Noname manuscript No.
(will be inserted by the editor)

Comparison of Gesture and Conventional Interaction Techniques for Interventional Neuroradiology

Julian Hettig · Patrick Saalfeld · Maria Luz · Mathias Becker · Martin Skalej · Christian Hansen

Received: date / Accepted: date

Abstract
Purpose Interaction with radiological image data and volume renderings within a sterile environment is a challenging task. Clinically established methods such as joystick control and task delegation can be time-consuming, error-prone, and interrupt the workflow. New touchless input modalities may have the potential to overcome these limitations, but their value compared to established methods is unclear.
Methods We present a comparative evaluation to analyze the value of two gesture input modalities (Myo Gesture Control Armband and Leap Motion Controller) versus two clinically established methods (task delegation and joystick control). A user study was conducted with 10 experienced radiologists by simulating a diagnostic neuroradiological vascular treatment with two frequently used interaction tasks in an experimental operating room. The input modalities were assessed using task completion time, perceived task difficulty, and subjective workload.
Results Overall, the clinically established method of task delegation performed best under the study conditions. In general, gesture control failed to exceed the clinical input approach. However, the Myo Gesture Control Armband showed a potential for simple image selection task.
Conclusion Novel input modalities have the potential to take over single tasks more efficiently than clinically established methods. The results of our user study show the relevance of task characteristics such as task complexity on performance with specific input modalities. Accordingly, future work should consider task characteristics to provide a useful gesture interface for a specific use case instead of an all-in-one solution.

J. Hettig, P. Saalfeld, M. Luz and C. Hansen
Faculty of Computer Science
University of Magdeburg, Germany
E-mail: hettig@isg.cs.uni-magdeburg.de

M. Becker and M. Skalej
Clinic of Neuroradiology
University Hospital Magdeburg, Germany

Keywords Human-Computer Interaction · Evaluation · Interventional Neuroradiology · Image-Guided Interventions

Introduction

Interventional radiology is an increasingly important branch of radiology, enabling minimally-invasive procedures to treat diseases in almost every organ system [1, 14]. Interventional neuroradiology is a sub-specialty of interventional radiology that focuses on the head, neck and spine, and offers new treatment options for many conditions such as aneurysms, stenosis, and strokes. Therefore, radiologic imaging is required to monitor the position of instruments (e.g., needles, catheters or stents) in relation to pathologies and at-risk structures. Interaction with this imaging data during an intervention is a challenging task for physicians due to the sterile environment.

A clinically established solution for vascular treatment is the use of an angiography system with input devices, e.g., joysticks, buttons, and touchscreens, wrapped in a sterile plastic sheath. However, physicians often need to change their position to reach these devices [8]. A second established solution is task delegation to a medical assistant in the operating room (OR) or a nearby control room. This is achieved by the interpretation of voice commands and gestures from the physician. In complex cases, physicians may have to leave the sterile OR to interact with a non-sterile workstation.

Consequently, they have to scrub out and in again to proceed with the intervention. These approaches can be time-consuming, inefficient, error-prone, and interrupt the workflow [15]. Direct control with a computer keyboard or mouse by the physician is not possible without breaking asepsis [21].

To this end, several methods for direct touchless gesture control were proposed. These methods are based on new input modalities and interaction paradigms, and have the potential to improve interaction with medical images. However, the value of these new approaches compared to established interaction techniques remains unclear. This value might depend on the complexity of tasks; however, only a few previous studies consider the possible correlations of task complexity with the advantageousness of different interaction modalities.

Therefore, we present a quantitative user study with medical experts (radiologists) to compare gesture-based interaction with the Myo Gesture Control Armband (Myo) and the Leap Motion Controller (LMC) against two clinically established interaction methods with an interventional angiography system, i.e., task delegation to a medical assistant and joystick control. In the study, we included two frequently executed tasks of image manipulation with different levels of complexity that are utilized in clinical routine. Based on the target to improve human-computer interaction (HCI), we examine the input modalities with respect to task completion time, subjective workload, and perceived task difficulty regarding three a priori individual comparisons.

Related Work.

To provide an alternative for clinically established input modalities, commercial interaction devices have been introduced to the sterile area of ORs for years. A system that uses the Myo armband for gesture interaction was presented by Hettig et al. 2015 [7]. They proposed the concept of a minimal gesture set to interact with a medical image viewer. Therefore, single gestures were mapped onto multiple functions to control the software. In a user study, they evaluated the recognition rate of the device, and in a clinical test showed its feasibility. Bizzotto et al. 2014 [3] presented an LMC-based gesture control plugin for a medical image viewer, which is based on the freely available GameWave App, to define their gestures and map them to the softwares functions. Mauser et al. 2014 [10] also presented an LMC-based gesture control for medical instruments as well as a medical image viewer. To avoid unintended gestures, they used a gesture set with a lock and unlock gesture. A feasibility test of medical image viewer control with the LMC during eleven dental surgeries was presented by Rosa et al. 2014 [20]. Hand gestures were developed as well as two-finger gestures for scaling, rotating, windowing, browsing images, and measuring. Mewes et al. 2015 [13] presented a natural gesture set to explore radiological images (projected onto a radiation shield) using the LMC. The results of their user study show that sterile and direct interaction with the LMC has the potential to replace conventional interaction devices in the OR. However, the optimal placement of the depth sensor close to the operator, the limited robustness of gesture recognition, and missing feedback are reported as problems. A two-handed gesture set for the LMC was developed by Opromolla et al. 2015 [17]. An evaluation with ten users showed that the LMC is too slow, not robust, and not flexible enough for use in the OR. An advantage is the natural interaction with the software. Park et al. 2016 [18] developed a universal LMC gesture mapper to work with arbitrary medical image viewers. Either two-handed gestures or one-handed gestures with a foot pedal form the user interface. This is achieved by mapping hand gestures to mouse events. The system is modular and battery-powered to provide maximum flexibility. The evaluation with one surgeon, unlike other publications, resulted in the LMC being significantly faster than mouse interaction, which the authors explain with the possibility of concurrent zoom and rotation. However, the gesture recognition rate ranged from 77-100%, with a false-positive rate of 52% for the double click gesture. For a general overview of touchless interaction with software in interventional radiology and surgery, see Mewes et al. 2016 [12].

