Teleoperation in Assembly: Effects of Different Visualization Methods on Performance and Workload of Expert and Non-Expert Operators

Teleoperation in der Montage: Auswirkungen unterschiedlicher Visualisierungsmethoden auf Leistung und Belastung von Experten und Nicht-Experten

Wissenschaftliche Arbeit zur Erlangung des Grades

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Abstract

Teleoperation stands as a potential solution for hybrid assembly, combining the strengths of both the technical system and the human operator. With this tool for remote assembly, operators oftentimes do not have a direct view of the remote site. Thus, a visualization method is required to enhance the operator's performance while posing minimal workload. While most research focuses on technological advancements of teleoperated systems and their visualization, there is a gap in understanding the human factors. Flat screens and head-mounted displays (HMD) are the most common visualization methods. However, current research presents contradictory results regarding performance and workload for operators while using flat screens or HMDs as visualization during teleoperation. Specifically, it remains unclear whether effects on the performance and workload of operators can be attributed to different dimensionality (2D vs. 3D) or to variations in the device (flat screen vs. HMD).

A study is conducted in the scope of this thesis to investigate the effects of different visualization methods on the performance and workload of an operator during teleoperated assembly. The investigation particularly focuses on differences between expert and non-expert operators. Both groups have distinct needs and preferences regarding visualization. Therefore, different visualization methods potentially affect the performance and workload of expert and non-expert operators differently.

For the study, gamers are considered expert operators due to their spatial abilities, skills with input devices, and their trust in technology. Both gamers and non-gamers perform an easy manipulation task of moving different shapes into a box with a teleoperated system. The system consists of two connected Franka Emika Robots by Franka Robotics GmbH with a Franka Hand gripper. Each study participant performs the task with four different visualization methods: direct view, 3D HMD, 2D HMD, and 2D screen. The distinction between the 2D and 3D HMD is made to distinguish between the effects of depth information (2D and 3D) and the device (HMD and screen). A ZED mini camera is used for stereoscopic video recording and the Oculus Rift as the HMD. The performance is evaluated by analyzing the Task Completion Time, whereas the subjective workload is evaluated via the standardized NASA Task Load Index questionnaire.

A between-within ANOVA statistical analysis for each performance and the workload did not find a significant difference between gamers and non-gamers. This finding might be attributed to all participants having a technical background and qualifying as expert users regardless of their gaming abilities. Thus, gamers are not an accurate representation of experts in teleoperation. Alternatively, an intuitive system design compensates for differences between gamers and non-gamers in performance and workload. However, a significant difference could be found between the visualization methods. Participants performed better and experienced less workload with visualization with stereoscopic depth information. The different devices only had a marginal influence on performance and workload. In view of these findings, future research should focus its efforts on enhancing depth perception (e.g. through improving secondary visual cues) to improve visualization during teleoperation with any device.

Kurzfassung

Mit zunehmender Automatisierung, steht die industrielle Montage vor Herausforderungen. Die Teleoperation bietet als Technologie der hybriden Montage einen Lösungsansatz, welcher die Stärken von menschlichen Bedienern und dem technischen System kombiniert. Bei der Teleoperation hat der Bediener oft keine direkte Sicht auf den Montagebereich, weshalb eine geeignete Visualisierung essenziell ist. Solch eine Visualisierung sollte den Bediener unterstützen, um dessen Leistung zu steigern und gleichzeitig die Belastung gering zu halten. Da der Fokus aktueller Forschung hauptsächlich auf technischen Aspekten der Teleoperation liegt, gibt es eine Forschungslücke zu den menschlichen Faktoren. Insbesondere ist unklar, ob die Dimensionalität (2D und 3D) oder das Gerät der Visualisierung (Bildschirm oder Head-Mounted-Display (HMD)) größeren Einfluss auf menschliche Faktoren haben.

Daher wurde in der Studie im Rahmen dieser Masterarbeit untersucht, welchen Einfluss verschiedene Visualisierungsarten auf die Leistung und Belastung des Bedieners haben. Dabei wurden insbesondere die Unterschiede zwischen Experten und Nicht-Experten untersucht. Beide Gruppen haben unterschiedliche Bedürfnisse und Präferenzen bezüglich der Visualisierung, weshalb sich unterschiedliche Visualisierungsmethoden möglicherweise unterschiedlich auf die Leistung und Belastung beider Gruppen auswirken.

Für die Studie werden Gamer aufgrund ihres räumlichen Denkens, ihrer Fertigkeiten im Umgang mit Eingabegeräten und ihres Vertrauens in Technik als Experten betrachtet. Sowohl Gamer als auch Nicht-Gamer führten eine einfache Manipulationsaufgabe aus, bei der verschiedene Formen mit einem teleoperierten System in eine Box befördert wurden. Das System besteht aus zwei miteinander verbundenen Franka Emika Robots der Franka Robotics GmbH mit der Franka Hand als Greifer. Alle Studienteilnehmenden führten die Aufgabe mit vier verschiedenen Visualisierungsmethoden aus: direkte Sicht, 3D HMD, 2D HMD und 2D Bildschirm. Die Unterscheidung zwischen 2D- und 3D-HMD dient dazu, zwischen dem Einfluss von Tiefeninformation und dem Gerät zu unterscheiden. Für das 3D Bild wurde eine ZED mini Kamera und als HMD eine Oculus Rift verwendet. Die Leistung wurde durch die Analyse der Bearbeitungszeit bewertet, während die Belastung anhand des standardisierten NASA Task Load Index Fragebogens bewertet wurde.

Die statistische Analyse (ANOVA) der Leistung und der Belastung ergab keinen signifikanten Unterschied zwischen Gamern und Nicht-Gamern. Dieses Ergebnis kann auf den technischen Hintergrund unabhängig von Gaming-Gewohnheiten der meisten Teilnehmenden zurückgeführt werden. Alternativ kann ein intuitives Systemdesign die Unterschiede zwischen Gamern und Nicht-Gamern hinsichtlich Leistung und Belastung ausgleichen. Es ließ sich jedoch ein signifikanter Unterschied zwischen den Visualisierungsmethoden feststellen. Die Teilnehmenden zeigten bei der Visualisierung mit stereoskopischer Tiefeninformation eine bessere Leistung und eine geringere Belastung. Die verschiedenen Geräte hatten nur einen geringen Einfluss auf Leistung und Belastung. In Anbetracht dieser Ergebnisse sollte zukünftig erforscht werden, wie die Tiefenwahrnehmung gefördert werden kann (z.B. durch verbesserte sekundäre visuelle Hinweise), um die Visualisierung während der Teleoperation zu verbessern.

Contents

1 Introduction

Society is currently undergoing a transformation with regard to the workplace. The shortage of skilled workers in Germany and increasing automation pose challenges for both industry and individuals (Bundesagentur für Arbeit, 2022). New technological developments offer the potential to address these challenges. One interesting technological approach is teleoperation. The term teleoperation is defined by Niemeyer et al. (2008, p. 741) as the operation of a robot by a human over a distance with a barrier in between. This technology can find an application in remote assembly. In view of current trends in production, such as increasing individualization, more flexible assembly is required. Automated systems often reach their limits and human workers have to take over the task. Teleoperation can enable a collaborative working mode with humans and robots from a remote position, uniting their strengths. Moreover, teleoperation can be employed in extreme situations where humans can not work on an assembly task directly, such as in clean rooms, for micro-scaled objects, or in hardly accessible locations like airplane wings.

However, remote operation often precludes a direct view of the task. In this case, the operator requires a visual display of the work task. The implementation of the visualization poses challenges since a large amount of information needs to be presented to the operator in such a way that they can easily understand the display and do not experience increased workload (Rea & Seo, 2022). A common method is to film the robot at the remote site and transfer it to a 2D screen for the operator. Next to screens, an Head-Mounted-Display (HMD) is a common type of visualization during teleoperation. HMDs are worn on the head and are able to display a three-dimensional image, thus enabling depth perception. Research suggests, that this visualization with stereoscopic depth information improves performance (Triantafyllidis et al., 2020). However, head-worn devices might also add more workload to the operator or influence the usability of a system. The influence of different visualization types, especially with and without stereoscopic depth information, on the performance and workload of operators during teleoperation in assembly shall be investigated in this thesis.

Such a teleoperated system in assembly needs to be operated by a highly skilled worker. However, many studies investigating teleoperation do not distinguish between novel and expert operators. Consequently, to be able to transfer findings from these studies to industrial applications, it is important to be aware of differences in teleoperation between expert teleoperators and novices. Both groups have distinct needs and preferences regarding visualization. Therefore, different visualization methods potentially affect the performance and workload of expert and non-expert operators differently. For example, expert operators are familiar with the teleoperated system and might not rely on 3D visualization as much as non-expert operators. Hence, while investigating different visualization methods during teleoperation in assembly, in this study the differences between experts and non-experts will be investigated. Since experts are rare in this field, gamers can be considered expert operators due to their spatial abilities, their skills with input devices, and their trust in technology (Nenna & Gamberini, 2022).

Regarding visualization during teleoperation, current research is controversial about what kind of visualization is the most beneficial to the operator in terms of performance and workload (Brooks et al., 2017; de Boer et al., 2023; Illing et al., 2020; Maciaś et al., 2020; Schmidt et al., 2014; Triantafyllidis et al., 2020). In view of this controversy, performance and workload should be assessed carefully when choosing the visualization method for an application. This thesis conducts a study to investigate the performance and workload of expert and non-expert operators during teleoperation. The results of this study can help determine which type of visualization is suitable for teleoperated assembly. An appropriate visualization strategy can help to ensure a less stressful workplace for the operator and thus increase occupational safety and worker satisfaction.

The following research questions arise for this study:

1. How can the differences between the investigated types of visualization be quantified considering operator performance and workload on the operator? How big are these differences?
2. Are there differences between expert and non-expert operators in performance and workload during operation for different visualization types? What are the differences and how can they be quantified?

To answer these research questions, a study was conducted in the scope of this thesis. Each study participant performed an easy manipulation task of moving shapes into a box while using a teleoperated system. The system consists of two connected Franka Emika Robots by Franka Robotics GmbH in combination with the Franka Hand as an endeffector. For the visualization system, a ZED mini camera is used in combination with the Oculus Rift as the HMD. For the study, each participant is categorized as a gamer or non-gamer as a representation of the expert level. Each participant completes the task with four different visualization methods: direct view, 3D HMD, 2D HMD, and a 2D screen. The distinction between the 2D and 3D HMD is made to distinguish between the effects of depth perception (2D and 3D) and the device (HMD and flat screen display). After each scenario, the participants fill out questionnaires to determine the subjective workload with the NASA Task Load Index (NASA-TLX) questionnaire. The performance is derived from the Task Completion Time (TCT). Both the workload and performance are evaluated statistically with an Analysis of Variance (ANOVA). The results from this analysis can help answer the research questions and either confirm or refute the following hypotheses.

- There is no significant difference in the performance of expert operators during teleoperated assembly between 2D and 3D displays.
- Non-expert operators perform better with a 3D display compared to a 2D display.
- The workload is higher for expert and non-expert operators while wearing an HMD.

The thesis starts with an overview of the **state of the art**. In particular, the definition of teleoperation and basic concepts of different visualization methods are introduced. Consequently, the background for the measures of performance and workload are explained before elaborating on the categorization of expert and non-expert operators. In the following chapter, the **study design** is presented, starting with the dependent and independent variables. To fully understand the study design, the task for the trials is explained+ as well as the criteria and recruiting strategy for the participants themselves. The study complies with ethical guidelines and is approved by the ethics committee, which is explained in this chapter. Subsequently, the technical set-up, consisting of the teleoperated system and the visualization system, is described. The procedure of the experiment is then presented. The chapter concludes with an explanation of the materials used, particularly the standardized questionnaires. The consequent chapter presents the **results** of this study. First, the demographics of the participants are elaborated, followed by descriptive and inferential statistics of four measures: speed and time, accuracy and error, workload, and preference. These results are **discussed** in the last chapter and set into context. Finally, the **conclusion** summarizes the findings of this thesis and gives an outlook on possible future research.

2 State of the Art

Today, teleoperation is used in various fields of applications, from performing surgical procedures to remotely steering Mars rovers. This thesis focuses on a less-explored area: industrial teleoperation systems. Although this area is not the typical use case, it holds promising opportunities for manufacturing applications, particularly with regard to Industry 4.0 developments. Motivated by this potential application field, this thesis investigates possibilities for teleoperation in assembly.

This first chapter aims to build a shared understanding of key definitions and concepts important for the topic of this thesis. The chapter begins by explaining fundamental concepts and definitions related to teleoperation in assembly, followed by an exploration of visualization methods and their role in teleoperation. The chapter then delves into relevant literature, introducing studies that examine performance and workload in similar teleoperation scenarios. This exploration helps provide context and structure to the relevant research findings incorporated in this thesis. To conclude, the chapter addresses the definitions of expert and non-expert operators. This discussion establishes a conceptual foundation for analyzing operator performance and workload during teleoperation in assembly.

2.1 Key Concepts Related to Teleoperation in Assembly

The origins of teleoperation date back to the mid-20th century, when teleoperation was initially developed to address the challenges posed by handling radioactive materials (Niemeyer et al., 2008, p. 744). Today, the application of teleoperation encompasses many different domains, including aerospace and its use in the medical field. Particularly in industrial manufacturing, especially during assembly processes, there is potential for using teleoperation systems. Despite this promise, there is a lack of research in this area. This thesis aims to contribute to fill this research gap by exploring the use of teleoperation in assembly within the industrial setting.

2.1.1 Definition of Teleoperation

The term "teleoperation" is defined by Niemeyer et al. (2008, p. 741) as the operation of a robot by a human over a distance with a barrier in between. This barrier can have various forms:

- **Scale**: Components that are too large or too small for humans to handle well,
- **Accessibility**: Components that are difficult to reach, for example, in an airplane wing, or
- **Material that harms humans or can be compromised by humans**: Radioactive material or chip production in a clean room.

Concrete examples of such barriers and general examples are elaborated in the following section. Subsequently, opportunities for teleoperation in industrial manufacturing are listed.

While the specific components of teleoperation systems can vary, a common architectural framework is illustrated in Figure 1. The teleoperation system consists of an operator site and a remote site

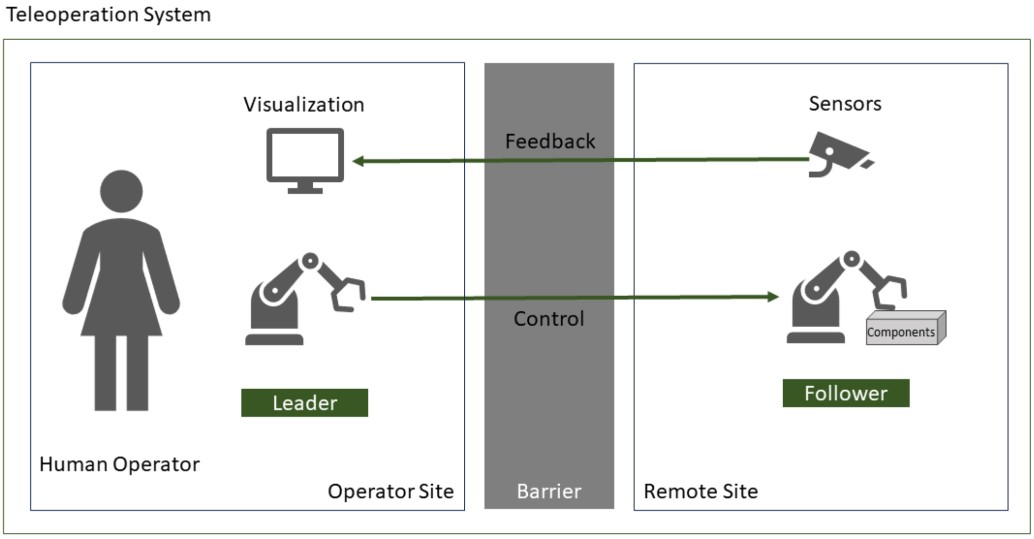


Figure 1 General setup of a teleoperation system adapted from Ferrell and Sheridan (1967)

separated by a barrier. The human operator handles the teleoperated system on the operator site and interacts with the input device – *the leader*. The input by the leader is then transmitted across the barrier to the remote site to the output device – *the follower*. The follower then translates these inputs into physical movements. This interaction enables the human operator to perform tasks remotely via teleoperation. To ensure the effectiveness of the teleoperation system, feedback from the remote site to the operator site is essential. This is realized by sensors registering measurements of the follower, task, and environment and subsequently communicating them back to the human operator. Finally, this data is visualized for the human operator. This setup is representative of a system where the operator is in full control, and the teleoperation system has little to no autonomy. This results in teleoperation serving as a tool rather than enabling collaboration between humans and machines (Luo et al., 2020).

2.1.2 Applications and Opportunities of Teleoperation

Overcoming a Barrier

As established before, teleoperation serves as a valuable tool to overcome various barriers, opening up a wide range of potential applications. One possible barrier is *scale*, in particular size and weight. Teleoperation can be employed to bridge the barrier of scale during the assembly of small objects like microchips (*microassembly*) or particularly large and heavy objects like gears (*macroassembly*) (Radi & Nitsch, 2010). In the context of microassembly the use of teleoperation can help solve multiple problems: Human operators face difficulties in handling very small items due to their lack of precise fine motor skills required for such tasks, making it challenging to maintain the necessary tolerances. Additionally, the small scale of items strains the human eyes. A teleoperated system can scale up the operator site and, thus, decrease the strain. With macroassembly, the robot can support the human operator with heavy lifting and, therefore, relieve them of physical strain. According to Radi and

Nitsch (2010) by employing teleoperation, the task can be scaled to a size better suited for the human operator.

Moreover, teleoperated robots prove invaluable to bridge the barrier of *accessibility*. They can help assemble parts in hard-to-access locations like airplane wings (Owan et al., 2017). Additionally, assembly at locations in challenging environments can profit from teleoperation. Teleoperated robotic systems make it possible to work in environments like in space that would otherwise not be possible to reach as easily (Rea & Seo, 2022). Another example of a hostile and hard-to-reach environment is off-shore locations. Teleoperation facilitates completing tasks like maintenance on off-shore plants without endangering the human operator (H. Chen et al., 2014).

Radi and Nitsch (2010) also explain the barriers related to *materials*. Teleoperation is a helpful tool for dealing with hazardous materials that pose health threats to humans, such as radioactive material. Furthermore, some materials require assembly in a clean room, which poses challenges for human operators. They need to wear protective equipment and take careful measures to avoid contaminating the product as well as the clean room. In this case, a teleoperated setup can enable assembly from a distance and spare the operator to suit up in protective gear.

