usual 2D support. On the other hand, hologram scored significant lower “performance” (Figure 2A). In weighting of each scale (Figure 2B), “Frustration” was the most important factor in both intraoperative supports. Surgeons always demand comfortable conditions in every operation as might be expected. Furthermore, “Effort (2.9)” and “physical demand (2.5)” were recognized as important sources in hologram support.

Discussion:

In the present study, an initial experience of intra-operative 3D hologram support was reported. The hologram was used: 1) just before parenchymal dissection (at the timing of IOUS) for operative planning; and 2) just before the hepatic hilar procedure for checking hilar anatomy. This hologram support contributed to "last-minute" simulation and not for "navigation" surgery.

The operators usually have various levels of stress and anxiety, not only regarding the parenchymal dissection line, but also the vascular anatomy in the hepatic hilum, the relationship between the tumors and major vessels, and so on. In the several steps involved in liver surgery, last-minute checking just before the commencement of the actual procedures can lead to the relief of the surgeon's stress and facilitate the performance of a safer and more accurate operation.

The hologram support system used for this study enabled the sharing of the same 3D CG from every operator's angle without any monitors. The 3D hologram also contributed to better spatial awareness [5, 7, 8]. HoloLens usually cannot be connected to the internet in the operating rooms by the problem of security. HoloLens for every surgeon who joined the operation was configured in the same Wi-Fi environment by Wi-Fi rooter. Such a Wi-Fi environment enabled the sharing of the hologram.

Furthermore, the operators could perform free and easy handling with gestures. Though it differed greatly in individuals, it took surgeons a while to get used to operate Hololens with hologram. Therefore, the scores of “physical demand” and “effort” became higher in NASA-Task load index. However, almost all surgeons had a sense of fulfillment with lower scores of “performance”.

Hologram technology has been in still early stages. First, the HMD such as Hololens should be refined into more light, simpler, easier to operate ones in consideration of questionnaires with NASA-Task load index. If a surgical magnifying glass has built-in MR technology, it might be an ideal and comfortable instrument. Hologram has been introduced into a simulation tool this time, and in the future, it can be also applied into a navigation tool as well. However, there have been major issues to overcome: 1) breathing movements; 2) the position gap of the liver due to laparotomy or liver mobilization; and 3) deformity during parenchymal dissection. If the hologram will add automatic registration ability, surgeons can perform real-time navigation projecting the hologram into real patients’ organs.

In conclusion, this initial experience suggests that a n intra-operative hologram contributed to “last-minute simulation” and not for “navigation”. The intra-operative hologram might be a new next-generation operation-supportive tool in terms of spatial awareness, sharing, and simplicity.

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Figure legends:

Figure 1A Case 1; Better imagination of multiple liver tumors

All surgeons finally could decide the locations of all the tumors and the dissection lines for all the tumors just before parenchymal dissection using the hologram.

Figure 1B Case 2: A safe hilar approach when an anatomical anomaly exists

The anatomy of hepatic hilum was carefully checked just before the hilar procedure using the hologram. Surgeons could easily switch the real patient's anatomy and that of the hologram.

Figure 2 NASA-Task load index workload

A. Mean rating for each subscale

Hologram scored significant higher "physical demand", "effort" , and lower "performance" than usual 2D support.

B. Weighting of each scale

"Frustration" was the most important factor in both intraoperative supports. "Effort (2.9)" and "physical demand (2.5)" were recognized as important sources in hologram support.