Several user studies analyze different touchless input modalities or focus on individual gestures for physicians. However, most of these studies investigate the general applicability of touchless input devices without focusing on an intraoperative setting or task. Interaction with medical image data using inertial sensors was proposed by Schwarz et al. 2011 [23]. They introduced a system that learns defined user gestures that are most suitable for a given task. Thus, the user can integrate their preferences and does not depend on a predefined gesture set. They performed a usability study with ten participants, which revealed good wearability of the system and a 90% recognition rate. This system was extended by a voice-based and handheld switch unlock method by Bigdelou et al. 2012 [2]. Their system was evaluated in a user study where eight different gestures were defined and tested. Gallo et al. 2013 [4] compared a mouse-based interface with two Kinect-based touchless interfaces which allow users to interact with 3D data with up to nine degree of freedom (DOF). Their experimental results show that there is a significant relation between the number of DOF simultaneously controlled by the user and the number of DOFs required to perform an accurate manipulation task in a touchless way.

Meng et al. 2016 [11] presented a novel user interface that allows the surgeon to personally perform touchless interaction with various medical systems. They evaluated their user interface in an OR-like setting. The participants had to perform several interactions with medical image data. The user study was analyzed using the System Usability Scale and the NASA-Task Load Index (TLX). Thus, improved efficiency and ease of use in comparison to other techniques is merely assumed. Existing comparative studies, which show advantages of gesture interaction compared to delegated interaction [9] or disadvantages compared to touchscreen interaction [22] are promising, but are not carried out with physicians. Jacob et al. 2014 [9] proposed a system using a Kinect based gesture set that is only active if the user is directed towards the display to avoid unintended interaction. A set of ten gestures was chosen and trained with ten surgeons. The interaction was evaluated in a user study with 20 participants, which revealed a 98% gesture recognition accuracy with 99% intent recognition. Saalfeld et al. 2015 [22] improved the gesture set of Mewes et al. [13] (especially the 3D rotation) and compared it to state-of-the-art touchscreen interaction. In a study with ten subjects, the task duration and intuitiveness of the gesture set for medical image manipulation were measured. Interaction with the LMC was significantly slower, except for 3D rotation, which leads to the conclusion that high-dimensional gestures are better for more complex interaction tasks. Additionally, the touchscreen interaction was described as more intuitive, which is partly ascribed to the more frequent use of touchscreens on smartphones and tablets.

A study with physicians was carried out by Onceanu and Stewart 2011 [16]. They compared an alternative optically-tracked joystick with mouse and delegated interaction. Here, the mouse outperformed the joystick and delegated interaction with respect to task completion time. However, no significant differences between the three input techniques were found regarding accuracy of 3D tasks.

Wipfli et al. 2016 [27] compared a Kinect gesture interface with OR-typical interaction task delegation and mouse interaction with medical data. After a study with 30 participants, they concluded that direct mouse interaction is significantly more efficient and has significantly higher user satisfaction than gesture control and task delegation. However, there were no significant differences in error rates.

To the knowledge of the authors, most of these studies investigate the general applicability of touchless input devices without focusing on an intraoperative setting. Thus, the value of these new approaches compared to established interaction techniques such as joystick interaction or delegation to an assistant (mouse and keyboard control) remains unclear. Moreover, the correlation between the task complexity and input modality was not considered.

Methods

In this work, we perform a user study to compare interaction with the Myo and LMC against clinical standards, i.e., task delegation to a medical assistant and the joystick control panel of an interventional angiography system. The study is designed in order to answer whether there is a difference between:

- Q1: different gesture and conventional input modalities, i.e.,
- Q2: direct and delegated execution of tasks,
- Q3: a specific gesture control and clinically established interaction methods,
- Q4: different gesture control modalities, and
- Q5: is there an interaction between used input modality and task complexity?

In detail, Q1 addresses general differences and Q2-Q4 discuss specific differences between individual input modalities. Q5 targets if a specific input modality is more suitable for a specific task.

The aim of new technology for HCI is the improvement of effectiveness and efficiency. Due to the predetermined goal of the individual interaction tasks (see Task Definition), effectiveness is excluded and only efficiency is observed. Furthermore, the task completion time is measured. According to Hockey [19] a user is able to compensate disadvantages of single methods (e.g., by higher effort). Therefore, differences in these two factors are hard to measure. For this reason, it is meaningful to look at subtle aspects such as effort, fatigue, and cognitive capacities, which are reflected in perceived task difficulty and subjective workload [11]. These decisions are also based on the remarks of our clinical partner about the importance of these aspects for the clinical integration.

Therefore, we simulate a neuroradiological vascular intervention with two frequently executed interaction tasks: a simple image selection task and a more complex alignment task. We analyze these three aspects in a study with 10 radiologists to examine the research questions in detail.

(a) (b) (c) (d)

Fig. 1: Utilized input modalities of our user studies. (a) Myo gesture control armband (based on myoelectric signals of the forearm), (b) Leap Motion Controller (camera-based), (c) joystick control panel of an interventional angiography system, and (c) simple computer mouse of a workstation.