Seizing Opportunities

Next to overcoming a barrier, teleoperation can also create opportunities in the face of current trends in industrial manufacturing. With changes in manufacturing processes, industrial production has shifted towards greater customization and more versatile small and medium production lines. Linsinger et al. (2018) suggests that the *flexibility and versatility* of teleoperated systems can accommodate a higher product variety and also shorten product cycles. In addition, Bortolini et al. (2017) emphasizes the usefulness of teleoperation in assembly for products designed for late customization. The flexibility of teleoperated systems facilitates the assembly of such customized products.

In assembly lines with a high level of automation, teleoperation also has areas of application. One useful application is *maintenance* tasks. In this case, a maintenance operator can access a robot in the automated assembly line in order to maintain the system with minimal interruption of the assembly process. Another application is *unanticipated events or emergencies* when the human operator's interception of the automated system is necessary (Rea & Seo, 2022). One potential situation involves a leader robot, controlled by a human operator, being able to access one of multiple follower robots when intervention is necessary. In this scenario, the human operator can access a specific robot requiring assistance, address the issue, and then disconnect once the problem is resolved, allowing the robot to resume its automated task.

Additionally, in the context of changing industrial processes, teleoperation can be a useful tool for teaching skills to a robot remotely. The human operator can demonstrate a task via the leader robot and the follower robot can then execute the skill. This enables a skill transfer from the human operator to the robotic system (Si et al., 2021).

2.1.3 Teleoperation in Assembly

As explained in the previous section, teleoperation can be utilized in assembly. According to Warnecke (1995, p. 1), production can be divided into two parts: *manufacturing*, involving the creation of individual components, and *assembly*, the combination of those components. Although production lines have been largely automated due to developments of Industry 4.0, assembly lines still rely heavily on manual labor.

Whether an assembly process can be automated or needs manual labor depends on different dimensions of the production process: productivity, variability, lot size, and flexibility. E. Lotter (2006, p. 193) explains, as shown in figure 2, that *automated assembly systems* are only reasonable with high lot sizes and productivity as well as low flexibility and variability. Respectively, *manual assembly* is characterized by low lot sizes and productivity as well as high flexibility and variability. A *hybrid assembly* combines automation and manual labor in cases that do not fit on either end of the dimensions mentioned above. Teleoperation can be classified into this category of hybrid assembly. Thus, teleoperation in assembly comes with the chances and challenges of hybrid assembly systems.

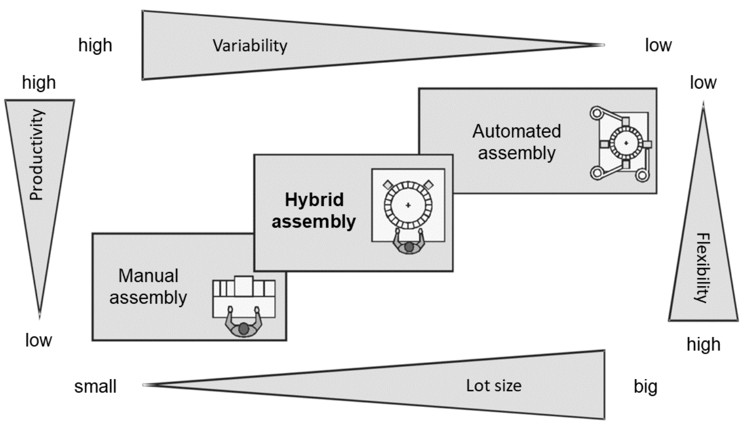


Figure 2 The dimensions of assembly translated from E. Lotter (2006, p. 193)

In light of evolving industrial production and the emergence of new challenges, the concept of hybrid assembly stands out as a potential solution to address arising issues. B. Lotter and Wiendahl (2006) identify three primary challenges associated with contemporary developments in industrial production that necessitate hybrid assembly:

- **Shorter product lifespan**: Present-day market trends frequently result in shorter product lifespans. Consequently, equipment designed for a specific product has limited utilization. In pursuit of economic and sustainable production, there is a growing need for more flexible operating equipment capable of accommodating various products.
- **Price pressure**: High material and labor costs demand a more efficient assembly to decrease overall costs.

- **Response capacity**: Assembly entails a wide variety of different tasks, and often adaptations during the assembly process are necessary. This requires highly flexible assembly systems and a workforce with advanced qualifications and skills.

To address the first and third challenge, more flexible manufacturing equipment operated by highly skilled workers is necessary. To this end, teleoperation emerges as a potentially useful technological approach. According to Draper (1995), the three main qualities of teleoperation are dexterity, the ability to perform as a general purpose machine, and the possibility to perform as a human-machine-system, therefore combining the strengths of both the human and the machine. These qualities align perfectly with the demands of the aforementioned challenges in modern production systems. Consequently, teleoperation stands out as an interesting solution representing a hybrid assembly system. This hybrid solution combines human skills with technological advances and while parts of the assembly system can be automated, the human operator still plays an essential role.

2.2 Visualization Methods

To facilitate effective communication between humans and machines, the human-machine interface should be well-designed. In figure 1 the interface is represented by the connection between the operator site and the remote site. While sensors gather data on the remote site, a visualization of the collected data is needed on the operator site. To help the human operator interpret this data seamlessly, it should be displayed in a modality a human can process well. According to EN ISO 9241-112:2017 (2017) this involves primarily visual, acoustic, and haptic modalities of information display in human-machine systems.

This thesis concentrates on the visual display of information as the primary modality. The implementation of visualization is generally challenging, given the substantial volume of information that must be presented to the operator. It is essential that this information is comprehensible and minimizes the potential for operator stress as well as operator error (Rea & Seo, 2022). A common method in teleoperation to visualize the remote site is to film the follower and transfer it to a screen for the operator at the operator site. Since teleoperation involves manipulation and movement, depth perception is advantageous for good performance in remote operations. It helps estimate distances and object sizes more accurately (J. Y. C. Chen et al., 2007). Regarding human vision, there are two main ways of experiencing depth perception: *binocular vision and secondary visual cues*.

Above all, how humans perceive depth depends on **binocular vision** – perceiving an image from two eyes. Hagendorf (2011) explains how binocular vision works: both eyes focus on one object. Due to the disparity between both eyes and their different angles to the viewed object, both eyes see a slightly different picture (see figure 3). The brain then combines these two pictures into a visual impression and can derive depth information.

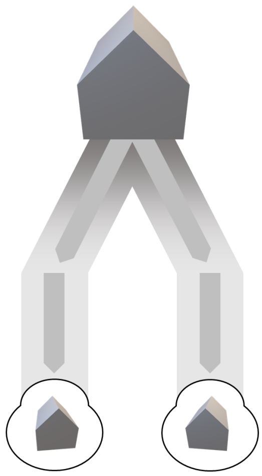


Figure 3 Explanation of binocular vision

In most cases, visualization during teleoperation happens digitally on a screen. There are two types of displays, *stereoscopic and monoscopic*, each relying on different mechanisms to create depth perception.

A **stereoscopic display** consists of two screens close to the eyes, each projecting a picture on one eye from a slightly different angle. These images match the natural disparity between the eyes as depicted in figure 4, thus creating depth perception (Hagendorf, 2011, p. 104). A *HMD* as depicted in figure 4a is an example of how the technological implementation of such a stereoscopic display can look like. According to ISO/TR 9241-380:2022 (2022) these HMDs are defined as an "electronic device that shows information on one or more displays attached to the head of a human".

(a) This image shows an HMD with a stereoscopic camera mounted on it (Stereolabs, n.d.)

(b) A stereo projection into the HMD with two slightly different images .

Figure 4 Stereoscopic display on a HMD

Monoscopic displays, however, show the same image to both eyes and therefore can not create depth perception through the disparity between two eyes (Hagendorf, 2011, p. 98). Nevertheless, it is important to recognize that depth perception is still achievable, as the human brain can leverage **visual cues** to extract depth-related information. These cues may include the size of objects, the overlap of different objects, perspective, shadows, or movement (Hagendorf, 2011, pp. 98). However, these visual cues are not exclusive to monoscopic vision; also in stereoscopic setups, they further support depth perception through the disparity between two eyes. Technological implementations of monoscopic displays involve using a 2D flat screen or an HMD with the same image projected on both screens in front of both eyes.

In this thesis, different visualization methods will be investigated and compared in terms of the performance and workload of the operator. Especially the comparison between monoscopic and stereoscopic displays is a topic of interest. One goal is to find a method of visualization that maximizes performance while minimizing workload.

2.3 Performance and Workload in Related Work

Which form of visualization offers maximum support while minimizing operator workload is currently a subject of research. Previous studies on visualization during teleoperated tasks present varying and sometimes contradictory results. Many of the studies concentrate primarily on technological aspects of teleoperation, with human factors receiving less attention. This section presents some of the few key papers that present research on human factors, discussing different results regarding the performance and workload of different visualization strategies during teleoperation.

2.3.1 Performance

Performance and workload are typical metrics to investigate and evaluate human factors in human-machine-interaction. However, both terms lack clear definitions and different studies often have different understandings of these concepts. This thesis relies on the definition of performance by Wickens and Hollands (2009). Following their definition, performance measures can be associated with one of four categories of raw data:

1. Measures of speed or time,
2. Measures of accuracy or error,
3. Measures of workload or capacity demands, or
4. Measures of preference.

Wickens and Hollands (2009) also state that performance measures highly depend on the task and evaluation goals of a study. For this reason, many different understandings of performance metrics in related studies exist. In general, most studies focus on points one, two, and three, where speed or time and accuracy or error are often summarized under the term performance, and workload is often investigated separately.

One key performance measure used in various studies is **TCT**, also referred to as time on task. The

TCT is the time it takes to complete a task from beginning to end. Upon investigating different visualization methods for teleoperation, Brooks et al. (2017) studied the TCT during a target detection task in Virtual Reality (VR) and found no significant difference for monoscopic and stereoscopic visualization. However, Illing et al. (2020) found a slight improvement of TCT during stereoscopic display in a search and rescue task in a real obstacle course. Triantafyllidis et al. (2020), Maciaś et al. (2020) and de Boer et al. (2023) all showed considerably improved in TCT during stereoscopic visualization as compared to monoscopic settings. Maciaś et al. (2020) investigated a search and rescue task similar to Illing et al. (2020). Triantafyllidis et al. (2020) investigated a pick-and-place task of different shapes in VR, while de Boer et al. (2023) studied a pick-and-place task of cubes.

Some of the referenced papers also investigated measures of **accuracy or error** — corresponding to the second category of performance measures by Wickens and Hollands (2009). This measure also highly depends on the task and the evaluation goals. Triantafyllidis et al. (2020) found a higher success rate and a lower distance error with stereoscopic displays during positioning shapes in virtual reality via teleoperation. Additionally, with the stereoscopic display, participants had a highly improved position and orientation accuracy. In another study Brooks et al. (2017) investigated the accuracy and error of novice and expert operators during a target detection task with navigation and manipulation. Accuracy was defined as targets that were recognized correctly, and error was the percentage of non-targets that were responded to. Experts slightly outperformed novices with a flat screen and had a significantly higher performance with an HMD. Similarly, de Boer et al. (2023) conducted a study where participants had to move small cubes from one container to another. They measured grab attempts, further categorized as failed and successful grab attempts. As a result, they found more failed grab attempts with monoscopic visualization compared to stereoscopic visualization.

2.3.2 Workload

Next to performance, another widely investigated measure characteristic for human factors research is **workload**. From the studies introduced above Illing et al. (2020), Triantafyllidis et al. (2020), Brooks et al. (2017), and Schmidt et al. (2014) used the *NASA-TLX* to investigate workload. The NASA-TLX is a well-known, quick, and easy questionnaire to evaluate workload. "The NASA Task Load Index is a multi-dimensional rating procedure that provides an overall workload score based on a weighted average of ratings on six subscales: Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort, and Frustration" (Human Performance Research Group, NASA Ames Research Center, 1986).

In their studies Illing et al. (2020) and Triantafyllidis et al. (2020) found the workload to be lower during stereoscopic visualization. Yet, Brooks et al. (2017) and Schmidt et al. (2014) reported a higher workload with HMDs. While stereoscopic visualization and HMDs are not necessarily connected, an HMD is the most convenient way to display a stereoscopic image. The above-mentioned studies did not distinguish if the effect of an increased workload was due to the visualization or the HMD. In this thesis, this distinction will be made to be able to attribute different workload scores to either the stereoscopic display or the HMD.

In summary, the literature suggests that TCT remains either the same or improves with stereoscopic displays. However, there is inconclusive evidence regarding the extent of this improvement. Workload is generally considered to increase with HMDs and to be lower with stereoscopic displays.

2.3.3 Limitations

While the reviewed papers provide valuable insights regarding the research question of this thesis, several limiting factors need to be reflected. Firstly, some studies give a **virtual task** in a simulated environment to the study participants (Brooks et al., 2017; Triantafyllidis et al., 2020), while others give tasks with real robots in a real environment (Illing et al., 2020; Maciaś et al., 2020; Schmidt et al., 2014). These studies indicate that the setting of the task in a real or virtual environment influences how the visualization affects humans. In the studies with virtual environments, the HMDs, which are usually designed for virtual reality might even have technological advantages.

Another aspect is the **type of task**. For assembly, which is the focus of this thesis, manipulation tasks are more relevant than navigation tasks. Navigation involves the operator moving the teleoperated robot in a remote site (e.g. during search and rescue), which requires a heightened sense of direction and increased spatial abilities of the operator. In addition, the movement of the robot creates additional secondary visual cues that support spatial perception. However, during a manipulation task (e.g. gear assembly), the teleoperated robot is stationary. The operator requires more fine motor skills and can rely less on secondary visual cues. All mentioned papers but Triantafyllidis et al. (2020) and de Boer et al. (2023) investigated navigation and manipulation tasks in combination. Visualization in navigation tasks profit largely from movement, as it creates depth perception as explained in the previous chapter 2.2. This is less applicable for manipulation. Teleoperation during navigation and manipulation tasks requires different skill sets. Although findings from one category can give indications for the other, they can not be applied directly without further investigation. Regarding teleoperation in assembly, studies of manipulation tasks are more relevant than navigation tasks.

Additionally, all reviewed papers study a relatively **small sample size** of 15 to 25 study participants. Often the gender and/or the age were not equally distributed. This means these studies are rather exploratory than statistical. This study strives for significant sample size in order to quantify the effects of different visualization methods.

Lastly, only Illing et al. (2020) and Brooks et al. (2017) address the differentiation between **novices and experts**. Their studies indicate that the experts performed better and experienced less workload.

2.4 Expert and Non-Expert Operators

In their studies, Illing et al. (2020) and Brooks et al. (2017) compared the teleoperation performance of novices and experts. Brooks et al. (2017) in particular considered gamers as experts in teleoperation. Generally, the classification of gamers varies strongly between different studies, but it is often based on the number of hours and frequency of playing video games. Brooks et al. (2017) defines a person as a gamer, "if at least one of their three most-played video games was as an 'action' video game, they played video games either daily or weekly, and played for greater than 1 hour per session".

Various existing research suggests, that gamers are better at teleoperation. For example, Nenna and Gamberini (2022) attribute gamers' enhanced teleoperation skills to improved visuospatial abilities and superior skills in handling input devices due to their experiences through video games. Additionally, the study indicates that these superior skills translate into better teleoperation performance as well as reduced workload due to a higher level of trust in technology among other factors. Gomer and Pagano (2011) agree with the finding that gamers outperform non-gamers in teleoperation and attribute this to better spatial abilities. Brizzi et al. (2018) observed a significantly lower task completion time with gamers, however, there was no significant difference in the accuracy of task completion. They also note that gamers display greater comfort in technical settings from the beginning, influencing their overall experience and performance.

In summary, gamers can be reasonably assumed to possess more refined teleoperation skills than non-gamers. Both groups have distinct needs and preferences regarding visualization. Therefore, different visualization methods potentially affect the performance and workload of expert and non-expert operators differently. Therefore, this study will distinguish between gamers and non-gamers.

3 Study Design

A well-grounded study design is necessary to investigate the impact of visualization types on the performance and workload of gamers and non-gamers. For the study conducted for this thesis, two independent variables were defined: visualization type and expert level. To study the effect of the visualization type, four different visualization scenarios are investigated: direct view, 2D-screen, monoscopic HMD, and stereoscopic HMD. The study was conducted in a mixed design. To distinguish the expert level, all participants were split into gamers and non-gamers between subjects. The experiment used a within-subjects design, where all participants from each group engaged with all four visualization types in a randomized order. Dependent variables included the performance and workload of the operator.

The chapter is structured as follows. First, independent and dependent variables, the task, and participants are introduced more closely. Afterward, the apparatus containing the teleoperated system and the visualization system are described. Finally, all materials, particularly the questionnaires used for the study, are explained.

3.1 Independent and Dependent Variables

The first of the two independent variables is the **type of visualization**. The main goal is to find quantitative differences between the four visualization types. It was established in the previous chapter (Chapter 2.3) that the difference between a monoscopic and a stereoscopic display is an interesting subject of research. Particularly, the effect on workload and performance of an operator of different devices, in comparison to the dimensionality, needs to be investigated. The monoscopic and stereoscopic HMD are introduced as visualization methods in addition to direct view and the 2D screen. The only difference between the monoscopic HMD and the screen is the device, while the only difference between the stereoscopic and the monoscopic HMD is the dimensionality. This facilitates the attribution of the effect on the operator to either the device (screen or HMD) or the dimensionality (monoscopic and stereoscopic). Each scenario covers one visualization method. All four scenarios are described in the following.

1. **Direct view**: The participants perform a teleoperated assembly task with direct view of the follower robot, meaning that participants can directly see the remote site without any barrier (e.g., partitioning wall) or intermediary device (e.g., camera and screen). There is no device for visualization (Figure 5).
2. **Monoscopic view via 2D screen**: In this scenario, the direct view of the follower robot is blocked by a partition wall. A stationary camera transmits the live image of the follower robot to a 2D screen next to the leader robot (Figure 6).
3. **Monoscopic view via HMD**: The direct view of the follower robot is blocked by a partition wall. A stationary camera transmits a live image of the follower robot to an HMD. The subject wears

Figure 5 An image of a participant operating the teleoperated system with direct view of the remote site

Figure 6 An image of a participant operating the teleoperated system with a monoscopic 2D screen

the HMD and sees the same image with both eyes. Thus, the subject sees a monoscopic video stream without depth information on the HMD (Figure 7).

4. **Stereoscopic view via HMD**: The direct view of the follower robot is blocked by a partition. A stationary stereoscopic camera transmits a live image of the follower robot to an HMD. The subject wears the HMD and thus sees a stereoscopic image with stereoscopic depth information (Figure 7).