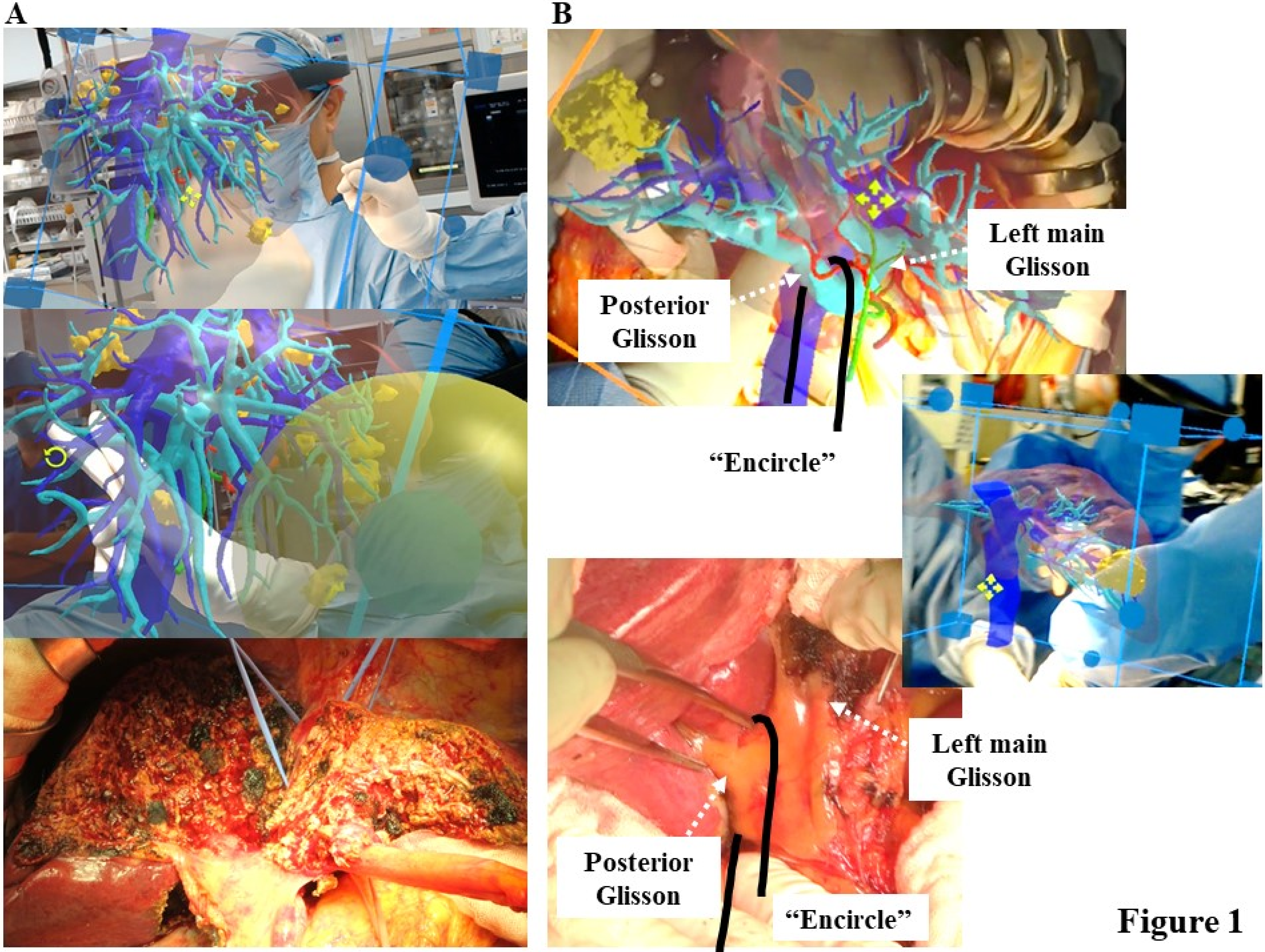
A
B
Left main Glisson
Posterior Glisson
"Encircle"
Left main Glisson
Posterior Glisson
"Encircle"