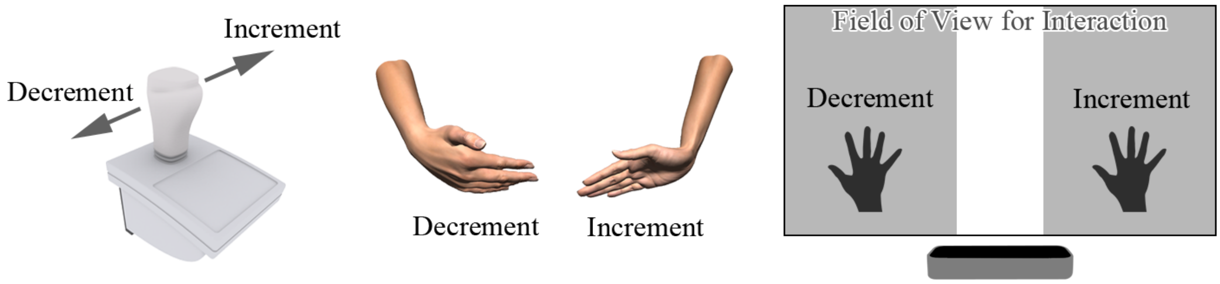

Fig. 2: Comparison of interaction with joystick (left), Myo (center) and LMC with field of view (right). The joystick is moved to the left and right to display, e.g., the next or previous image, respectively. The same applies to the hand gestures of the Myo and the hand positions in defined areas in the field of view of the LMC.

Input Modalities

In our studies, the following four input modalities are used (showcased in Fig. 1 a-d):

– Myo (Thalmic Labs Inc., Kitchner, Canada).
– LMC (Leap Motion, Inc., San Fransico, CA, USA).
– Joystick on the control panel of an interventional angiography system (Siemens Artis zeego).
– Task delegation to an assistant on a workstation (using a standard computer mouse) in a nearby control room.

We choose the Myo and LMC as gesture input modalities that offer a simple, wearable, and location-independent interaction and a compact device for finger interaction, respectively. Furthermore, both were already used and evaluated in interventional radiology to interact with medical image data [7, 13].

The interface provided for both gesture input modalities was designed correspondingly to the clinically established interaction of an angiography system, which implements the interactions for radiological images and volume renderings independently. Accordingly, a custom software was developed and the gesture input modalities were adapted for both tasks separately. Software Development Kits for the Myo (v1.0.1) and LMC (v2.3.1) were employed. The software *syngo.via* is used in the clinical system, which was the fundament for the visual representation and functionality, and was recreated within our custom software to achieve a consistent and comparable interaction with the image data. The participating assistant was familiar with this software and had basic medical knowledge.

Gesture Sets

The given gesture set of the Myo contains five hand gestures which rely on muscle contraction in the forearm, and the LMC's given gesture set contains four finger gestures. As the basis for our gesture control, we applied freehand gestures for the LMC and Myo to a system which is comparable to a previous work [7], wherein a gesture set was presented for the Myo that intentionally used as few gestures as possible. They presented a minimal gesture set for the Myo that intentionally used as few gestures as possible. In order to achieve this, each software function is divided into two parameters (e.g., decrement and increment or rather next and previous slice), which describe the interaction with the specific function. This means that single gestures can be utilized for multiple functions to change their corresponding function parameter. We adopted this system in order to overcome the problems concerning the systems robustness (unintended or undetected execution of gestures) and also reduce the gesture set (Myo) to gestures that are not exhausting, have a high recognition rate, and have a low error rate (with the exclusion of *double tab* and *spread fingers* gestures).

Correspondingly, we used the *wave out* (away from the body) and *wave in* (to the body's core) gesture for image selection and alignment (decrement and increment of function parameter), and the *fist* gesture to activate and deactivate the system to prevent unintended interaction. Likewise, due to the robustness, we did not implement specific finger gestures for the LMC. Instead, different areas in the field of view (FOV) of the sensors were used to enable the interaction, e.g., the hand's position on the left (decrement) or right (increment) side of the sensor is used for interaction, which is comparable to the usage of the joystick. All available functions were parameterized using the hold and wait paradigm, where a defined time period of gesture execution is necessary (single and continuous steps). A comparison of the interaction is seen in Fig. 2. Additional visual feedback in form of icons indicated the active function as well as the executed interaction.

Catheter Navigation

To define meaningful tasks for our study, we focused on the clinical workflow of diagnostic neuroradiological interventions to get an overview of a possible pathology and analyzed the important steps with a neuroradiologist with more than 20 years of experience. Furthermore, a previous workflow analysis by Hübler et al. [8] was considered in the process. In this scenario, the radiologist has to guide a catheter from the groin, through the femoral, external iliacal, and commune iliacal arteries, abdominal and thoracic aorta, and common and internal carotid arteries, into the vessel system of the head.

First, a contrast agent is administered for a digital subtraction angiography (DSA) and medical images show the distribution of the contrast agent in the vessel tree. Based on these images, the radiologist selects an overlay image (road map) to guide the catheter to the desired location, i.e., the pathological structures, such as aneurysms, stenoses and thromboses. Second, either one or two working planes (depending on the type of the angiography system) of the detector of the angiography system are selected by the physician. To accomplish this, an additional 3D DSA series is acquired to generate a 3D volume rendering of the vessel tree. Finally, the radiologist can rotate this volume rendering to define how the detector has to be oriented to get axial and frontal projections of the supplying vessel and pathological structure.

Task Definition

Based on this workflow and associated interaction with image data, we extracted two frequently used interaction tasks (T):

- T1: Selection of a specific overlay image based on a DSA to guide the catheter (2D interaction)
- T2: Alignment of a volume rendering for a defined working plane (3D interaction)

For both interaction tasks, the DOF is directly related to task complexity [4]. While T1 has 1 DOF (backwards and forwards), T2 allows 3 DOFs (positive and negative rotation around three axis).