The second independent variable in this study is the expert level in teleoperation. As explained in Chapter 2.4, it can be assumed that gamers have a higher expert level in teleoperation than non-gamers. In this study, the definition of "gamer" is adapted from the definition of Brooks et al. (2017). Accordingly, a gamer is defined as someone who plays video games **regularly**, plays at least **one hour a week**, and plays **immersive games** where they navigate a virtual world. More detailed information on what games are considered immersive can be found at the end of this chapter (Chapter 3.7).

To analyze the independent variables visualization and expert level, two main dependent variables were investigated: performance and workload. These two measures are explained in more detail in

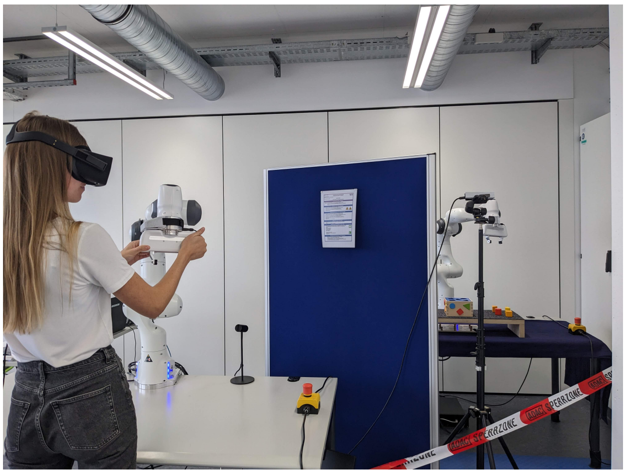


Figure 7 An image of a participant operating the teleoperated system with either a monoscopic or stereoscopic display on the HMD

Chapter 2.3. Performance is determined by the TCT and workload is measured with the NASA-TLX. With 59 individuals participating in this study, the opportunity arises to collect additional data during their participation in the study. This supplementary data, beyond the primary focus of workload and performance, will be analyzed at a later point in time outside the scope of this thesis. A list of all collected data with the respective method of collection is shown in Table 1. A more comprehensive description of the questionnaires follows in this chapter (Chapter 3.7).

Table 1 List of all collected data during the study organized by data category

Category	**Data**	**Description**	**Method of collection**
Personal Data	Demographical data	Age and gender	Collected via questionnaire at the beginning
	Visual impairment	Report about necessary visual aid (e.g. glasses) and about near-sightedness or far-sightedness	Recorded via questionnaire at the beginning
	Prior experience with HMD	Extend of experience (no experience - a lot of experience)	Recorded via questionnaire at the beginning
	Prior experience with remote operation like drones or race cars	Extend of experience (no experience - a lot of experience)	Recorded via questionnaire at the beginning

Table 1 List of all collected data during the study organized by data category

Category	Data	Description	Method of collection
	Affinity towards Technology	Affinity for Technology Interaction Scale (ATI)	Recorded via questionnaire at the beginning
	Gaming behavior	Gaming frequency (never - frequently), gaming hours per week, type of games played most frequently and ranking of devices played on by frequency played	Recorded via questionnaire at the beginning
Subjective questionnaires	Usability	System Usability Scale (SUS)	Recorded via questionnaire after each scenario
	Workload	NASA-TLX	Recorded via questionnaire after each scenario
	Final questions	Four questions, whether the difference between the two scenarios with the HMD was detected, ranking of scenarios from easy to hard, and suggestions for improvement for visualization and the teleoperated system	Recorded via interview questions after all scenarios
Objective measures	Performance	TCT	Retrieved from video recording
	Grab attempts	Number of grab attempts until grasp was successful	Retrieved from video recording

Table 1 List of all collected data during the study organized by data category

Category	Data	Description	Method of collection
	Corrections	Boolean variable (yes/no), denoting whether correction was necessary after releasing the shape to fall into the hole	Retrieved from video recording
	Workload	Blood Volume Pulse, constantly fluctuating changes in electrical properties of the skin, peripheral skin temperature, and motion-based activity are recorded	Recorded on Empatica E4 wristband
	Robot movement and forces	Movement of the joints and forces measured on gripper	Recorded with a script accessing robot data via Franka Control Interface (FCI)

3.2 Task Description

A task suitable for this study must meet the following requirements. Above all, it should be easily it should be easily comprehensible and require minimal explanation. This enables non-experts to complete the task in all scenarios in a reasonable time. Additionally, since this thesis focuses on teleoperation in assembly, the task should be representative of an assembly process, such as a pick-and-place task. However, the task does not need to be an industrial assembly task since the focus lies on the investigated human factors rather than the task. Ideally, the task should pose a moderate challenge and engage participants to keep them attentive and actively involved in the task. The task should strike a balance — not too simple to become monotonous, but not too difficult to frustrate participants. Both extremes would affect performance as well as workload.

3.2.1 Practice Task

Before starting with the trials, all participants were given a practice task to acquaint themselves with the teleoperated system. The practice task consisted of a farm-themed puzzle for kids (Figure 8). Such puzzles are familiar to most, which minimizes the necessary explanation during the practice task. Participants were instructed to place every puzzle piece in its corresponding slot, which resembled a pick-and-place task. Each puzzle piece had a small knob where it could be gripped. All pieces were arranged in the right order beforehand by the study administrator since the primary goal of this task was to familiarize participants with the system rather than to pose a strategic challenge.

Figure 8 Practice task: a farm-themed puzzle

3.2.2 Experimental Task

During the experiment, participants were given a different task from the practice task. Instead, they were presented with a sorting box as shown in Figure 9. The task was to place four different shapes (cube, cylinder, semicircle, and triangle) into the box by dropping them in their respective openings in the lid of the box. One of each shape was placed on a specific spot on each side, with the box in the middle. The semicircle and triangle are not placed in symmetrically identical orientations but in the same orientation on both sides. As a result, the shapes on both sides need to be rotated in the same direction and at the same angle and are, therefore, better comparable. Moreover, the gripper often reached its limit during rotations. Thus, the rotation necessary for bringing the shape into the right position was minimized. Participants were instructed to follow a specific sequence from front to back, first on the left side and then on the right side: cube, cylinder, semicircle, and triangle. Before each trial, the robot was moved into the starting position. The TCT was measured from first moving the robot until the shape was fully placed in the box, confirmed by auditory feedback of the shape falling into the box.
This task was selected because it meets all the aforementioned criteria. It is a well-known game without a technological barrier, requiring minimal explanation. Moreover, the goal is clear: all shapes need to be placed into the box. The task is similar to a pick-and-place task in assembly, including accuracy in gripping, rotation, and placement. Additionally, it provides a reasonable challenge and some variety, making the task engaging to participants. All measurements of the shapes, the box, and their placement are shown in Figure 10a, 10b, and 11.

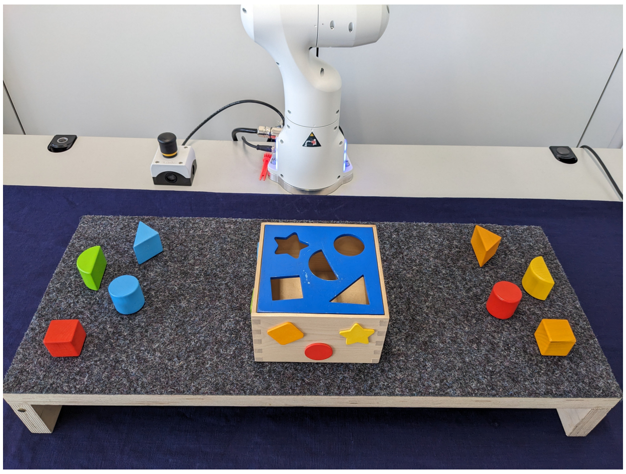
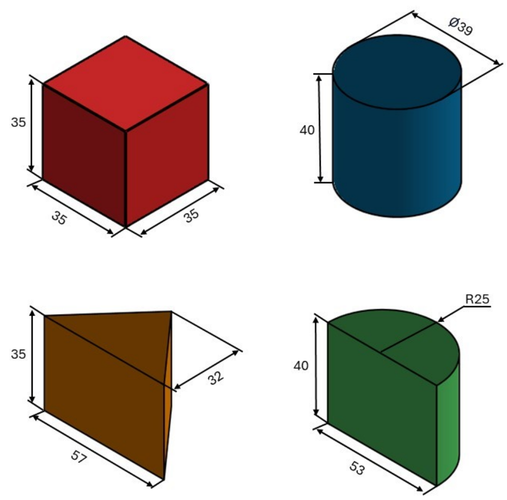
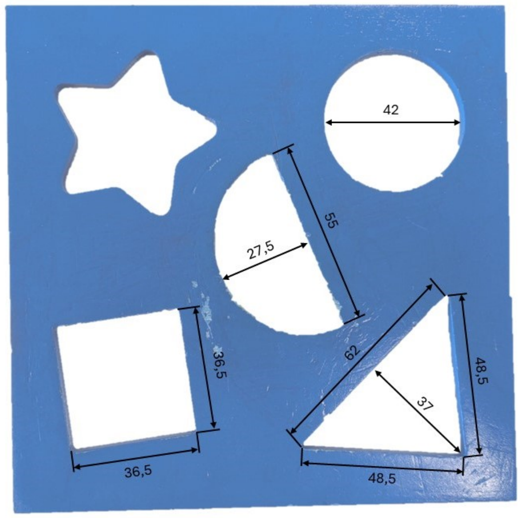


Figure 9 Task during trials: a sorting box



(a) All measurements of the shapes (measurements in mm)



(b) All measurements of the openings matching the relevant shapes in the box (measurements in mm)

Figure 10 The measurements of relevant shapes and openings in the box (measurements in mm)

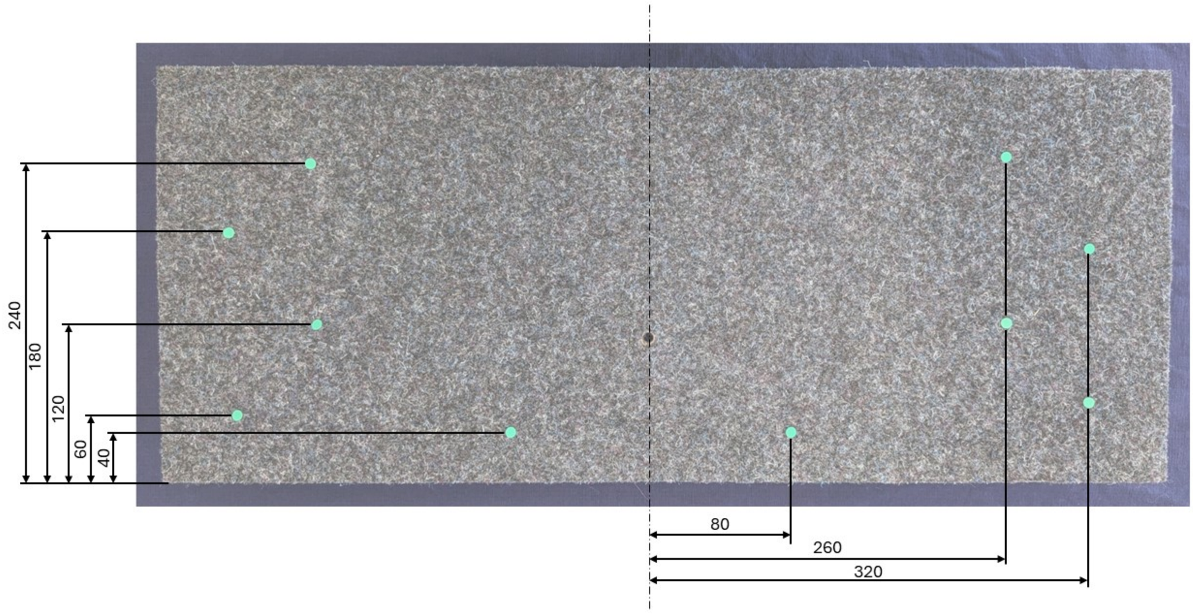


Figure 11 Each shape and the box were placed on the respective green dot

3.3 Participants

The target number of participants for the study was calculated by the Software G*Power with the effect size of 0.14, an alpha error of 0.05, and a power of 0.8 in order to conduct a two-factorial mixed ANOVA statistical analysis for each dependent variable. The effect size was calculated from data from a previous study at the Chair of Ergonomics at Technical University Munich (TUM) (Prinz & Bengler, 2023) with the same apparatus and a comparable study design. Based on this calculation, the goal was to recruit 59 participants. Of those targeted 59 participants, half should be gamers and the other half non-gamers in order to allow for a meaningful comparison between the two groups. I recruited participants via posters in the mechanical engineering building at TUM, via social media posts on my private accounts, and at the Chair of Ergonomics. In addition, a slide informing about the study was shown in some lectures that taught content related to the topic of the study. To recruit gamers, I contacted the student organization "Munich eSports" and posted about the study on their discord channel.

To take part in the study, the following criteria need to be met. The exclusion criteria listed below prevent from taking part in the study.

Inclusion criteria:

- The participant must be between 18 and 65 years old.
- They must be able to give their consent.

- They must either have normal vision or corrected-to-normal vision with visual aids like glasses or contact lenses.

Exclusion criteria:

- The participant does not have stereo vision.
- They did not give their consent.
- The participant is pregnant.

The experiment may be terminated if a participant decides to withdraw their consent without the need for specifying a reason. The experiment may also be terminated if a participant experiences discomfort during the experiment (e.g., simulator sickness) or if unforeseen technical difficulties arise, preventing the experiment from proceeding.

3.4 Ethical Considerations

This research followed the ethical principles outlined in the Declaration of Helsinki and complied with the local statutory requirements of Bavaria, Germany. The Ethics Committee of the Technical University of Munich reviewed the study involving human participants and approved the proposal without objections under reference number 2023-545-S.

Prior to their participation in the study, all study participants provided their written informed consent. Throughout the study, a number of safety measures were implemented to ensure a safe experimental environment for all participants.

Wearing an HMD can lead to simulator sickness, which participants might experience in the form of slight dizziness and discomfort (Brooks et al., 2017). Therefore, participants were asked regularly about their well-beeing during planned breaks. In case of simulator sickness, the experiment could have been interrupted at any time. According to Brooks et al. (2017), simulator sickness mostly only occurs when wearing an HMD for more than 20 minutes. As the duration of wearing an HMD is set at a maximum of 5 minutes per trial, the risk of simulator sickness is considered to be low.

Throughout the study, the data record of each participant is managed via an ID for anonymity. This number is retained when the results are analyzed and reported. All data is initially stored locally and transferred to a restricted-access server at the Leibniz-Rechenzentrum of the Technical University of Munich. Only those involved in the preparation, execution, and evaluation of the experiment have access to the stored data. After completion of the experiments and the analysis of the data, locally stored files will be deleted, while the files stored at the Leibniz-Rechenzentrum will be saved for 10 years for reasons of good scientific practice. The collection of personal data will be kept to a minimum.

3.5 Apparatus

The technical setup of the study reflects the basic architecture of a teleoperated system as shown in 1. Figure 12 shows the general architecture applied to the teleoperated system used in the study from a birds-eye-view. The leader and the follower are represented by two robotic arms by Franka Robotics GmbH (Franka Emika Robot), which links the operator site with the remote site. On the remote site, a ZED mini camera streams a video as feedback to the visualization device, which is either a 21 inch Fujitsu screen or an Oculus Rift as the HMD, depending on the scenario.

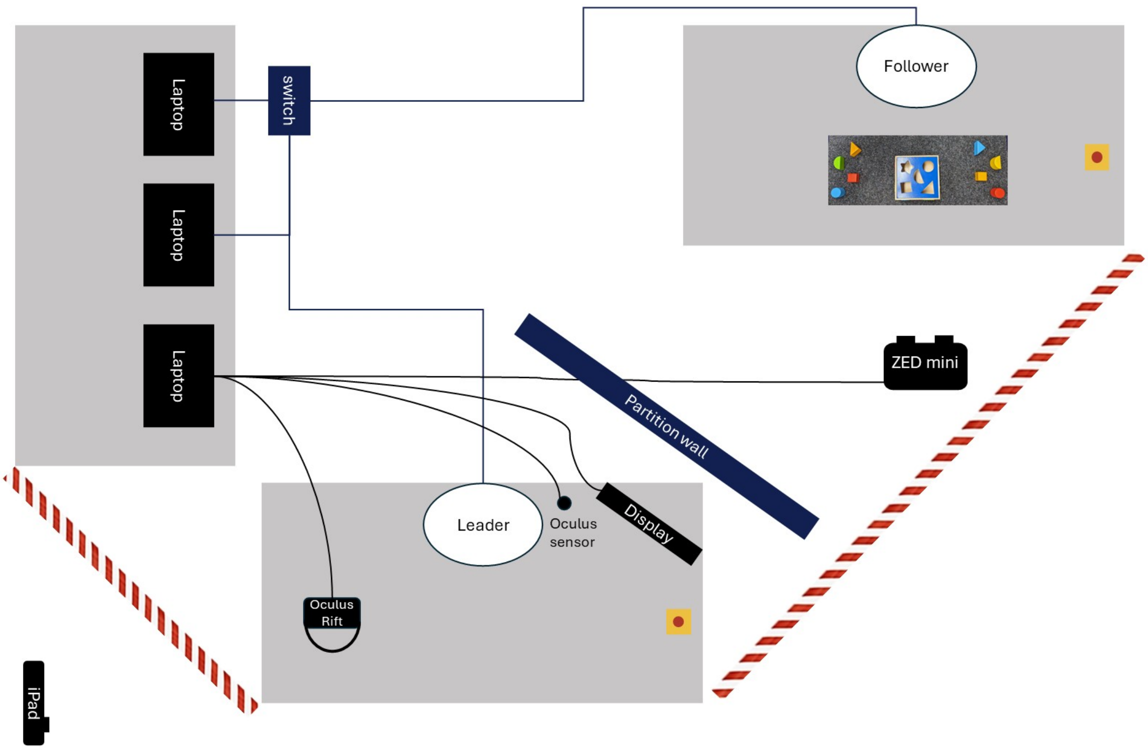


Figure 12 The schematic setup analogous to the general architecture of teleoperated system

3.5.1 Teleoperated System

The teleoperated system consists of two robotic arms by Franka Robotics GmbH provided by the Chair of Ergonomics. When the operator moves the leader robot at the operator site, the follower robot executes the exact same movement with a latency of 0.207 ms (measured by a ping test) in real time at the remote site. Each robot is controlled by a Linux PC with custom teleoperation scripts running with the FCI activated. Both robots and both PCs are connected via ethernet and an 8-port gigabit desktop switch by TP-Link. The connection enables bilateral force feedback while moving the robots. To grasp objects, a two-finger parallel gripper (Franka Hand) is mounted on both robots as an end effector. By closing and opening the fingers of the gripper of the leader, an object can be grasped or released by the follower. The gripper is not able to provide a real-time connection and force feedback. The latency between the leader and the follower gripper is about 0.85 ms, which was measured from video recordings.