Figure 1

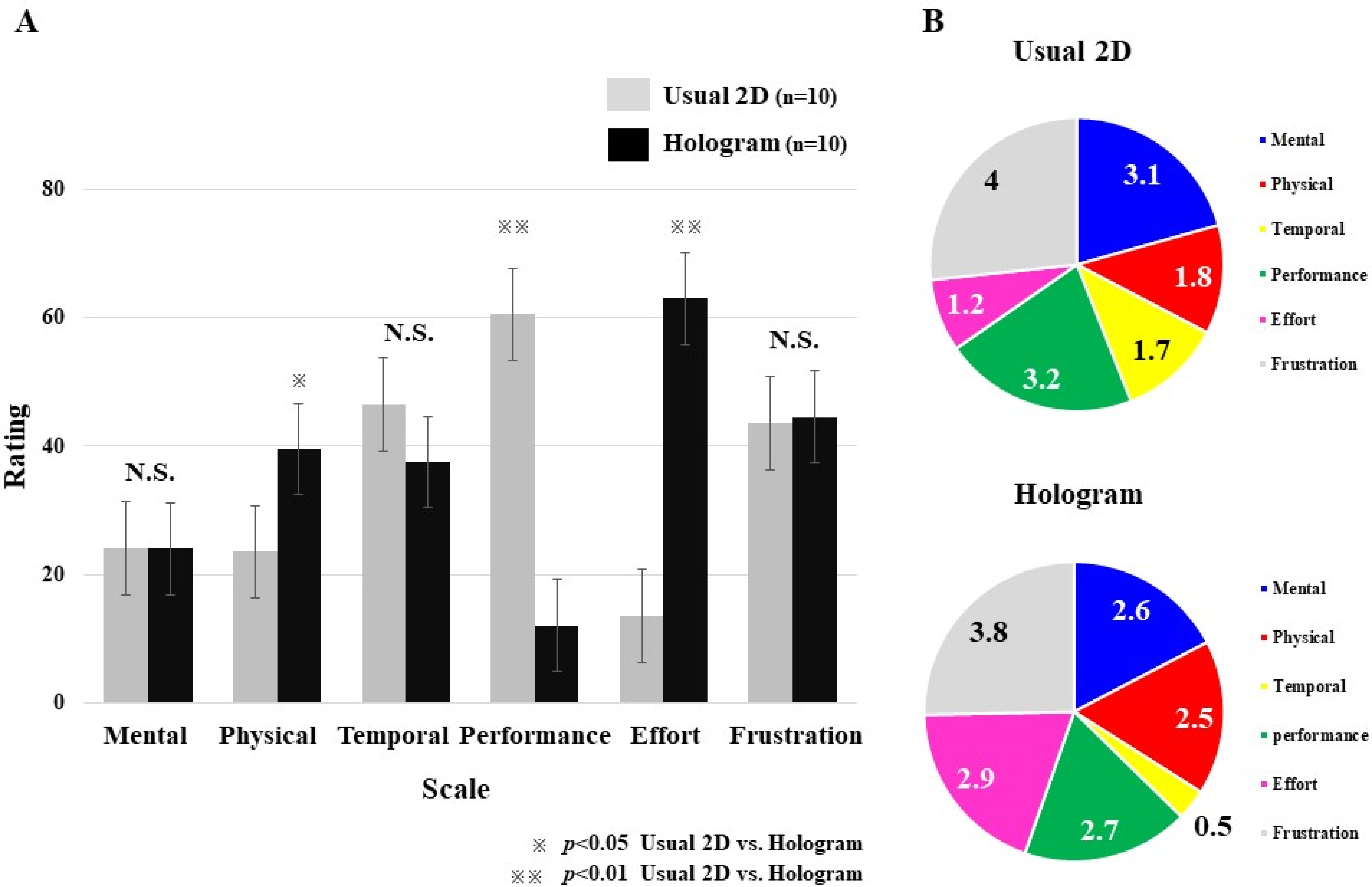
A
Usual 2D (n=10)
Hologram (n=10)
80
60
40
20
0
Rating
N.S.
※
N.S.
※※
※※
N.S.
Mental
Physical
Temporal
Performance
Effort
Frustration
Scale
※ p<0.05 Usual 2D vs. Hologram
※※ p<0.01 Usual 2D vs. Hologram
B
Usual 2D
4
3.1
1.8
1.7
3.2
1.2
Mental
Physical
Temporal
Performance
Effort
Frustration
Hologram
3.8
2.6
2.5
0.5
2.7
2.9
Mental
Physical
Temporal
performance
Effort
Frustration

Figure 2