Experimental Design

The user study was conducted in an experimental OR (see Fig. 3) to preserve a consistent, repeatable, and realistic environment. A medical head phantom (including aorta) was used to simulate the steps of the clinical workflow described above (catheter navigation). In addition, sterile working conditions were simulated by using gloves and sterile sheath to cover the control panel. We used a real patient data set with two clearly identifiable aneurysms of the right internal carotid and right medial cerebral artery. The study itself was conducted using a within-subject design, in which each participant performed both tasks (T1 and T2) four times with four different input modalities. The sequence of the four input modalities was balanced across the participants. Furthermore, a characterization of the patient was provided. The study process consisted of an introductory presentation of each input modality, the laboratory setup, and the defined workflow. Subsequently the following three steps were carried out for each input modality (see Fig. 4):

- *Training:* Participants were introduced to each input modality and were given unlimited time to learn the interaction with a medical data set (unrelated to the study data set) before each run. Task delegation was considered as an input modality, which

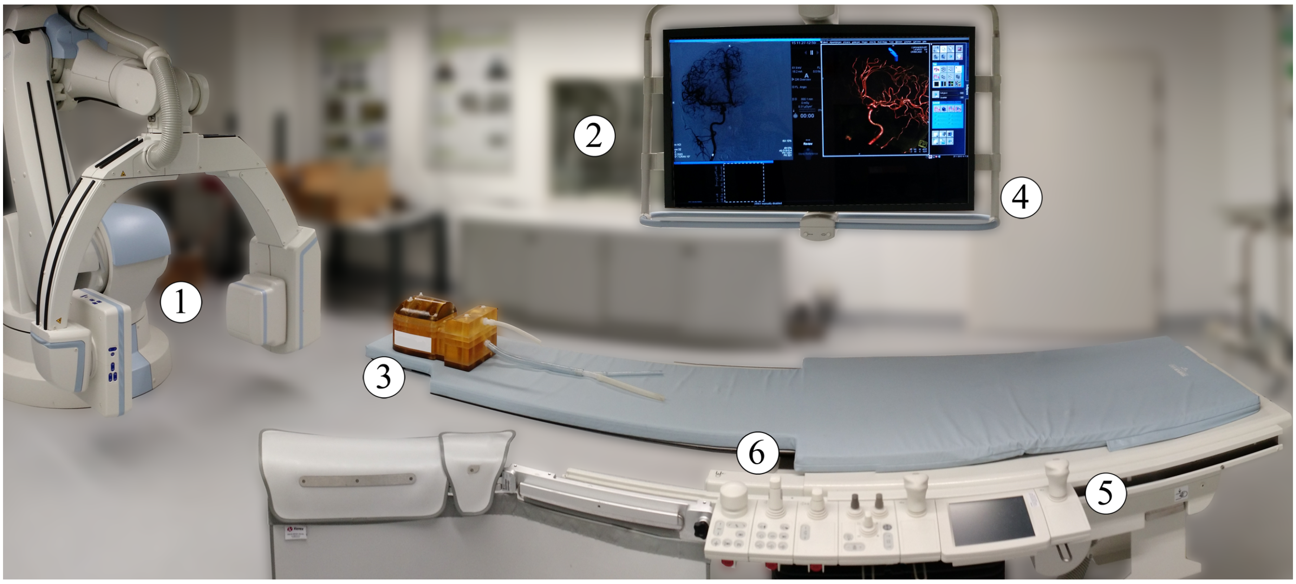

Fig. 3: Experimental OR with angiography system (Siemens Artis zeego) and medical head phantom. 1) C-arm, 2) control room, 3) medical head phantom, 4) large screen display, 5) angiography system control panel, and 6) position of the LMC.

also included a training session, wherein the participant practiced the communication and commands with the assistant.

- *Catheter Navigation:* This task was derived from the defined workflow and was intended to simulate a primary task to be performed during an intervention, i.e., inserting a catheter into the head phantom and administering the contrast agent.
- *Interaction Task:* The participant had to interact with the acquired image data, i.e., the 2D and 3D interaction with temporal 2D DSA images (T1) and a generated 3D volume rendering (T2), respectively.
- *Debriefing:* At the end of the study, a debriefing was performed to receive subjective individual feedback about the study itself, the preferred input modalities, and further improvements.

Three dependent measures were used to assess participants' performance: 1. task completion time 2. perceived task difficulty using a Single Ease Question (SEQ) [26] 3. subjective workload using the NASA-TLX questionnaire [6].

The task completion time and perceived task difficulty were analyzed by a two-way ANOVA for repeated measures, where one factor represents the four input modalities (Myo, LMC, joystick, and delegation; this analysis is directly related to research question Q1) and one factor represents the two interaction tasks (T1 and T2), respectively.

Subjective workload was analyzed by a one-way ANOVA for repeated measures with only one factor representing the four input modalities. Furthermore, the data was analyzed by three independent a priori planned contrasts of means (individual comparisons). The first contrast (Q2) addressed effects of direct (averaged over Myo, LMC, and joystick) and indirect interaction (delegation). The second contrast (Q3) included a comparison of gesture interaction (averaged over Myo and LMC) with clinically used input modalities (averaged over: joystick and delegation). The third contrast (Q4) compared both gesture interactions (Myo and LMC). For task completion time and perceived task difficulty, a contrast analysis was performed for each task separately. All contrast analyses were performed by a two-sided t-test for paired samples and α was adjusted for task completion time and perceived task difficulty, since the analysis was performed for each task separately (Q5).

Our participant pool includes 8 residents (4 neuroradiologists, 3 radiologists, 1 neurologist), 1 consultant physician and 1 senior physician (both neuroradiologists). They were in average 32.5 years old (range: 25 to 55), had an average of five years of professional experience (range: 0.5 to 26), 5 were male, 5 were female, and all subjects stated that they are right-handed.