The robots are about 2.3 m apart, with the follower robot 1.50 m to the side and 1.70 m to the rear. This offset positioning of the follower robot ensures that the leader robot does not block the view of the follower robot in direct view condition. During the other scenarios (2D screen and HMD), a video of the follower robot is streamed from a camera positioned 1.30 m from the follower robot. This camera is mounted at a height of 1.58 m in order to represent an egocentric perspective on the task at the remote site.

3.5.2 Visualization System

The camera capturing the image for visualization is a ZED mini by Stereolabs (Figure 13). The ZED mini is a stereoscopic camera that can stream two separate images with a disparity matching human eyes (see Chapter 2.2). The ZED mini streams the camera feed to a PC with Windows 10, where the visualization is managed. For each type of visualization, an executable program was written in Unity. For the scenarios with the HMD, it is necessary to connect the ZED camera with the Oculus Rift used as the HMD. The Oculus Rift comes with a sensor that captures the position of the HMD, which was positioned next to the leader robot. The integration of a stereoscopic stream from the ZED camera to the Oculus Rift was facilitated through a plugin developed by Stereolabs (2023). Custom adjustments were made to the executable programs using the plugin, ensuring that the virtual projection of the image remained stationary relative to the Oculus sensor, even as the HMD was in motion. Subsequently, a program was developed to generate a monoscopic video stream, differing only from the stereoscopic stream by projecting the same image (from the left camera of ZED mini) to both eyes of the Oculus Rift. In the scenario with the flat screen display, the Windows PC was connected to the flat screen display via HDMI, showcasing a direct stream from the left camera of the ZED mini. Since the Oculus Rift is limited to 720 p at 60 fps, the stream to the 2D screen was also set to these specifications. This ensures that the only difference between the two monoscopic displays is the dimensionality. During all scenarios (including direct view), the Windows PC showed the video stream from the left ZED camera. This stream was recorded via Windows Game Bar screen recording for later analysis. Additionally, an iPad recorded the participant in a video from their left side during the whole experiment for the purpose of future analysis of ergonomic pose.

Figure 13 ZED mini mounted on a tripod

3.6 Procedure

The entire process of the experiment is visualized in Figure 14. The respective times for each step are annotated in this figure.

Introduction

As the study administrator, I welcomed the participants at the beginning of each trial. As soon as the participant was ready, I gave a short introduction about the background, the research goal, and the process of the study. It was not mentioned that the focus of the study lies on performance and workload, so the participants are not biased. Before the trial began, every participant was given time to read the consent form carefully before signing it, which was the condition for participation. Then, I checked if the participant had stereo vision by conducting a Lang Stereotest. If the person did not have stereo vision, they still participated in the study, but their data was excluded from the statistical analysis. After this test, I gave an introduction on how to operate the teleoperated system. A more detailed record of this introduction and the whole trial, is available in Appendix Appendix A. As part of the introduction, the participant was asked to put on the Empatica E4 wristband and start recording. I explained that the button on the Empatica wristband is an event marker and needs to be pressed at the beginning and the end of each scenario upon instruction. In the next step, the participant started with their practice task of solving a puzzle as described in Section 3.2. During their practice task, I gave hints relating to the operation of the robot arm and gripper, for example, how to close the gripper if it was stuck. After completing the practice task, the participant filled out the first questionnaire, providing demographic data along with information about prior experience with technology related to the study, and their gaming behavior.

Four Randomized Scenarios

While the participant filled out the questionnaire, I prepared the setup for the first of the four randomized scenarios and changed the task to the experimental task: a sorting box with different shapes (see chapter 3.2). When the participant was ready to continue, I explained the new task and the order of the shapes to be placed into the box (cube, cylinder, semicircle, and triangle). Before a scenario with the HMD, I explained how to put on the HMD and adjust it to fit well. As soon as the participant was ready, I started the necessary recordings and the participant started working on the task. During the experiment, I did not give hints or answer questions that might influence the participant. I only answered questions about the study's progress, for example, what shape comes next. After the last shape was dropped into the box, I stopped the recording and the participant filled out the NASA-TLX and SUS questionnaire. During this time, I prepared for the next scenario. This procedure was repeated for all four scenarios.

Final Interview

After the last scenario and the last questionnaire, I asked the participant a few final interview questions as documented in Chapter 3.7. Finally, they received some sweets or an apple as a thank you before leaving.

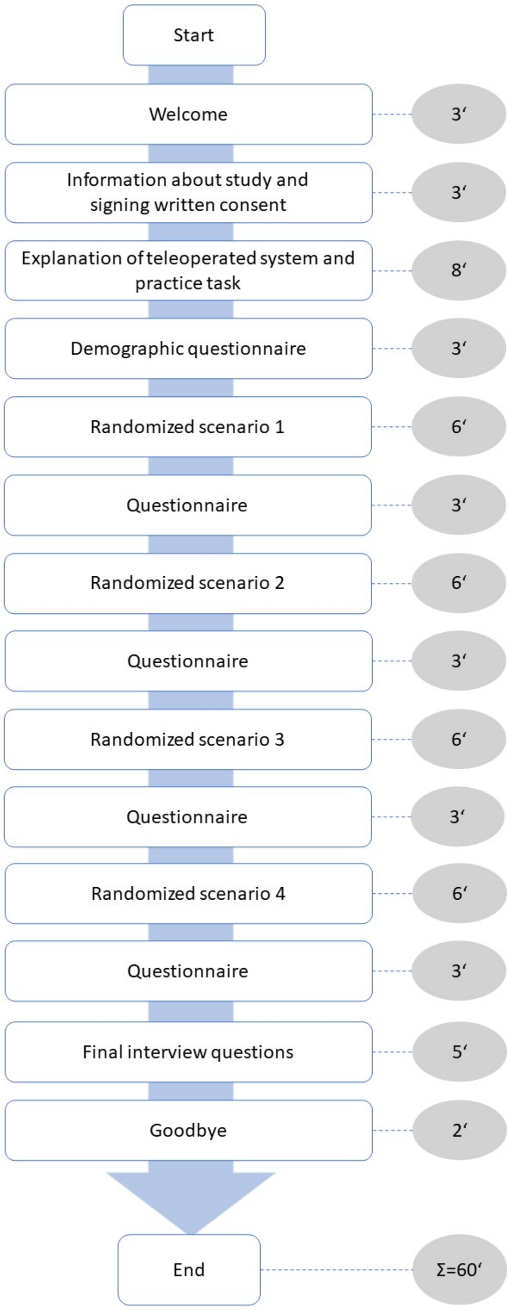


Figure 14 The process of each trial with duration in minutes

3.7 Materials

In the preceding sections, several tests and questionnaires were introduced, each of which will now be explained in greater detail. These tests and questionnaires are standardized and validated, ensuring scientific results. In the subsequent section, the specific objectives and process of each test and questionnaire will be explained. These tests and questionnaires include the Lang-Stereotest, the demographic questionnaire, ATI, NASA-TLX, SUS, and the final interview questions. All questionnaires are recorded via the software LimeSurvey and can be found in the Appendix Appendix B.

3.7.1 Lang-Stereotest

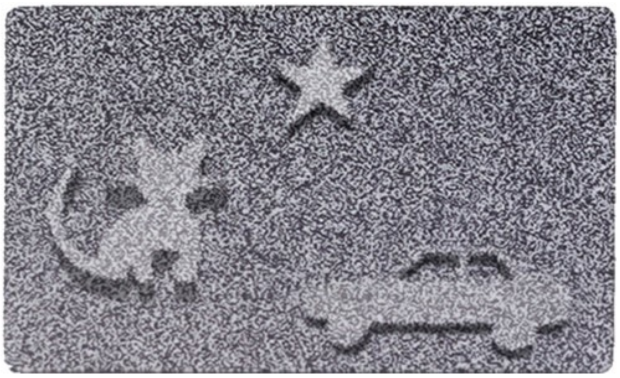
One of the exclusion criteria for participants, as outlined in section 3.3, was the inability of stereo vision. Stereo vision is required for this study since a key research goal is to investigate differences between stereoscopic and monoscopic displays. For individuals without stereo vision, both displays would appear the same since they are not able to perceive or process stereoscopic depth information. Grehn (2019, pp. 511) lists strabism and big differences in eyesight between both eyes as the main reason for a lack of stereo vision. He also suggests the Lang-Stereotest as a method to test for stereo vision. It is a quick and easy test commonly used in routine medical examinations with children. The Lang-Stereotest was used to check for stereo vision after signing the informed consent before engaging with the system. The manufacturer of this test (Lang-Stereotest AG, n.d.) provides an explanation of the test with an instruction manual.

The Lang-Stereotest consists of one card with a random dot pattern (Figure 15a). Only with stereo vision, three shapes, a star, a cat, and a car (see Figure 15b) are visible. For the test, the participant needs to wear their corrective eyewear and should be positioned in a way that avoids reflections from windows or lamps. The study administrator holds up the card to the participant without moving in a distance between 30 and 40 cm and asks, "Do you see anything?" without giving any hints. Depending on the answer, there are different results as provided in the instruction manual by Lang-Stereotest AG (n.d.):

- **Positive**: Correctly naming and pointing out all test figures.
- **Negative**: No 3D object can be detected.
- **Doubtful**: One or more objects may be localized but are not identified correctly.

It is important to note that during this study, the Lang-Stereotest was not conducted by a medical professional and, therefore, did not replace an eye examination with a specialist. For the scope of this study, this simple test is deemed sufficient to test for stereo vision.

(a) This image shows the Lang-Stereotest with its case (Lang-Stereotest AG, n.d.)



(b) This image shows the Lang-Stereotest how a person with stereo vision would see the three shapes (Lang-Stereotest AG, n.d.)

Figure 15 The Lang-Stereotest

3.7.2 Demographic Questionnaire

The demographic questionnaire was filled out by participants before starting with the scenarios. Apart from the standard questions about age and gender, data about eyesight is also collected. Participants are asked if they need a visual aid like glasses and, if this is the case, if they are near-sighted, far-sighted, or both. Given the focus on visualization in this study, understanding the visual capabilities of the participants is important.
Furthermore, information about prior expertise is collected. Participants are asked if they have worked with HMDs before. Moreover, they report their expertise level regarding remote control. Remote control of drones or race cars requires the same skills as teleoperation. This information is important for the study to understand better the technical background and skills of the participants. Also, the questionnaire documents whether a person qualifies as a gamer according to the definition of this study. Firstly, every participant was asked how regularly they played video games. If the answer to this question was "never", the questionnaire ended there. Otherwise, the gaming habits are further investigated. Firstly, they were asked how many hours per week they play video games and then under which category their 3-5 most played video games fall. In the following, the categories are described, which are oriented on the genres of the study done by Kemp (2023) with additional examples.

- **Shooter**: Counterstrike, Call of Duty, Overwatch, Fortnite
- **Sandbox**: Minecraft, Terraria, Starbound
- **Action adventure**: Zelda, The Witcher, Assassin's Creed
- **Simulation**: Cities: Skylines, Flight simulator, farming simulator, SIMS
- **Multiplayer online battle arena (MOBA)**: League of Legends, Dota 2, Vainglory
- **Sports**: FIFA, MBA, Madden
- **Racing**: Forza, iRacing, Trackmania

- **Strategie**: StarCraft, Age of Empires, Civilization
- **Puzzle**: Sudoku, candy crush
- **Fighting**: Tekken, Mortal Combat, Street Fighter
- **Action Platform**: Super Mario, Little Big Planet, Cuphead
- **Online Boardgames**: Chess, Monopoly, Uno

People exclusively playing online tabletop games (e.g. chess) or puzzles (e.g. Sudoku) are not considered gamers since these games do not require spatial awareness. Additionally, a ranking of the participants' most used gaming devices was collected. Participants were asked to rank PC/laptop, console, smartphone/tablet or other devices from most to least used. This information reveals the participants' expertise with different input devices.

3.7.3 Affinity for Technology Interaction Scale

The ATI was also part of the demographic questionnaire. It is a standardized and validated questionnaire that describes a person's tendency to actively engage in technology interaction or rather avoid it (Franke et al., 2019). Participants were asked about their interaction with technology, and they answered nine statements on a six-point Likert scale from "completely disagree" (coded as 1) to "completely agree" (coded as 6). Three of the nine items are negatively worded, and the coding needs to be reversed before the evaluation. To calculate the overall score, the mean over all items is computed. More detailed information about the background, validation, and conduction of this questionnaire is provided by Franke et al. (2019). The ATI can help to find out valuable background information about participants. Technological affinity and gaming are closely associated with each other. As explained in Chapter 2.4 in the literature review, Brizzi et al. (2018) explains how improved performance of gamers is strongly linked to being more comfortable with technology. Utilizing a metric like ATI enables a more nuanced exploration of this effect, allowing for a more precise attribution of improved performance to either gaming or a general affinity with technology.

3.7.4 NASA Task Load Index

The NASA-TLX is a standardized and validated test to investigate workload. It consists of six dimensions: Mental demands, physical demands, temporal demands, performance, effort, and frustration (Human Performance Research Group, NASA Ames Research Center, 1986). Each dimension is rated on a scale from 0 to 100 after each scenario. At the end, a questionnaire comparing all dimensions with each other determines the weight of each dimension, depicting how important every dimension is to the participant. The weight of each dimension is then multiplied by the score of each dimension. This result gives an indication of the workload of each dimension and can be helpful for a more differentiated investigation. Additionally, the overall score can be calculated by computing the mean over all dimensions to get a more comprehensive result.

3.7.5 System Usability Scale

The SUS is a standardized and validated test to investigate usability quickly with minimal effort. ISO 9241-11 (2018) defines usability as the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use". Thus, the SUS helps to identify if and to what extent participants in the study can operate the teleoperated system effectively, efficiently, and to their satisfaction. As Brooke (2014) explains, the SUS consists of ten items that are rated by the participant on a 5-point Likert scale from "completely agree" to "completely disagree". Items 2, 4, 6, and 8 are reversed. To calculate the final score, the mean over all items is computed. This final score, a value between 1 and 100, can be put in context by comparing it to an absolute adjective rating scale.

3.7.6 Final Interview Questions

At the end of the experiments, I asked the participants four final questions. The form of an interview was chosen over a questionnaire to give the participants more freedom for their answers. The first question aimed to check if the participants recognized the difference between the stereoscopic and the monoscopic HMD. Next, the participants were asked to rank the four scenarios (direct view, 2D screen, monoscopic, and stereoscopic HMD) from easiest to hardest. Finally, feedback and suggestions for improvement of the visualization and teleoperated system were gathered, providing participants with the opportunity to express any thoughts, identify weaknesses of the system, and contribute ideas for future improvements. Sometimes, these open questions required follow-up questions for a better understanding of the participants' responses. I took notes as the participant responded.

3.8 Statistical Analysis

A statistical analysis is conducted to answer the research questions and either confirm or disprove the hypotheses. After a first exploration of the data and a summary of descriptive statistics, a mixed two-factor ANOVA was used to analyze the independent variables performance (represented by TCT) and workload (represented by NASA-TLX). An ANOVA can identify significant differences between means of two or more groups by analyzing variances. The six dimensions of the NASA-TLX are then further analyzed with a mixed two-factor Multivariate Analysis of Variance (MANOVA). A MANOVA includes more than one independent variable. The data was prepared utilizing the software Microsoft Excel. All statistical analysis, including the generation of diagrams, was conducted in the integrated development environment RStudio using the software environment R.

4 Results

Following the methodology explained in the previous chapter, the study performed for this thesis was conducted and produced the results presented in the following chapter. First, the descriptive statistics of the participants are elaborated. Afterward, the chapter is divided into the four measures of performance by Wickens and Hollands (2009) introduced in Chapter 2.3: measures of speed and time (TCT), measures of accuracy and error (grab attempts, corrections, and gripper error), measures of workload (NASA-TLX), and measures of preference (SUS). Additionally, the answers to the final interview questions are presented. For each analyzed dependent variable, descriptive and inferential statistics are reported.

4.1 Participants

In preparation for the study, the setup and study design were tested with 3 participants in a prestudy. The system and some questionnaires were adapted before the trials began. Questions on the expertise level on VR technology and remote control were added to the demographic questionnaire and the NASA-TLX was extended to the full questionnaire instead of the raw NASA-TLX. A total of 69 participants took part in this study. After the first six trials, the task and the teleoperated system were adjusted to mitigate errors with the gripper. These trials are excluded from the analysis. Of the remaining 63 participants, two are excluded due to technical system errors. One participant experienced extreme frustration and required significant intervention by the study administrator during the trial. Therefore, they are excluded from the analysis. With one participant, the Lang-Stereotest was inconclusive; thus, the participant did not meet the criteria of stereo vision. They still participated in the experiment and their results will be reported descriptively in Chapter 4.6, but their data was excluded from the statistical analysis.

Of the remaining 59 participants, 37 were male and 22 female. Their age ranged from 18 to 65 (M = 26.24 years, SD = 6.25). 31 participants were gamers (5 female, 26 male) and 28 non-gamers (17 female and 11 male). Most gamers (n = 20) stated that a laptop or PC is their gaming device of choice. Only six use their smartphone for gaming most often and five use a console. Gamers play between 1 h and 28 h per week (M = 6.19 h, SD = 6.66). The ATI measured a score between 2.22 and 5.89 for all participants, which represents an above-average affinity towards technology (M = 4.74, SD = 0.70, Cronbach's alpha = 0.85). The mean score of gamers (M = 4.83) was slightly higher than the score of non-gamers (M = 4.64). Besides, of the 59 participants, 47 either work or study at TUM, and 12 are not affiliated with TUM.

Participants' levels of experience with VR and HMDs varied, with 14 reporting no experience, 37 indicating little experience and 8 considering themselves medium to extremely experienced. In terms of experience with remote control, 8 reported no experience, 36 little experience, and 15 considered themselves medium to extremely experienced.

From all 59 participants, 25 did not need any visual aid, whereas 34 participants required a visual aid because they were either near-sighted (29), far-sighted (3) or both (2). One person did not wear glasses, although they usually wear them in some cases (e.g. cinema).