Results

The statistical results of the ANOVA and t-tests are shown in Table 1, and a descriptive analysis is shown in Table 2.

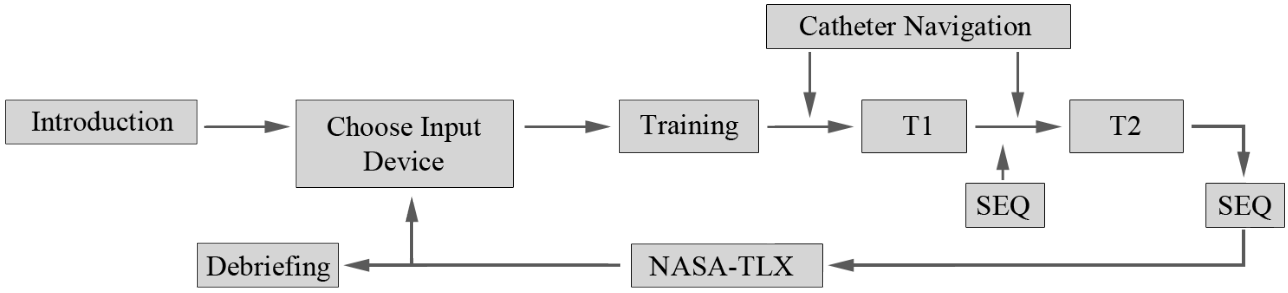

Fig. 4: Main steps of our user study. SEQ and NASA-TLX questionnaires are used to assess subjective workload and perceived task difficulty.

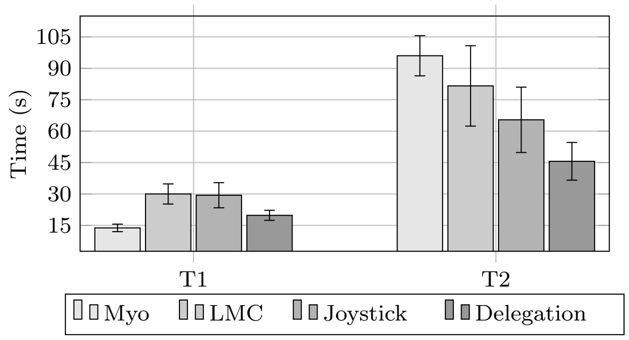

Fig. 5: Mean values and standard errors for **task completion time**, while showing the difference between the 2D interaction task T1 and the 3D interaction task T2.

Task Completion Time

The analysis of the task completion time shows a significant result for the factor *Task* (see Fig. 5). Subjects needed significantly ($p < 0.01$) less time to interact with 2D compared to 3D data, which is ascribed to the lower task complexity.

Task completion time for the 2D interaction task T1 was best using the Myo, followed by task delegation. The participants needed a similarly long period of time using the joystick and LMC. This result is reflected in a significant ($p < 0.01$) advantage of the Myo compared to LMC. All other contrasts are not significant.

A completely different result emerged for the 3D interaction task T2. Task completion time was best for task delegation, followed by joystick control, and LMC. Participants required more time to perform T2 using the Myo. The contrast analysis shows a significant ($p = 0.01$) difference between direct and delegated interaction, as well as between gesture and clinically established methods ($p < 0.01$). No effects could be found between both gesture input modalities (Myo and LMC).

Perceived Task Difficulty

The analysis of the perceived task difficulty revealed a significant ($p < 0.01$) effect for the factor *Task*, i.e., participants perceived T1 to be much easier than T2 (see Fig. 6). The easiest way to fulfill T1 was the delegation to an assistant, followed by the Myo, and joystick. The LMC was rated the most difficult. This result was supported by a significant ($p < 0.01$) contrast on direct and delegated interaction. Other contrasts show only medium or small effects. Concerning T2, it was most easy to delegate the task, followed by using the LMC. The perceived task difficulty was relatively similar for Myo and joystick. No single contrast revealed a significant difference. However, the analysis revealed a medium effect for the comparison between direct and delegated interaction.

Subjective Workload

The effects of the four input modalities on subjective workload assessed by the NASA-TLX are visualized in Fig. 7. The effect for the overall workload was large, but failed to reach a significant value ($p = 0.06$). The lowest workload was found for task delegation, followed by the LMC and joystick control. The highest subjective workload was reported for the Myo. A more detailed analysis revealed that task delegation caused low workload almost in all dimensions, except for the dimension mental demand. The highest workload for the dimensions physical demand, effort, and frustration was reported for the Myo. The contrast analysis showed only a significant ($p = 0.02$) result for the comparison between direct and delegated interaction.

Debriefing Feedback

Overall, all input modalities were assessed positively. Especially, both gesture input modalities were rated as

Table 1: Summary of the statistical results of the ANOVA and t-tests for task completion time, perceived task difficulty, and subjective workload ($*\alpha < .025$ for task completion time and perceived task difficulty contrasts, $\alpha < .05$ for all others). The Interaction Effect describes the interrelation between input modality and task.

Statistical Parameters		**df**	**F**	**t**	**p**	**sig**	η^2_{part}	**d**	**Effect**
Task Completion Time									
	Input Modality	3, 27	2.34		0.13		0.21		large
	Task	1, 9	57.43		< 0.01	*	0.87		large
	Interaction Effect	3, 27	3.04		0.08		0.25		large
Contrast T1	Direct vs. Delegated	9		1.61	0.14			0.51	medium
	Gesture vs. Standard	9		0.59	0.57			0.19	no effect
	Myo vs. Leap	9		3.34	< 0.01	*		1.06	large
Contrast T2	Direct vs. Delegated	9		3.23	0.01	*		1.02	large
	Gesture vs. Standard	9		4.20	< 0.01	*		1.33	large
	Myo vs. Leap	9		0.54	0.60			0.17	no effect
Perceived Task Difficulty									
	Input Modality	3, 27	2.63		0.10		0.23		large
	Task	1, 9	12.79		< 0.01	*	0.59		large
	Interaction Effect	3, 27	1.20		0.32		0.12		medium
Contrast T1	Direct vs. Delegated	9		3.54	< 0.01	*		1.12	large
	Gesture vs. Standard	9		1.41	0.19			0.44	small
	Myo vs. Leap	9		1.62	0.14			0.51	medium
Contrast T2	Direct vs. Delegated	9		1.93	0.09			0.61	medium
	Gesture vs. Standard	9		0.00	1.00			0.00	no effect
	Myo vs. Leap	9		1.00	0.34			0.32	small
Subjective Workload									
	Input Modality	3, 27	3.46		0.06		0.28		large
Contrasts	Direct vs. Delegated	9		2.92	0.02	*		0.93	large
	Gesture vs. Standard	9		1.47	0.18			0.47	small
	Myo vs. Leap	9		1.96	0.08			0.61	medium

fast, sterile and intuitive. However, there is little sense of control due to the lack of haptic feedback. More practice with these modalities, could enable a more efficient interaction compared to the clinically established methods. The joystick was mentioned to be precise and prior experience favored the interaction. Regarding the level of expertise of our participants, no major differences showed up concerning the interaction with the input modalities. Only the mental transfer between the current and target orientation of the volume rendering (T2) turned out to be complicated. Due to the amount of participants (2 experts and 8 residents) no statistical statement is possible.

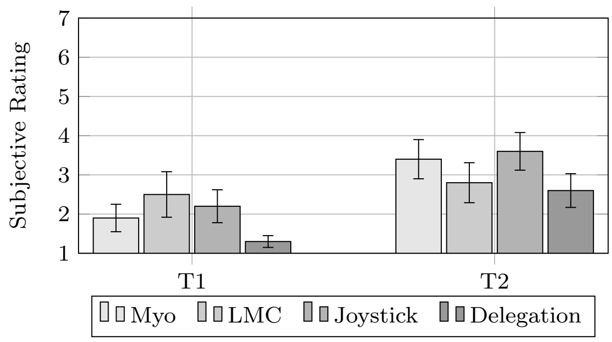

Fig. 6: Mean values and standard errors for **perceived task difficulty** (SEQ). The values are based on a 7-point Likert scale from 1 = very easy to 7 = very difficult.

Discussion

In this work, we compared two gesture-controlled systems (Myo, LMC) with two clinically established interaction methods (joystick control, task delegation) for neuroradiological interventions in terms of two frequently used interaction tasks (T1, T2). T1 is described as the simple 2D interaction (1 DOF) with DSA images to determine a specific overlay image that show the distribution of contrast agent in a vessel tree, and T2 as a more complex interaction (3 DOFs) with a 3D volume rendering to define the orientation of a working

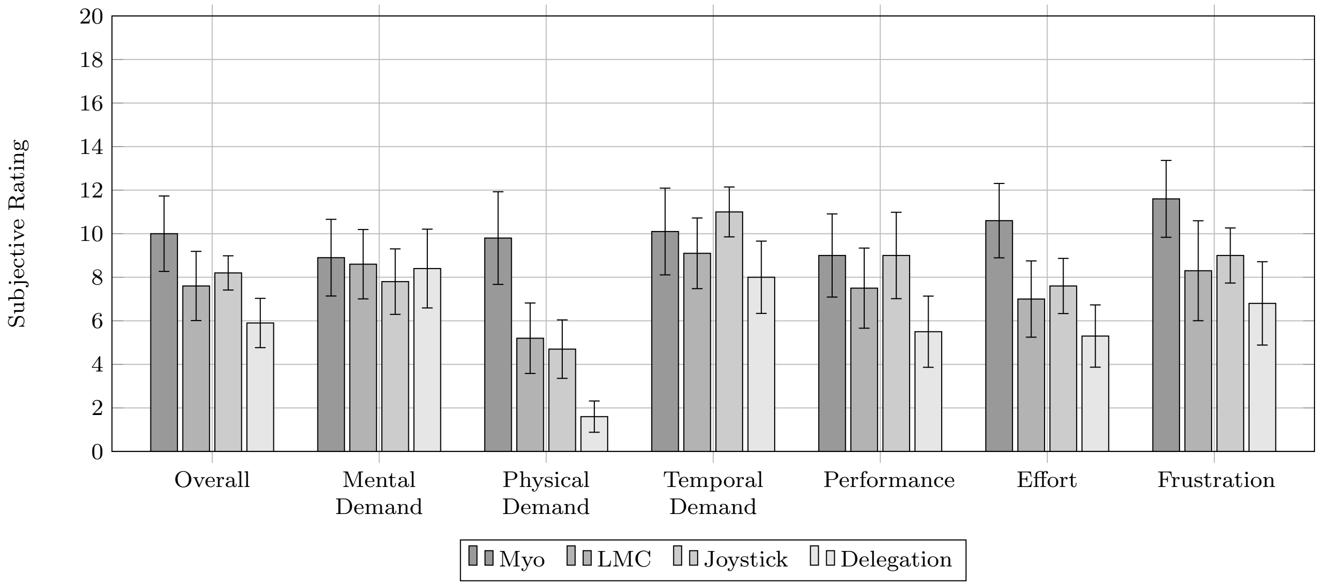

Fig. 7: **Subjective workload** measured using NASA-TLX. The box plots visualizes the overall mean value and the standard error, and the detailed results for six subscales (mental demand, physical demand, temporal demand, performance, effort, and frustration). The values are based on a scale from 0 to 20.

Table 2: Overview of the individual mean values and standard deviation of task completion time, perceived task difficulty (SEQ) and subjective workload (NASA-TLX).