4.2 Measures of Speed and Time

The TCT is the main performance measurement in this study and defined as the time duration to finish a task. It was measured for each shape of the task individually, starting from the participant moving the robot arm until the first shape was successfully placed into the box. The successful placement was confirmed by auditory feedback (the sound of the shape falling into the box). The TCT of all consecutive shapes was measured from the moment the previous shape was successfully placed in the box until the consecutive shape was successfully placed in the box. All individual TCTs were summed up to a total TCT describing the time to finish the whole scenario. If a technical error without the participant's fault occurred during the task (the robot or gripper stopping, requiring a restart), the time from the beginning of the error until the robot was moved again was subtracted from the TCT. All TCTs were derived from a video recording and measured in seconds.

Due to some technical issues, participants encountered problems with the gripper when picking up the cube on the right side. The gripper would not grasp the object and instead stop the gripper fingers at a certain distance. To continue with the operation, a manual restart of the gripper system was necessary. Unfortunately, the reason for this technical error could not be determined. In most cases, the participant was able to continue to move the cube after the restart. In six cases, however, the error persisted even after multiple restarts of the system. If the error persisted, I advised the participant to leave out the cube and continue with the next shape, the cylinder. For these six cases, no TCT for the cube was measured. To avoid excluding these six participants from the study due to a missing data point, the missing value was extrapolated from other measurements. For this calculation, the mean over the ratios of TCT from the left to the right cube in all other scenarios was determined and then multiplied with the TCT of the left cube. The index of each variable consists of the shape, the side, and the scenario number: $TCT_{\text{cube-right/left, Scenario Number}}$. This was the resulting formula, with the indices representing the scenarios:

$$TCT_{\text{cube-r,0}} = TCT_{\text{cube-l,0}} \cdot \left[\left(\frac{TCT_{\text{cube-r,1}}}{TCT_{\text{cube-l,1}}} + \frac{TCT_{\text{cube-r,2}}}{TCT_{\text{cube-l,2}}} + \frac{TCT_{\text{cube-r,3}}}{TCT_{\text{cube-l,3}}} \right) \div 3 \right]$$

The raw TCT data with the replaced values highlighted can be found in Appendix Appendix C.

4.2.1 Descriptive Statistics

The means and standard deviations of the total TCT of both groups (gamers and non-gamers) in all four scenarios(direct view, stereoscopic HMD, monoscopic HMD, and flat screen display) are listed in Table 2 and visualized in Figure 16. Between all scenarios, the median of the non-gamers is higher than the median TCT of the gamers, which shows that non-gamers needed more time to complete the task. However, the difference is less pronounced in the scenarios with stereoscopic depth information (direct view and stereoscopic HMD). Overall, for both groups the scenarios with stereoscopic depth information show a lower TCT than scenarios without stereoscopic depth information. This indicates that stereoscopic depth information decreases the time it takes for participants to complete the task.

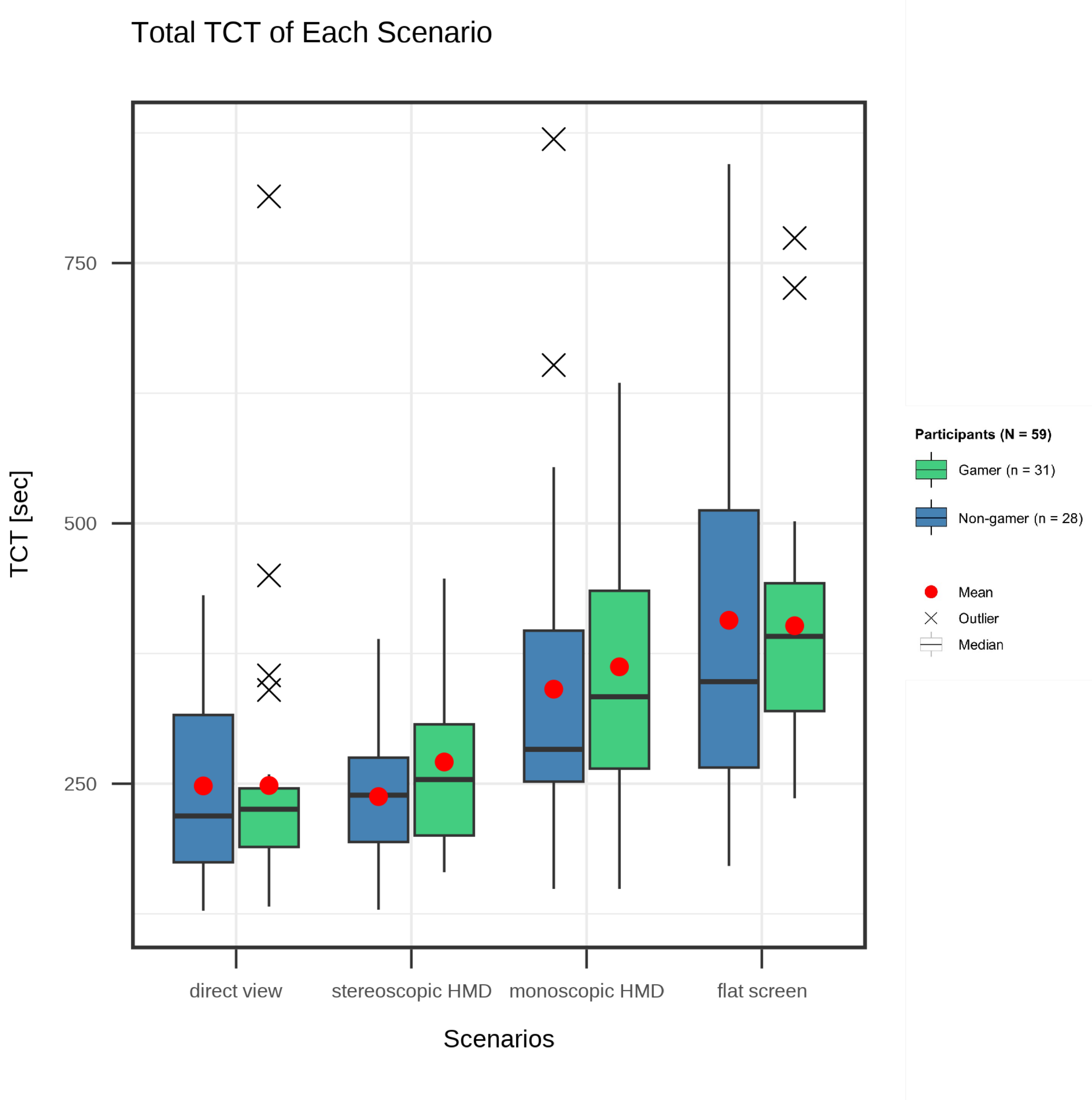


Figure 16 Boxplots of the total TCT of each scenario

In Figure 17 and Figure 18, the individual TCT for each shape is presented. These figures illustrates the positive skew of the distribution with many outliers towards higher TCTs. For both groups and all

Table 2 Overview of means and standard deviations of TCT data

Scenario	Mean [sec] and Standard Deviation
Direct view	Gamer: M = 247.87, SD = 84.29 Non-gamer: M = 248.29, SD = 129.15
Stereoscopic HMD	Gamer: M = 237.61, SD = 65.85 Non-gamer: M = 270.86, SD = 81.73
Monoscopic HMD	Gamer: M = 340.77, SD = 157.94 Non-gamer: M = 362.25, SD = 130.63
Flat screen display	Gamer: M = 406.94, SD = 179.03 Non-gamer: M = 401.68, SD = 120.31

four scenarios, the median TCT of the left cube and the triangles on both sides exhibit higher TCTs than the remaining shapes. However, the differences are more distinct in the scenarios with the flat screen display and the monoscopic HMD.

4.2.2 Inferential Statistics

To investigate if the differences between the mean total TCTs are significant, an ANOVA is conducted. Before the ANOVA model is created, the data needs to comply with all assumptions for an accurate analysis (normal distribution, variance homogeneity, covariance homogeneity, and sphericity). Accordingly, a robust ANOVA is conducted in the following. Finally, post-hoc tests provide further indication of differences between scenarios and their respective effect size.

Assumptions

Firstly, the TCT data is analyzed to determine whether the TCT data represents **normal distribution**. A Shapiro-Wilk Test conducted for each group for all four scenarios shows a significant deviation (marked with * in Table 3) from normal distribution for both groups in direct view and the flat screen display scenario as well as for gamers in the scenario with monoscopic HMD. A visual examination of the Q-Q plot confirms the results from the Shapiro-Wilk Test (Figure 19). To accommodate for this deviation from normal distribution, a robust ANOVA is conducted.

Table 3 Overview of results of the Shapiro-Wilk Test on TCT data

Scenario	Shapiro-Wilk Test
Direct view	Gamer: W = 0.911, p = 0.0136* Non-gamer: W = 0.618, p < 0.0001*
Stereoscopic HMD	Gamer: W = 0.975, p = 0.654 Non-gamer: W = 0.928, p = 0.0560
Monoscopic HMD	Gamer: W = 0.848, p = 0.0004* Non-gamer: W = 0.931, p = 0.0658
Flat screen display	Gamer: W = 0.910, p = 0.0126* Non-gamer: W = 0.842, p = 0.0006*

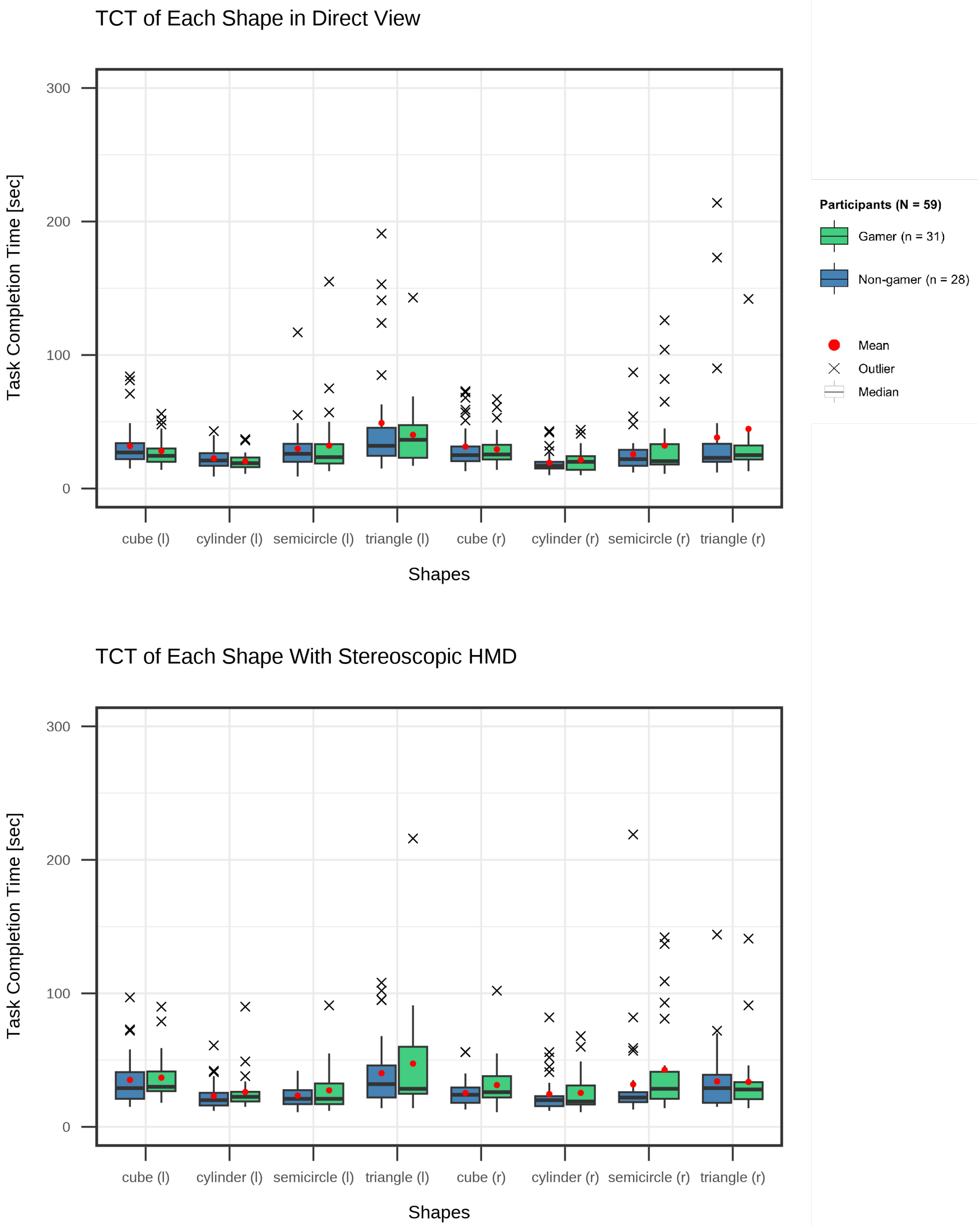


Figure 17 Boxplots of the TCT per shape for direct view and stereoscopic HMD

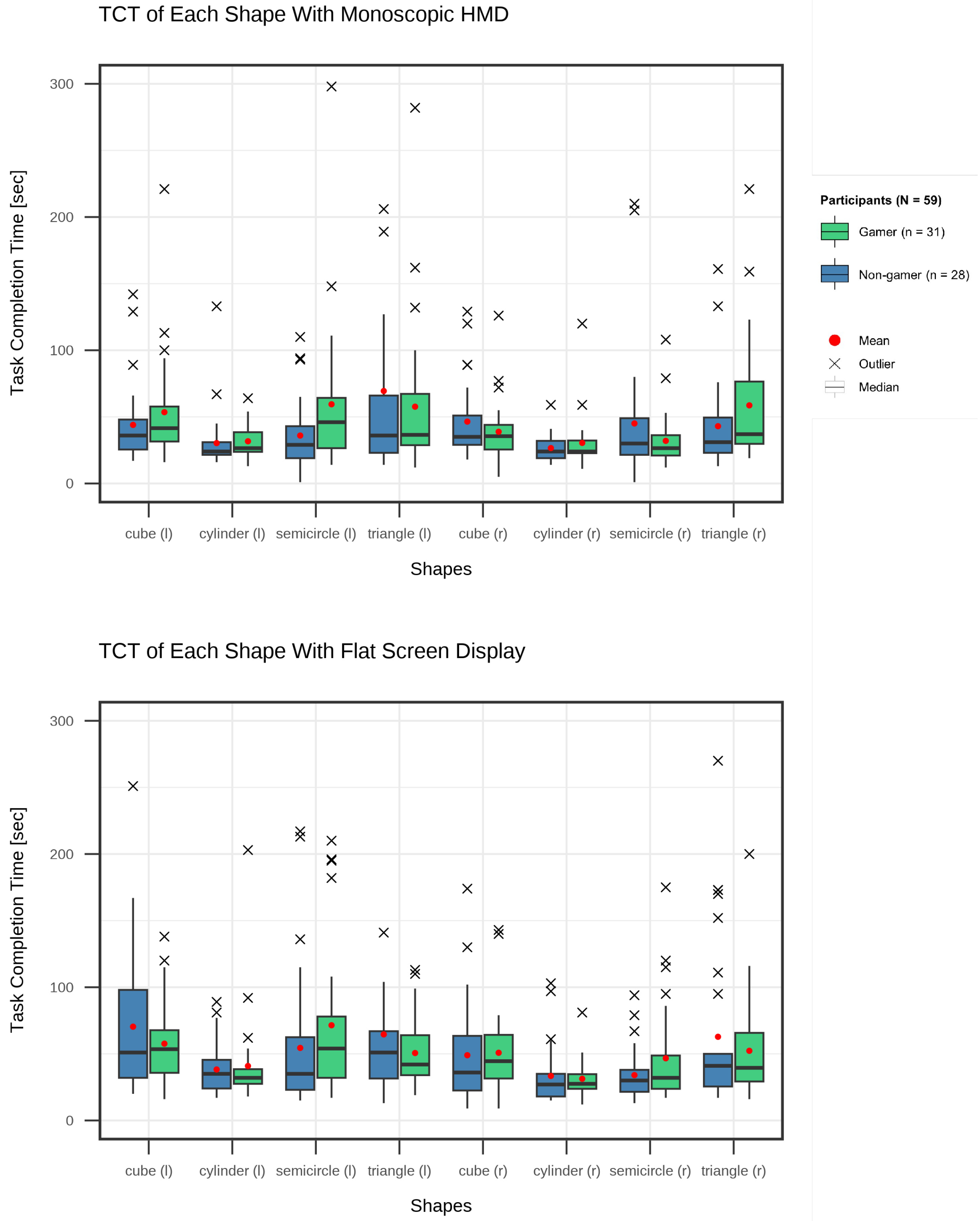


Figure 18 Boxplots of the TCT per shape for each visualization scenario

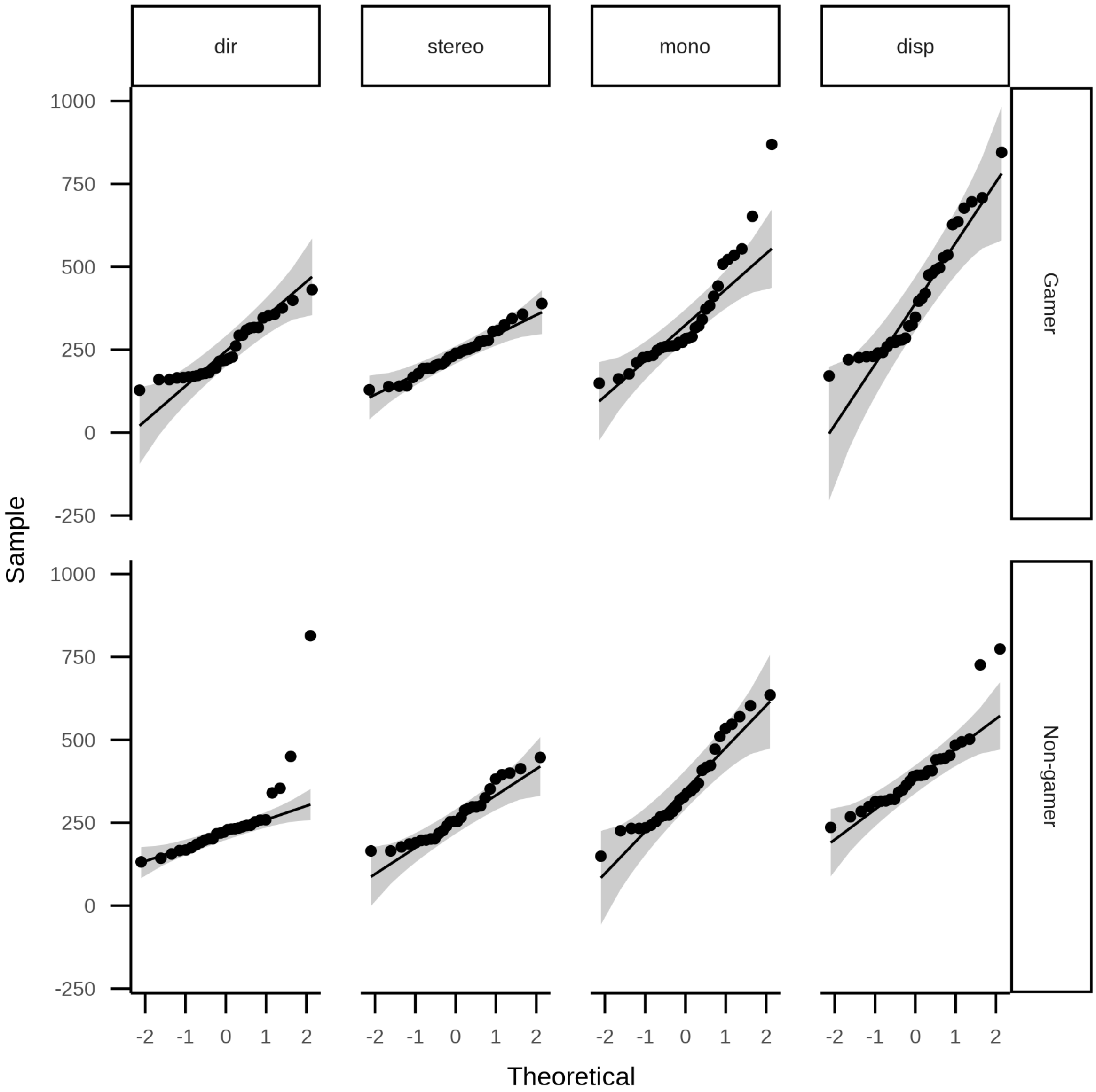


Figure 19 Q-Q plot of TCT data

Furthermore, **variance homogeneity** of the TCT data is investigated. The Levene's test showed no significant results for direct view ($F(1,57) = 0.065$, $p = 0.800$), stereoscopic HMD ($F(1,57) = 1.46$, $p = 0.233$), and monoscopic HMD ($F(1,57) = 0.011$, $p = 0.916$). However, it showed significant results for the flat screen display ($F(1,57) = 6.13$, $p = 0.016$). Therefore, the flat screen display scenario does not fulfill the assumption of variance homogeneity. Lastly, **Covariance homogeneity** is investigated. The Box's M-test for homogeneity of covariance matrices does not find a significant effect ($F(1,57) = 1.35$, $p = 0.245$), which indicates covariance homogeneity.