Input Modality	**Task Completion Time**		**SEQ**		**NASA-TLX**
	T1	T2	T1	T2	
Myo	13.9s ± 6.7s	47.1s ± 27.8s	1.9 ± 1.1	3.4 ± 1.6	10.0 ± 5.5
LMC	29.1s ± 18.9s	83.6s ± 91.1s	2.5 ± 1.8	2.8 ± 1.6	7.6 ± 5.0
Joystick	29.7s ± 14.8s	65.1s ± 49.6s	2.2 ± 1.3	2.6 ± 1.3	8.2 ± 2.5
Task Delegation	19.7s ± 6.7s	47.1s ± 27.8s	1.3 ± 0.5	2.6 ± 1.3	6.0 ± 3.6
Total	23.1s ± 6.1s	73.0s ± 25.3s	2.0 ± 1.0	3.1 ± 1.0	

plane. A study with 10 radiologists was performed in a clinically oriented setup including the simulation of a neuroradiological catheter intervention.

Our research questions (Q1-Q5) can be answered as follows: Q1, asking if there is a difference between different input modalities, could be answered in the negative since the comparison of input modalities revealed no statistical significant ($p = 0.06$) result. However, a more detailed comparisons between different input modality groups revealed some significant results.

Regarding the difference between direct and delegated execution of tasks (Q2), the study results show that delegated interaction was perceived as easier and having lower workload compared to direct interaction (see Table 1, Subjective Workload, Direct vs. Delegated). Moreover, T2 could be performed faster with delegation in comparison to direct interaction techniques. When looking at the difference between gesture control and clinically established interaction methods (Q3), the clear advantage of clinically established interaction methods emerged only for the task completion time and only for T2.

This suggests that the selected gesture input modalities do not differ from clinically established techniques (task delegation and joystick) in general, but may differ for other gesture input modalities. The difference may instead be expected between certain input modalities independent of the input modality group. With regard to the different gesture control techniques (Q4), a clear advantage emerged for the Myo regarding only the task completion time for T1. Regarding Q5, which addresses the possible interaction between the input modality used and the executed task, we found no statistical significant differences. However, Fig. 5 shows the presence of an interaction between task and input modality in terms of task completion time and the significant results of a priori planned tests confirm this assumption (e.g., Myo vs. Leap for T1 and T2).

Concerning Q2, Wipfli et al. [27] presented contradictory results, wherein the participants performed better with direct interaction techniques than with delegating the task to a third person. However, the authors utilized test scenarios consisting of several different tasks with varying complexity that may have impacted the communication between participants and the third person and prolonged task execution. A good example of task delegation with an established working relationship is shown by Stevenson et al. [25], where a medical experts instructs non-experts in tertiary-level telehealth. However, this requires about one hour of training prior to the intervention, which is beneficial for the communication compared to a short training phase, but might not be available in clinical routine. Regarding Q3, the results of our study are in accordance with the results of Saalfeld et al. [22]. In contrast to our results, the benefit of the standard technique emerged for simple 2D tasks. The reason might lay not in the gesture control device itself, but in the provided user interface. As stated by Gallo et al. [4], the usage of more DOFs has a benefical influence on user performance. Furthermore, neglecting task and interface characteristics may cause contradictory results to previous studies as well, and should be considered in future research. The results of our study show the relevancy of task characteristics to performance with specific input modalities.

Moreover, Stevenson et al. [24] underline the importance of the diversity of patient data type and use, surgical procedures, and the setting characteristics for the design of gesture-based control. In case of an interventional angiography system, multiple input devices, e.g., touchscreen, joysticks, buttons and foot pedals, for different specific tasks are provided. Accordingly, hand gesture-based systems should focus on specific tasks that can improve the clinical workflow and support the physician, rather than providing a complete all-in-one solution with an extensive interface. Such a solution shows a variety of feasible functionality, but do not provide any valuable results, since some of those functions are not used in clinical routine. Standardized gestures should be discussed in cooperation between different research groups and industrial partners, to build up for a real clinical trial and effective use of gestures in medicine. Consequently, extensive analyses of workflows, tasks, and surroundings are necessary, which include the DOF for the interaction.

Different factors may influence the usage of input modalities during an intervention. The LMC and the joystick are two input modalities which have a fixed position at the table. In our study, the device placement benefited the interaction with LMC and joystick. In neuroradiological settings, positions of physicians and medical assistants frequently change during an intervention [8]. Using a location-independent device such as the Myo, would result in a non-fixes interaction space, which might reduce the movement expense during an intervention, and thus intervention time.

In case both of the physician's hands are required for a workflow step, hand gesture-based interaction might lead to an interruption of the intervention.

Interruptions can negatively affect the outcome of an intervention, e.g., in terms of operation time (physicians need to re-orientate themselves and re-position the instruments). Depending on the medical procedure, hands-free interaction techniques could avoid interruptions in the workflow. Accordingly, other input modalities, e.g., voice, gaze, or foot control, should be properly considered. In addition, an appropriate combination of input modalities, e.g., gaze and foot interaction such as described in Göbel et al. [5] should be investigated.

To sum up, novel input modalities such as the Myo have the potential to take over single tasks more efficiently than clinically established methods. The results of our study show the relevance of task characteristics to the performance of specific input modalities. To represent a real added value, hand gesture interfaces in interventional radiology need to be designed for a specific use case instead of providing an all-in-one solution. Accordingly, future work should focus on this correlation to develop effective human-machine interfaces that support medical interventions.

Conflict of interest

The authors declare that they have no conflict of interest.

Funding

This work is partially funded by the Federal Ministry of Education and Research (BMBF) within the *STIMULATE* research campus (grant number 13GW0095A).

Ethical standard

For this type of study, formal consent is not required.

Informed Consent

Informed consent was obtained from all individual participants included in the study.