ANOVA

Since not all assumptions were met fully, a **two-factorial mixed-design robust ANOVA** was conducted to compare the effect of four different visualization types on TCT. This analysis computes a two-way between-within subjects ANOVA on the trimmed means. The analysis revealed that there was no statistically significant interaction between the effects of the group (gamer and non-gamer) and the scenario (direct view, stereoscopic HMD, monoscopic HMD, and flat screen display) ($Q = 0.8251$, $p = 0.491$). Simple main effects analysis showed that the group did not have a statistically significant effect on the TCT ($Q = 0.5835$, $p = 0.4505$). However, the type of visualization scenario did have a statistically significant effect on the TCT ($p < 0.001$).

4.2.3 Summary

The interaction plot in Figure 20 summarizes the findings of the prior analysis. The figure illustrates the mean TCTs of all scenarios between the groups. It shows the difference between scenarios with and without stereoscopic depth information, with a bigger difference between the monoscopic HMD and the flat screen display than between the stereoscopic HMD and direct view. The strong similarity to horizontal lines indicates the non-significant effect of the group on TCT. The means of both groups are approximately on one level and, therefore, do not show a significant difference. During the scenario with the flat screen display, participants had the highest mean TCT and, therefore needed the longest time to complete the task. Generally, the visualization scenario has a significantly bigger influence on the TCT than group belonging.

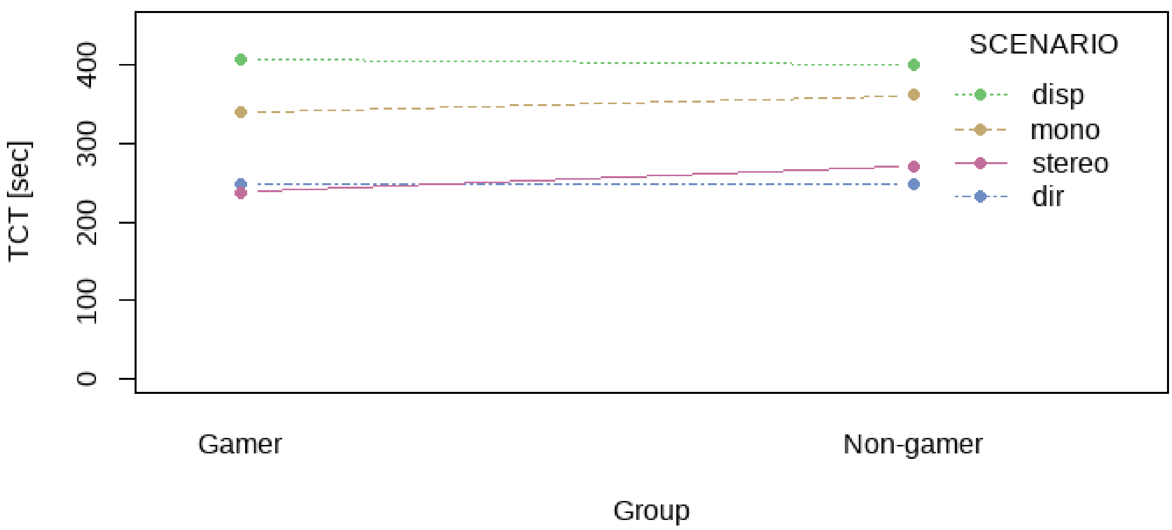


Figure 20 Interaction plot between both groups of TCT in all four scenarios

4.3 Measures of Accuracy and Error

Two relevant accuracy measures were introduced for this study: grab attempts and corrections. Both parameters are described in the following only descriptively and not analyzed statistically since they are not the primary focus of the research questions of this thesis. Furthermore, the number of gripper errors is reported.

4.3.1 Grab Attempts

The number of grab attempts denotes how often the gripper is closed in order to grasp an object. This number of grab attempts includes unsuccessfully and successful grabs. This measure indicates how accurately the participant positions and operates the gripper in order to grasp the object. The minimum number of grab attempts during a scenario is eight. This represents the optimal case where all shapes are grasped on the first try during a trial.

Figure 21 illustrates the mean number of grab attempts per scenario. No significant difference can be identified between gamers and non-gamers in this figure. However, the scenarios with stereoscopic depth information require significantly fewer grab attempts than the scenarios without stereoscopic depth information. A visualization with stereoscopic depth information reduces the amount of grab attempts necessary to grasp an object.

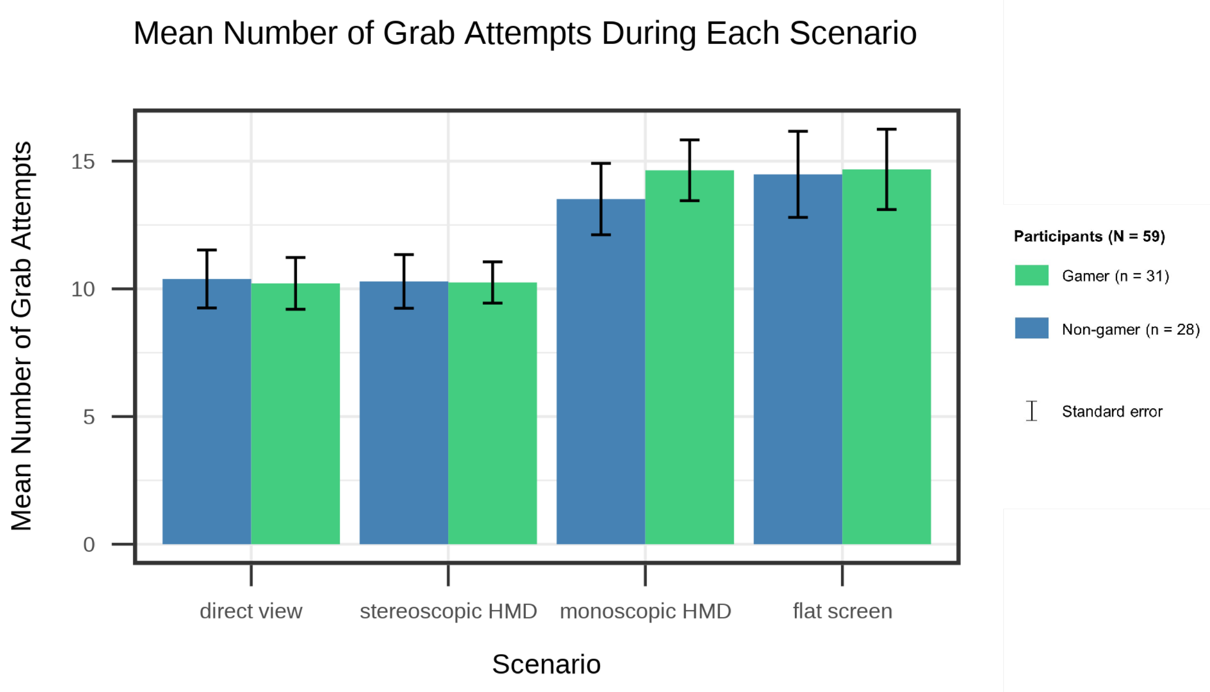


Figure 21 The mean number of grab attempts for each scenario by group

4.3.2 Corrections

Another measure of accuracy is whether corrections were performed or not. When the participant has grasped the shape, the next step is to move the shape to its respective hole and drop it into the box. When released, in some cases, the shape did not drop into the box right away but landed on the lid of the box or got stuck in the hole. With a few corrections, like poking the shape or grasping the shape and releasing it again at a better angle, the shape would land in the box. However, participants made corrections in many ways, so it was difficult to count corrections in a standardized way. Instead, it was only registered as a boolean value if any kind of correction was performed.

The results of a count of corrections show that gamers required fewer corrections than non-gamers

(Figure 22 and 23). Moreover, a difference between scenarios with and without stereoscopic depth information can be detected. In scenarios without stereoscopic depth information (monoscopic HMD and flat screen display), corrections were made more often. Additionally, shapes on the left side required more corrections than those on the right (the participants first moved the shapes on the left and then on the right). These results suggest a learning effect.

4.3.3 Gripper Error

As explained in Chapter 4.2, a technical error occurred with the gripper during teleoperation. Participants encountered problems with the gripper when picking up the cube on the right side. The gripper would not grasp the object and instead stop the gripper fingers at a certain distance. To continue with the operation, a manual restart of the gripper system was necessary. Unfortunately, the reason for this technical error could not be determined. In most cases, the participant was able to continue to move the cube after the restart. Figure 24 and 25 provide an overview over the occurrence of this error for each scenario per shape and illustrate well the gripper error occurring mostly with the right cube. In total, the gripper error occurred 23 times during the scenario with direct view, 28 times during the scenario with stereoscopic HMD, 22 times during the scenario with monoscopic HMD, and 27 times during the scenario with the flat screen display. Gamers produced this error 55 times, while non-gamers produced it 45 times.

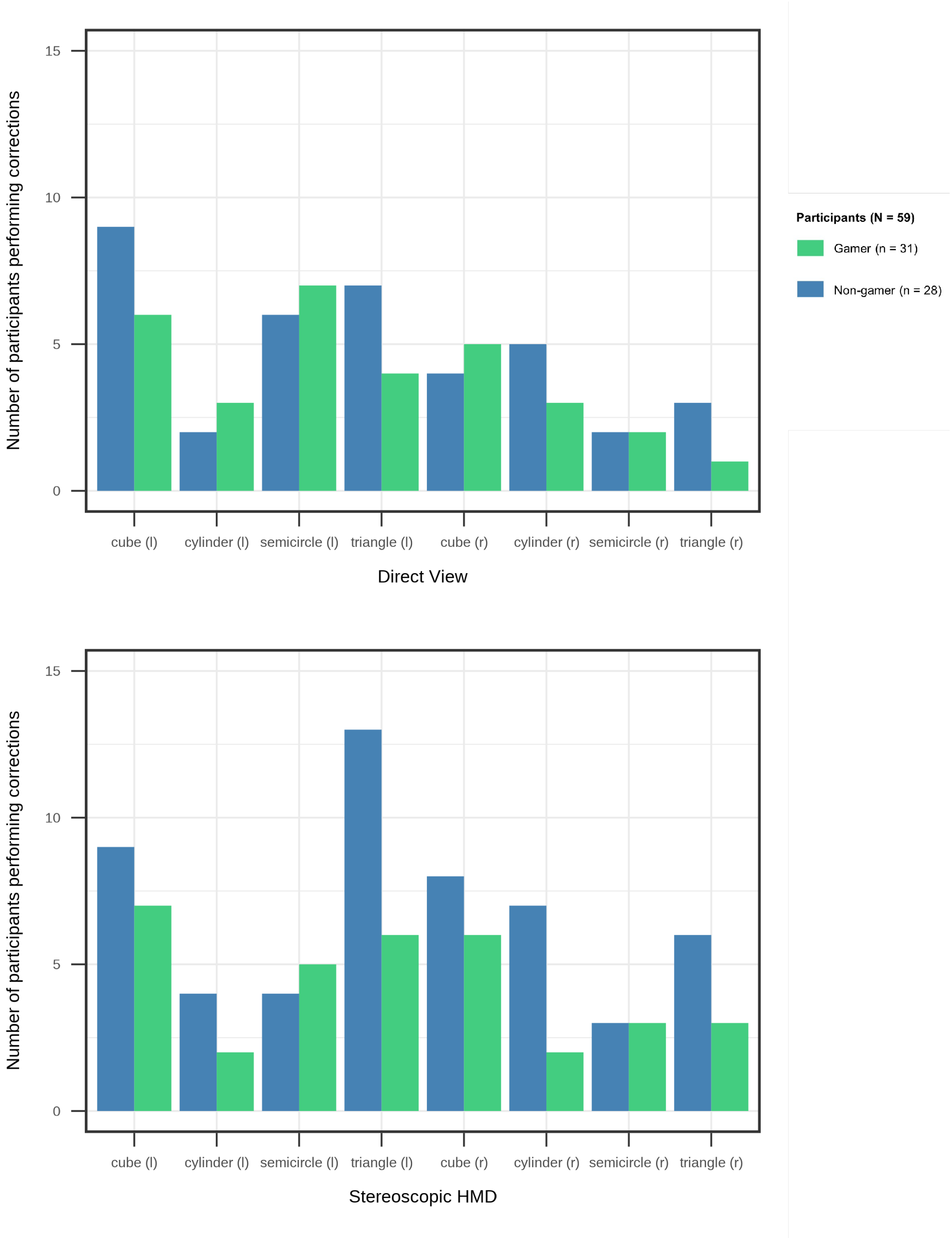


Figure 22 The number of participants who needed corrections by group and shape for direct view and stereoscopic HMD

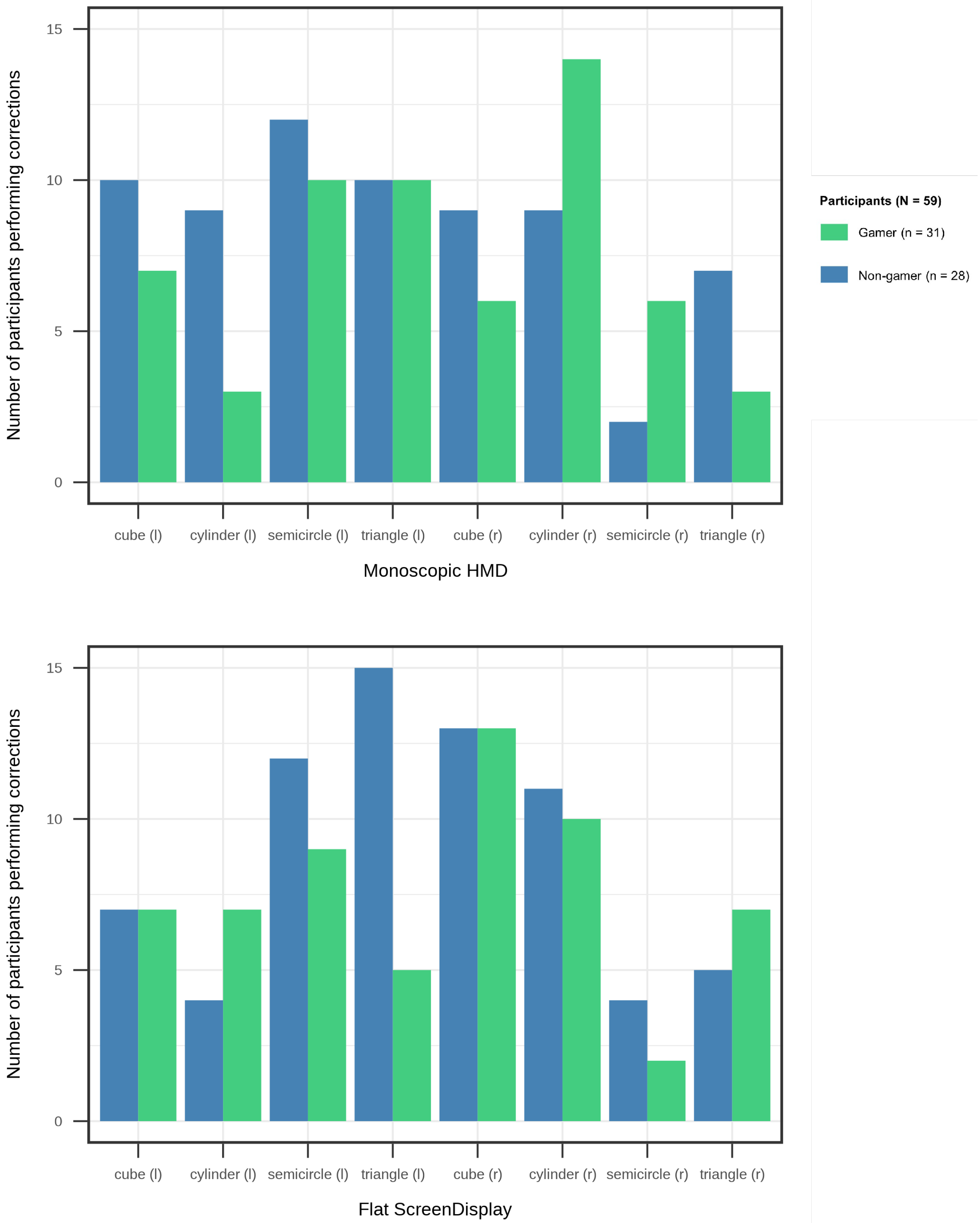


Figure 23 The number of participants who needed corrections by group and shape for monoscopic HMD and flat screen display

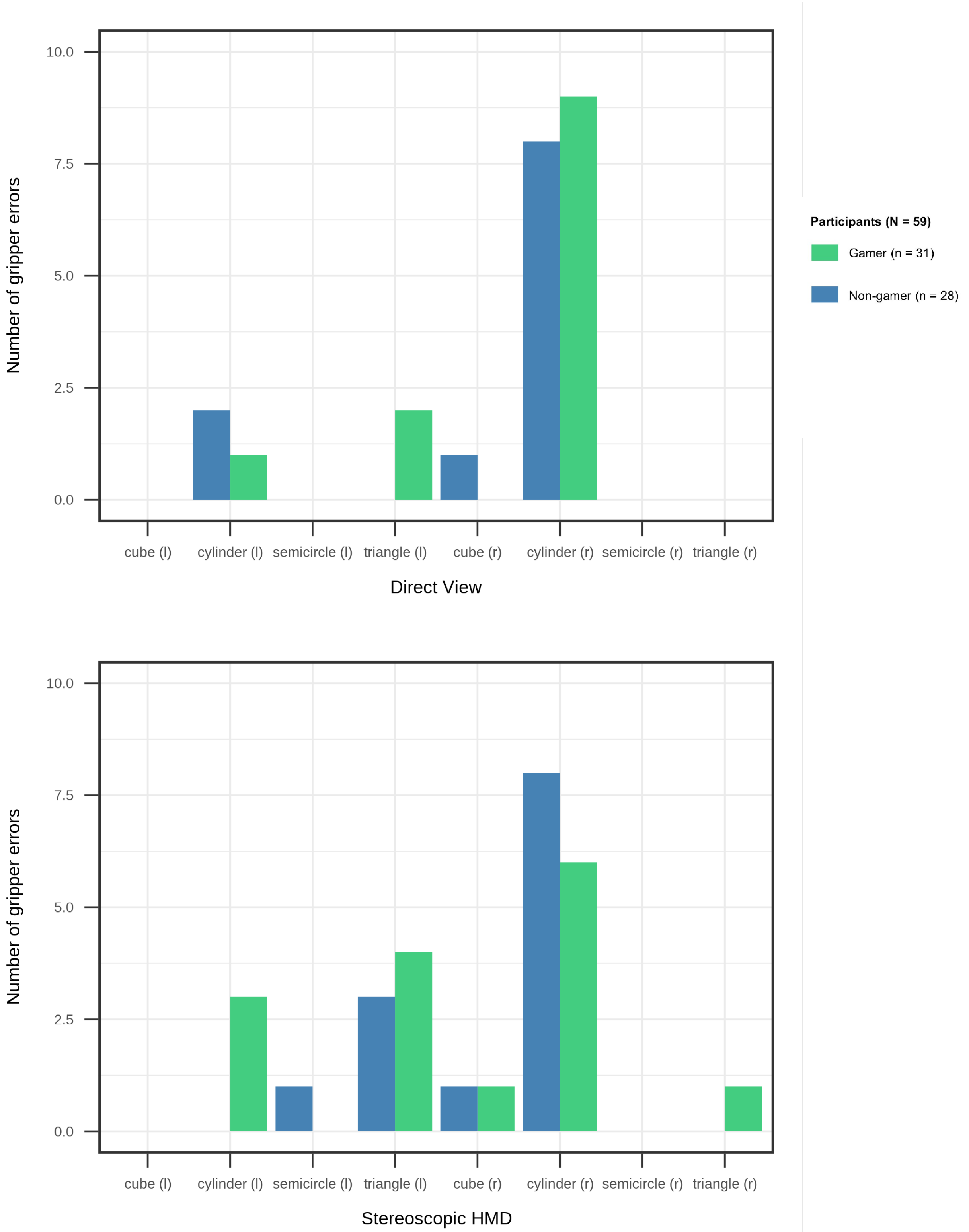


Figure 24 The number of gripper errors by group and shape for direct view and stereoscopic HMD

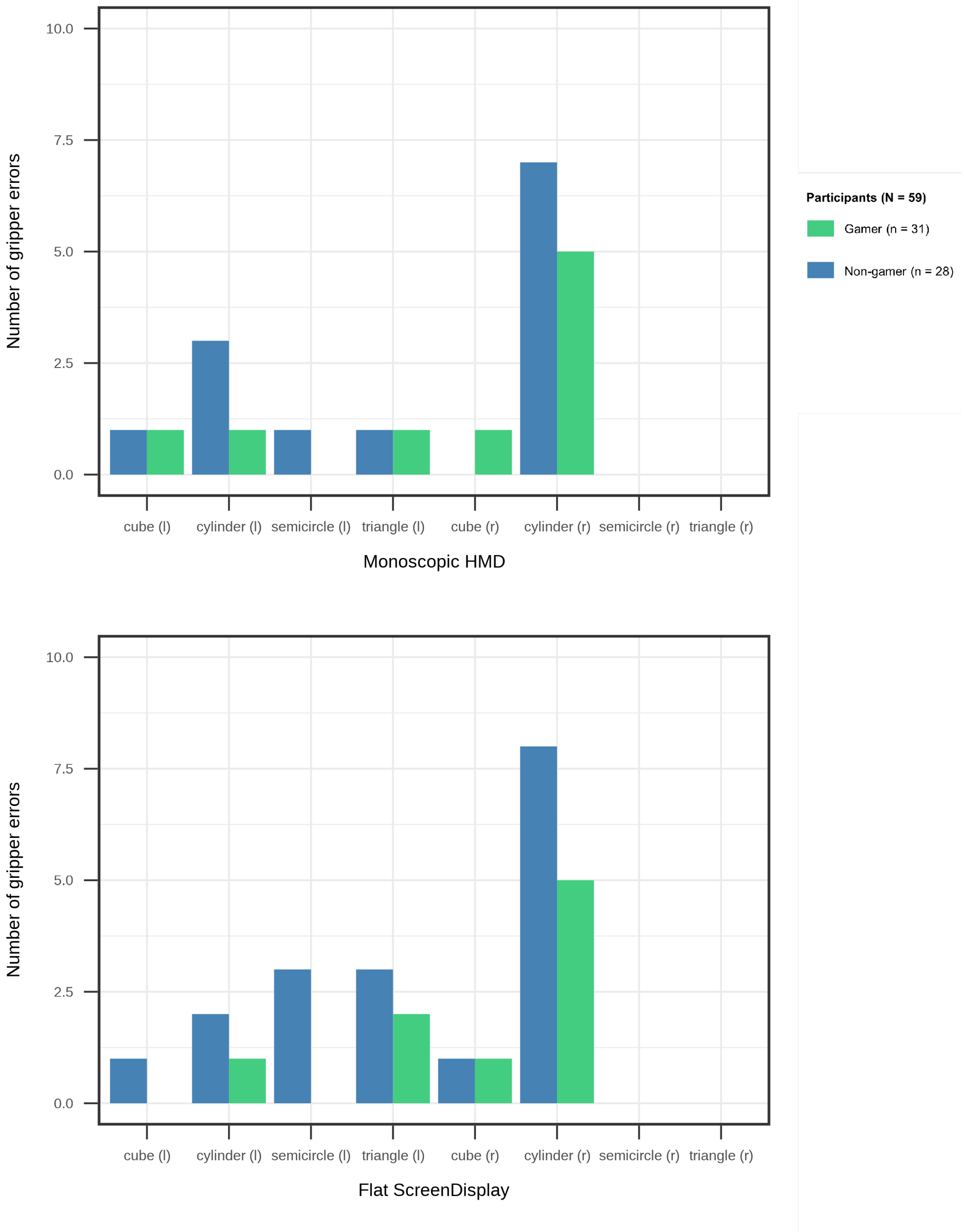


Figure 25 The number of gripper errors by group and shape for monoscopic HMD and flat screen display

4.4 Measures of Workload

As introduced in Chapter 3.7.4, the NASA-TLX measures the subjective workload and is administered in two steps. After each scenario, the rating for each dimension was recorded on a scale from 0 to 100. After all four trials, the weight of each dimension was determined by a pairwise comparison between all dimensions, in which the participants stated which dimension they considered more important for this particular task. The score for each dimension is then multiplied by the rating to determine the individual NASA-TLX scores for each dimension. Additionally, a mean over the scores of all dimensions returns the total NASA-TLX score.

4.4.1 Descriptive Statistics

Table 4 presents the means and standard deviations of both groups across all four scenarios, and Figure 26 visually represents these findings. Gamers experienced a higher workload according to their mean NASA-TLX score than non-gamers, except during the scenario with the stereoscopic HMD. Furthermore, the standard deviation is approximately the same throughout all scenarios for both groups. Overall, the scenarios without stereoscopic depth information have a higher NASA-TLX score than the scenarios with stereoscopic depth information. Similarly to the TCT, the workload is reduced in scenarios with stereoscopic depth information.

Table 4 Overview of means and standard deviations of NASA-TLX data

Scenario	**Mean Score and Standard Deviation**
Direct view	Gamer: M = 31.00 , SD = 20.14 Non-gamer: M = 24.71, SD = 17.56
Stereoscopic HMD	Gamer: M = 27.65, SD = 16.80 Non-gamer: M = 32.46, SD = 22.13
Monoscopic HMD	Gamer: M = 40.61, SD = 22.07 Non-gamer: M = 37.11, SD = 17.73
Flat screen display	Gamer: M = 46.36, SD = 22.54 Non-gamer: M = 40.54, SD = 18.78

Figure 27, 28, and 29 show the individual NASA-TLX scores for each dimension. Based on these figures, the following observations can be made. Firstly, the physical demand has a low rating in all scenarios for gamers and non-gamers and thus has no significant influence on the overall NASA-TLX score. The temporal demand shows similar results. However, the results for the flat screen display scenario with gamers stand out with a higher mean and median than the other scenarios and group belonging. The performance and effort dimensions show a low rating and only small differences between scenarios and the groups. Subsequently, in the mental effort and frustration dimension, a significant difference between scenarios with and without stereoscopic depth information can be observed. Overall, scenarios with stereoscopic depth information show a lower NASA-TLX score. This indicates less workload for visualization with stereoscopic depth information. In the mental dimension non-gamers report higher scores, while in the physical, temporal and performance dimension gamers report higher score. The other dimensions show no significant differences.

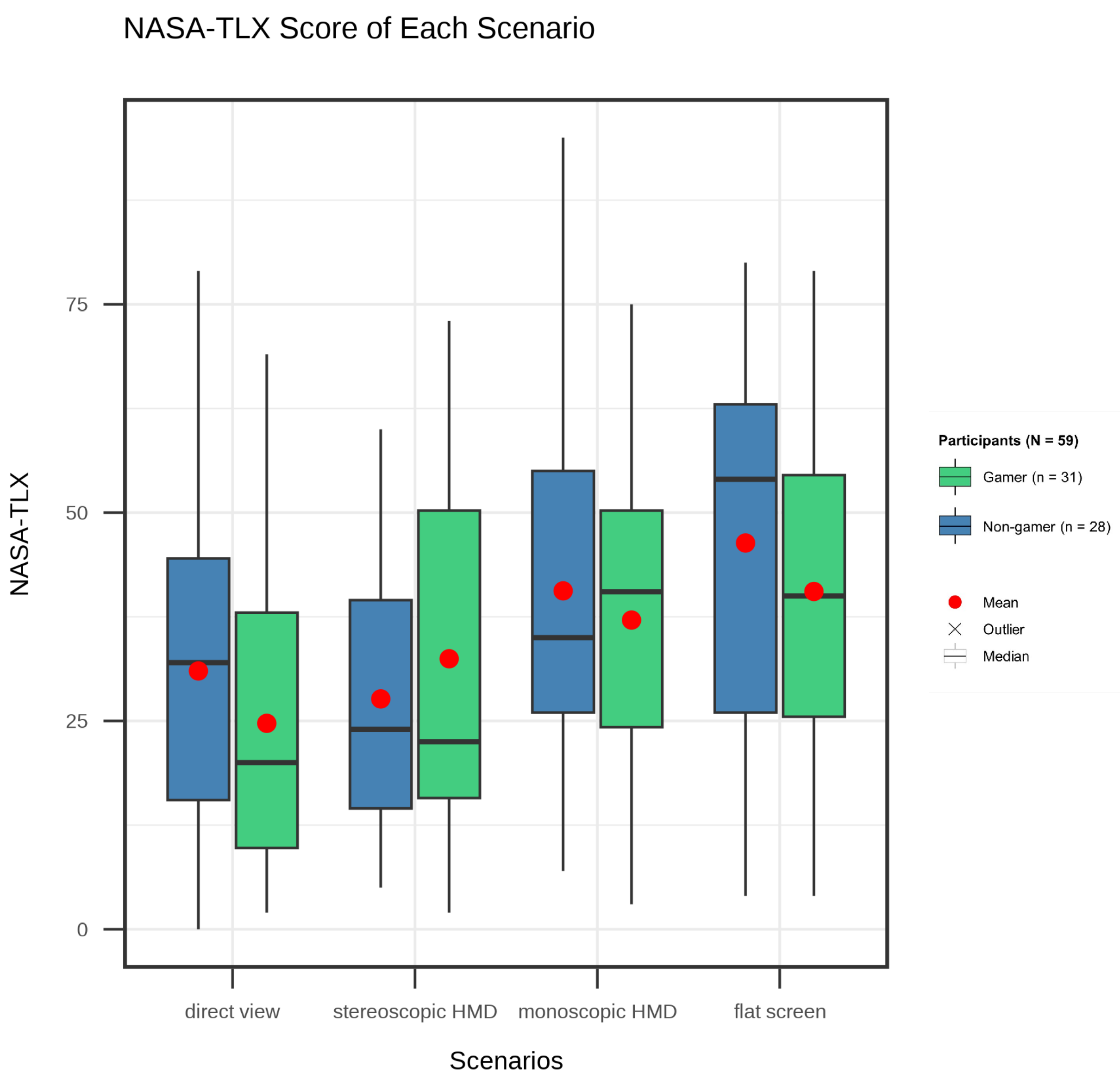


Figure 26 Total NASA-TLX for each scenario

4.4.2 Inferential Statistics: Overall Score

Assumptions

Firstly, the NASA-TLX score is analyzed for **normal distribution**. A Shapiro-Wilk Test conducted for each group for all four scenarios showed a significant deviation (marked with * in Table 5) from normal distribution for non-gamers with stereoscopic HMD and for gamers in the scenario with the flat screen display. However, visual examination of the Q-Q plot shows no extreme outliers (Figure 30). Therefore, the data is considered to be normally distributed.

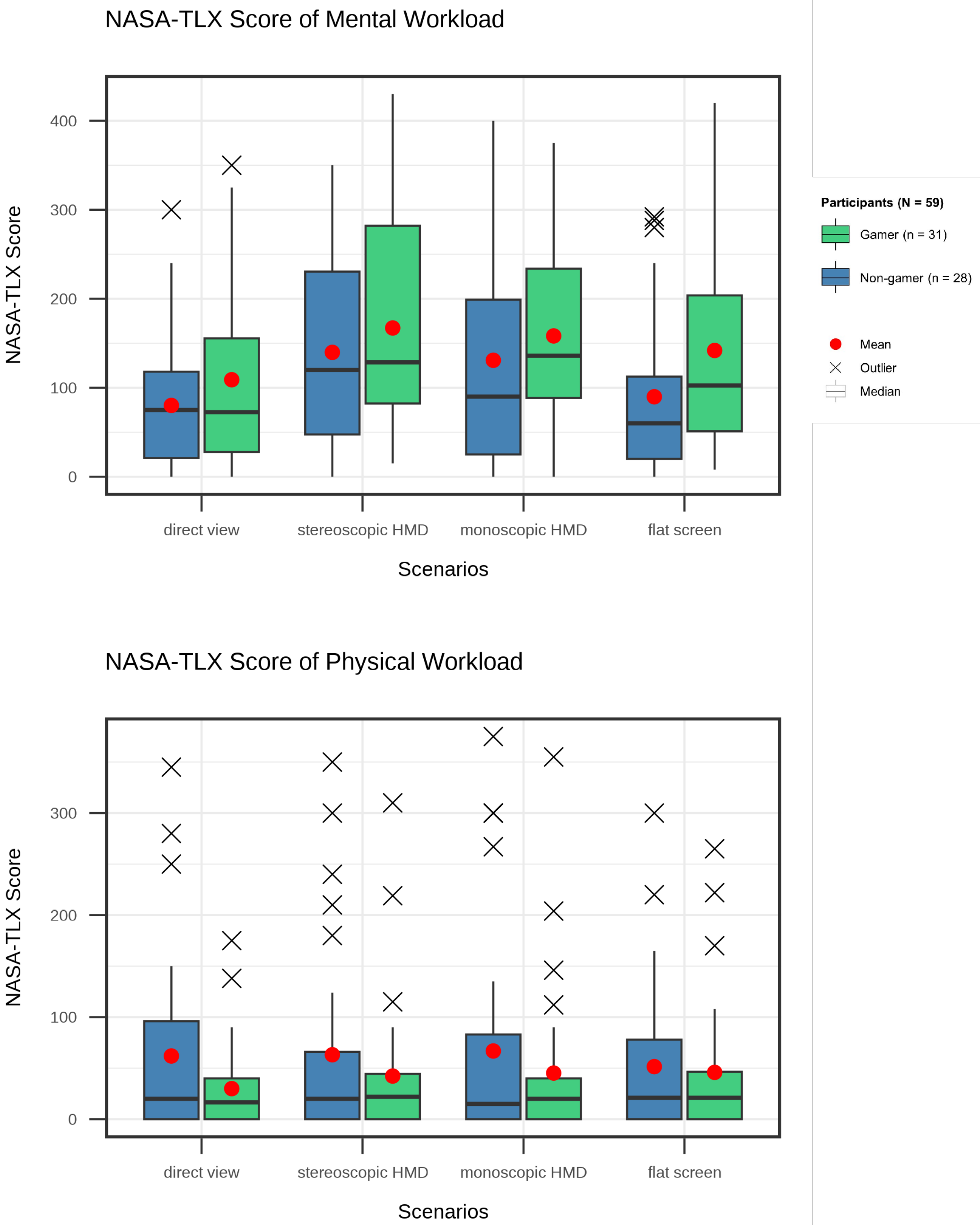


Figure 27 NASA-TLX scores for each scenario and group for the mental and physical dimension