References

1. Ahmed K, Keeling AN, Khan RS, Ashrafian H, Arora S, Nagpal K, Burrill J, Darzi A, Athanasiou T, Hamady M (2010) What does competence entail in interventional radiology? Cardiovasc Intervent Radiol 33(1):3–10
2. Bigdelou A, Schwarz L, Navab N (2012) An adaptive solution for intra-operative gesture-based human-machine interaction. In: Proceedings of the International Conference on Intelligent User Interfaces, ACM, pp 75–84
3. Bizzotto N, Costanzo A, Bizzotto L, Regis D, Sandri A, Magnan B (2014) Leap motion gesture control with osirix in the operating room to control imaging first experiences during live surgery. Surgical innovation 1:655–656
4. Gallo L (2013) A study on the degrees of freedom in touchless interaction. In: SIGGRAPH Asia 2013 Technical Briefs, ACM, p 28
5. Göbel F, Klamka K, Siegel A, Vogt S, Stellmach S, Dachselt R (2013) Gaze-supported foot interaction in zoomable information spaces. In: Extended Abstracts on Human Factors in Computing Systems (CHI), ACM, pp 3059–3062
6. Hart SG, Stavenland LE (1988) Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In: Advances in psychology, pp 139–183
7. Hettig J, Mewes A, Riabikin O, Skalej M, Preim B, Hansen C (2015) Exploration of 3D Medical Image Data for Interventional Radiology using Myoelectric Gesture Control. In: Eurographics Workshop on Visual Computing for Biology and Medicine, pp 177–185
8. Hübler A, Hansen C, Beuing O, Skalej M, Preim B (2014) Workflow Analysis for Interventional Neuroradiology using Frequent Pattern Mining. In: Proceedings of the Annual Meeting of the German Society of Computer- and Robot-Assisted Surgery (CURAC), pp 165–168
9. Jacob MG, Wachs JP (2014) Context-based Hand Gesture Recognition for the Operating Room. Pattern Recognition Letters 36:196–203
10. Mauser S, Burgert O (2014) Touch-free, gesture-based control of medical devices and software based on the leap motion controller. Studies in Health Technology and Informatics 196:265–270
11. Meng M, Fallavollita P, Habert S, Weider S, Navab N (2016) Device and system independent personal touchless user interface for operating rooms. In: International Conference on Information Processing in Computer-Assisted Interventions (IPCAI)
12. Mewes A, Hensen B, Wacker F, Hansen C (2016) Touchless interaction with software in interventional radiology and surgery: A systematic literature review. International Journal of Computer Assisted Radiology and Surgery Accepted: 2016/08/31
13. Mewes A, Saalfeld P, Riabikin O, Skalej M, Hansen C (2016) A gesture-controlled projection display for CT-guided interventions. International Journal of Computer Assisted Radiology and Surgery 11(1):157–164
14. Odisio BC, Wallace MJ (2014) Image-guided interventions in oncology. Surgical Oncology Clinics of North America 23(4):937–955
15. O'Hara K, Gonzalez G, Sellen A, Penney G, Varnavas A, Mentis H, Criminisi A, Corish R, Rouncefield M, Dastur N, Carrell T (2014) Touchless interaction in surgery. Commun ACM 57(1):70–77
16. Onceanu D, Stewart AJ (2011) Direct surgeon control of the computer in the operating room. In: Medical Image Computing and Computer-Assisted Intervention – (MICCAI), pp 121–128
17. Opromolla A, Volpi V, Ingrosso A, Fabri S, Rapuano C, Passalacqua D, Medaglia CM (2015) A usability study of a gesture recognition system applied during the surgical procedures. In: Design, User Experience, and Usability: Interactive Experience Design, pp 682–692
18. Park BJ, Jang T, Choi JW, Kim N (2016) Gesture-controlled interface for contactless control of various computer programs with a hooking-based keyboard and mouse-mapping technique in the operating room. Computational and Mathematical Methods in Medicine
19. Robert G, Hockey J (1997) Compensatory control in the regulation of human performance under stress and high workload: A cognitive-energetical framework. Biological psychology 45(1):73–93
20. Rosa GM, Elizondo ML (2014) Use of a gesture user interface as a touchless image navigation system in dental surgery: Case series report. Imaging science in dentistry 44(2):155–160
21. Rutala WA, White MS, Gergen MF, Weber DJ (2006) Bacterial Contamination of Keyboards: Efficacy and Functional Impact of Disinfectants. Infection Control 27(4):372–377
22. Saalfeld P, Mewes A, Luz M, Preim B, Hansen C (2015) Comparative Evaluation of Gesture and Touch Input for Medical Software. In: Mensch und Computer Proceedings, pp 143–152
23. Schwarz LA, Bigdelou A, Navab N (2011) Learning gestures for customizable human-computer interaction in the operating room. In: Medical Image

Computing and Computer-Assisted Intervention – (MICCAI), pp 129–136
24. Stevenson D, Gardner H, Neilson W, Beenen E, Gananadha S, Fergusson J, Jeans P, Mews P, Bandi H (2016) Evidence from the surgeons: gesture control of image data displayed during surgery. Behaviour & Information Technology pp 1–17
25. Stevenson DR (2011) Tertiary-level telehealth: A media space application. Computer Supported Cooperative Work (CSCW) 20(1):61–92
26. Tedesco DP, Tullis TS (2006) A Comparison of Methods for Eliciting Post-Task Subjective Ratings in Usability Testing. In: Usability Professionals Association (UPA), pp 1–9
27. Wipfli R, Dubois-Ferrière V, Budry S, Hoffmeyer P, Lovis C (2016) Gesture-Controlled Image Management for Operating Room: A Randomized Crossover Study to Compare Interaction Using Gestures, Mouse, and Third Person Relaying. PloS one 11(4):e0153,596