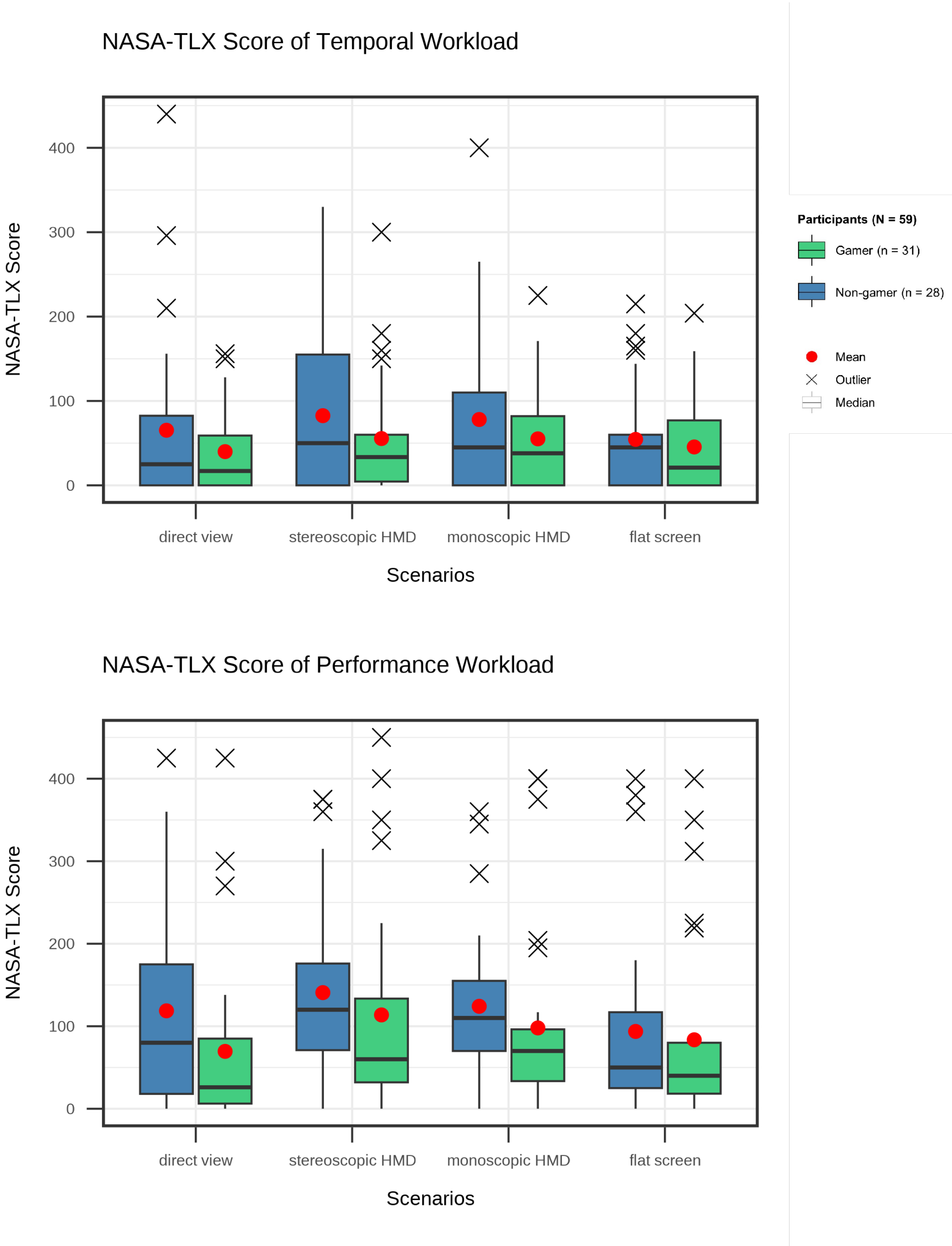


Figure 28 NASA-TLX scores for each scenario and group for the temporal and performance dimension

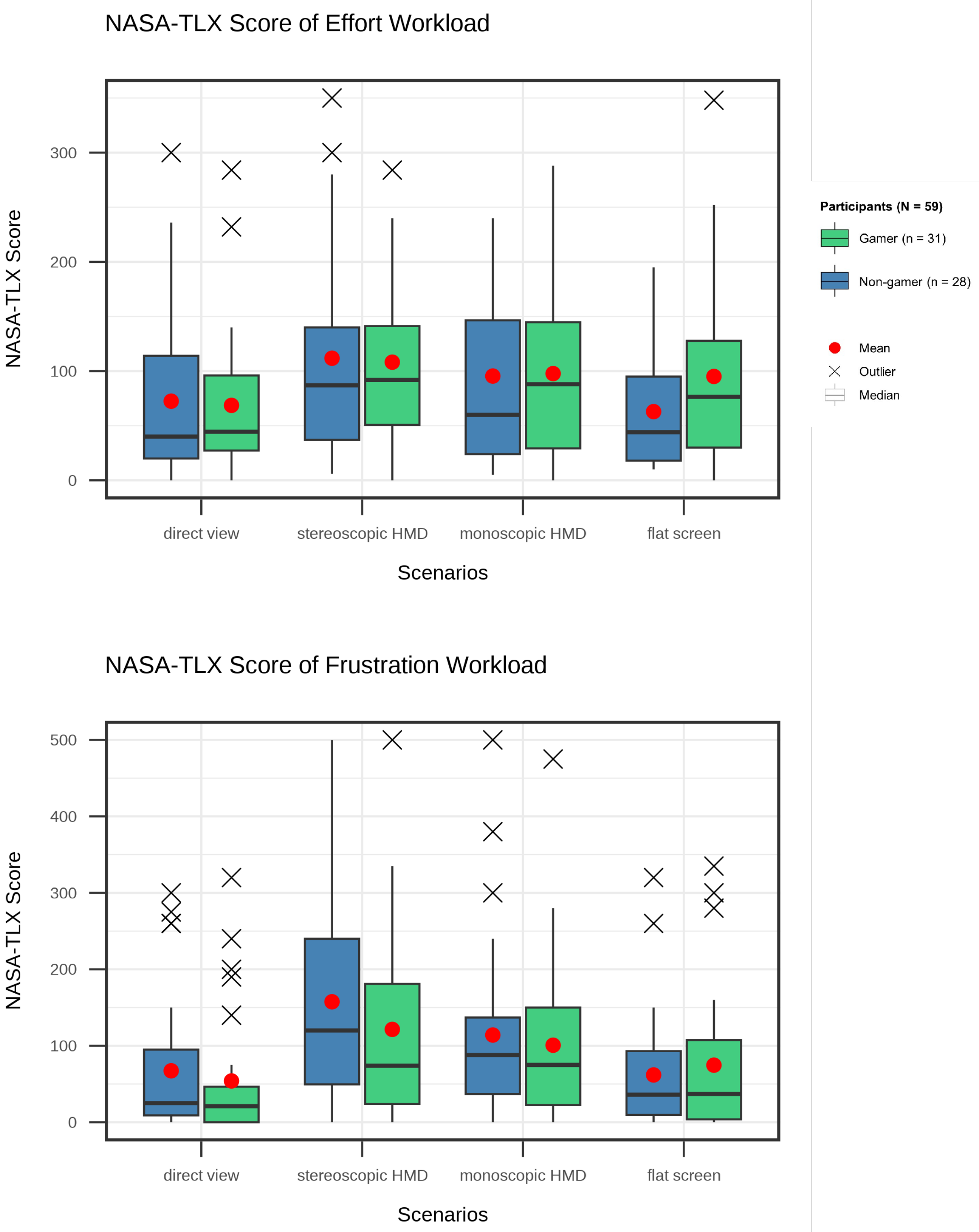


Figure 29 NASA-TLX scores for each scenario and group for the effort and frustration dimension

Table 5 Overview of results of the Shapiro-Wilk Test on NASA-TLX score data

Scenario	**Shapiro-Wilk Test**
Direct view	Gamer: W =0.0.969, p = 0.495 Non-gamer: W = 0.935, p = 0.083
Stereoscopic HMD	Gamer: W = 0.935, p = 0.061 Non-gamer: W = 0.913, p = 0.023*
Monoscopic HMD	Gamer: W = 0.960, p = 0.291 Non-gamer: W = 0.978, p = 0.808
Flat screen display	Gamer: W = 0.924, p = 0.031* Non-gamer: W = 0.972, p = 0.637

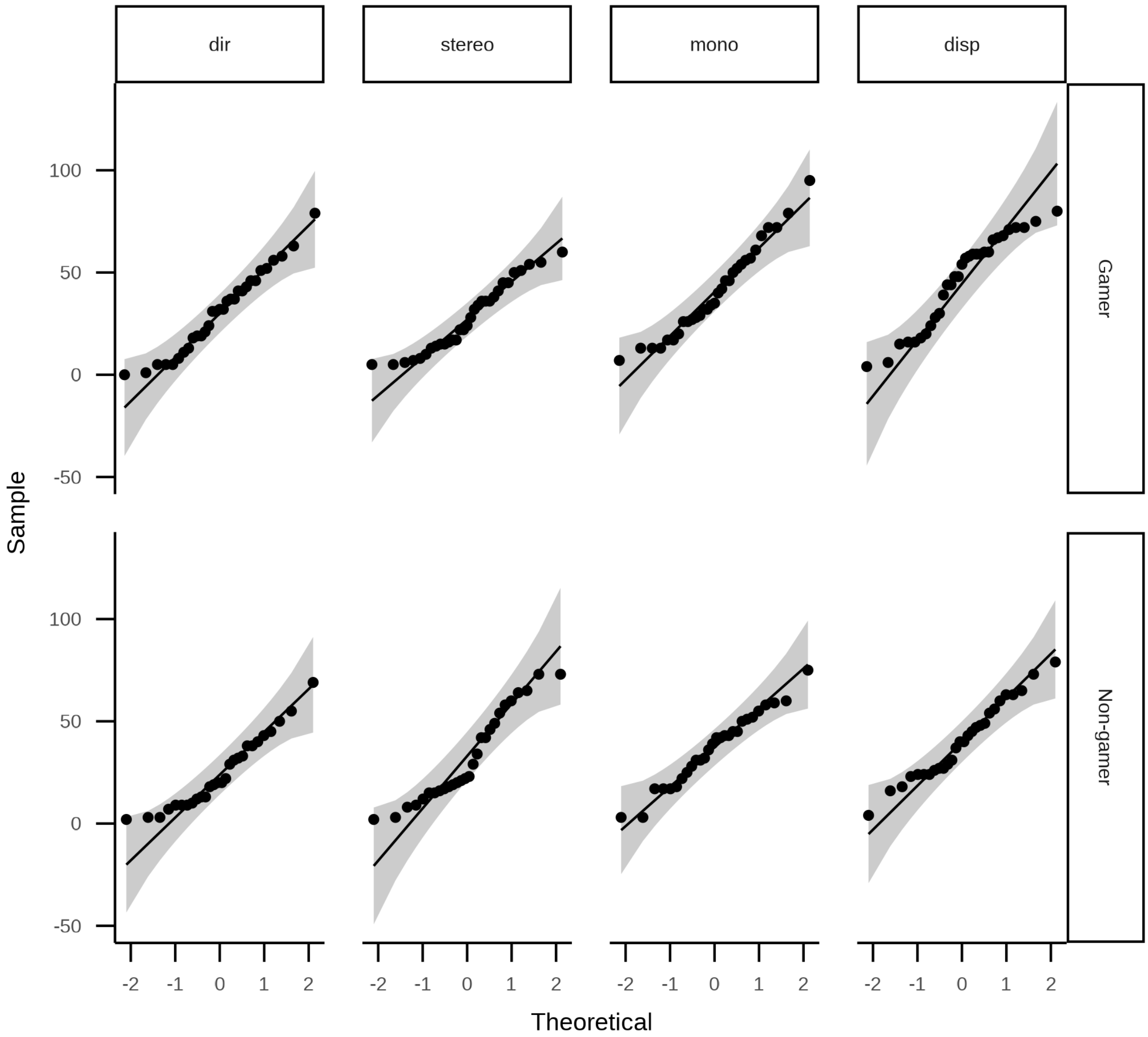


Figure 30 Q-Q plot of NASA-TLX score

Furthermore, **variance homogeneity** is investigated. The Levene's test showed no significant results for direct view ($F(1,57) = 0.534$, $p = 0.468$), stereoscopic HMD ($F(1,57) = 1.44$, $p = 0.235$), monoscopic HMD ($F(1{,}57) = 1.26$, $p = 0.266$), and the flat screen display ($F(1{,}57) = 1.01$, $p = 0.318$). Therefore, variance homogeneity can be assumed. Lastly, **Covariance homogeneity** is investigated. The Box's M-test for homogeneity of covariance matrices does not find a significant effect ($F(1{,}57) = 0.880$, $p = 0.348$), which indicates covariance homogeneity.

ANOVA

A two-factorial mixed-design ANOVA was conducted to compare the effect of the four different visualization types on the NASA-TLX score. The analysis revealed that there was no statistically significant interaction between the effects of the group belonging and the scenario ($F(3, 171) = 2.131$, $p = 0.098$). Further, simple main effects analysis showed that the group did not have a statistically significant effect on NASA-TLX ($F(1, 57) = 0.416$, $p = 0.052$). However, the scenario did have a statistically significant effect on the NASA-TLX (p < 0.001). Since the assumption of sphericity was not met, a Greenhouse-Geisser correction was applied to the resulting values of the analysis.

Post-Hoc Tests

After the analysis, a pairwise t-test can be applied to reveal significant differences between scenarios. The results of the pairwise t-tests for the recorded TCT data are presented in Table 6. The comparison between direct view and stereoscopic HMD does not show a significant result, indicating no relevent differences between those scenarios. The same is true for the comparison between monoscopic HMD and the scenario with a flat screen display. However, all other comparisons show significant results, indicating significant differences. This shows, that there are significant differences of the overall NASA-TLX score between scenarios with and without stereoscopic depth information. With a value of $\eta = 0.115$, the effect size is considered to be medium-sized.

Table 6 Results of pairwise t-test of NASA-TLX score data

Scenario	t-value and significance
Direct view - Stereoscopic HMD	$t = -0.904$, $p = 0.37$
Direct view - Monoscopic HMD	$t = -4.47$, $p < 0.001$*
Direct view - Flat screen display	$t = -6.42$, $p < 0.001$*
Stereoscopic HMD - Monoscopic HMD	$t = -4.13$, $p < 0.001$*
Stereoscopic HMD - Flat screen display	$t = -4.77$, $p < 0.001$*
Monoscopic HMD - Flat screen display	$t = -1.57$, $p = 0.122$

4.4.3 Summary of Total NASA-TLX Score

The interaction plot in Figure 31 summarizes the findings of the prior analysis. The figure illustrates the mean NASA-TLX scores of all scenarios between the groups. It shows the difference between scenarios with and without stereoscopic depth information, with a bigger difference between the monoscopic HMD and the flat screen display than between the stereoscopic HMD and direct view. The strong similarity to horizontal lines with the scenarios without stereoscopic depth information indicates a non-significant effect of the group on NASA-TLX score. However, the lines between the means of the scenarios with stereoscopic depth information cross, hinting at an influence of the group. As a result, gamers experienced less workload with the stereoscopic HMD while non-gamers experienced a higher workload compared to the direct view and vice versa. During the scenario with the flat screen display, participants had the highest mean NASA-TLX score and, therefore, the highest workload. Generally, the visualization scenario has a significantly bigger influence on the workload than group belonging.

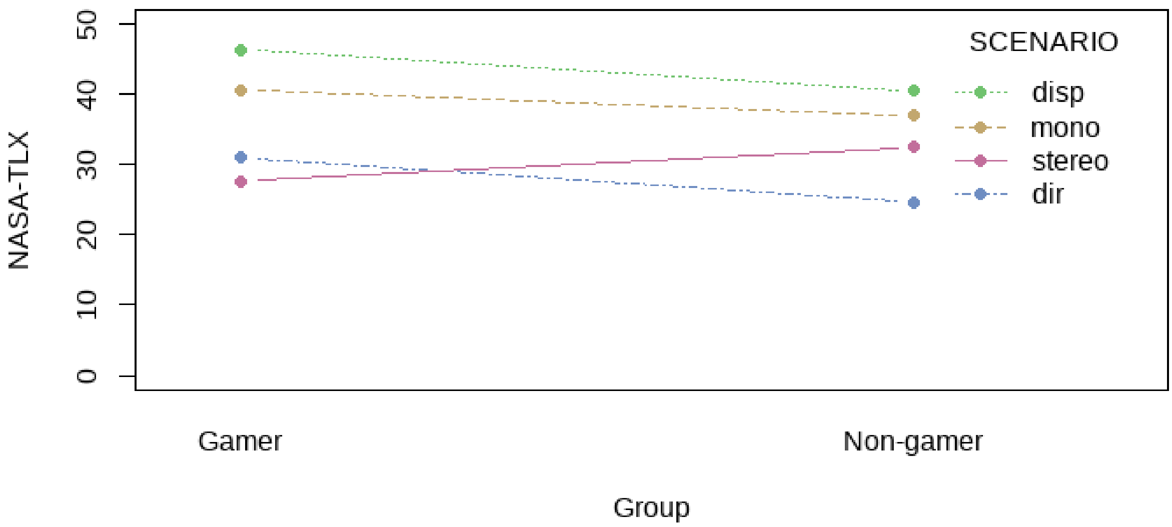


Figure 31 Interaction plot between both groups of the means of the NASA-TLX scores in all four scenarios

4.4.4 Inferential Statistics: Individual Scores

For a more comprehensive understanding of the workload, the NASA-TLX can be broken down into its six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. This individual analysis for each dimension can reveal which dimensions have more influence on the overall score than the others. In order to analyze the impact of each dimension on the overall NASA-TLX score, a mixed design two-factorial MANOVA was conducted.

Assumptions

Firstly, each dimension of the NASA-TLX score is analyzed for **normal distribution**. A Shapiro-Wilk Test conducted for each group for all four scenarios for each dimension showed a significant deviation from normal distribution in most cases. The multivariate Shapiro-Wilk Test shows a significant result ($W = 0.808$, $p < 0.001$), indicating a deviation from multivariate normal distribution. A visual examination of the Q-Q plots in Appendix Appendix J shows extreme outliers in the dimensions physical demand, temporal demand, performance, and frustration. The data deviates from normal distribution.

Several data transformations (log, sqrt, 1/x) were tried out. However, none of the transformations improved normal distribution. Moreover, a robust version of a mixed two-factorial MANOVA is not available to handle data with deviation from normal distribution. Therefore, the results from the individual dimensions are only reported descriptively in Chapter 4.4.1.

4.5 Measures of Preference

As discussed in Chapter 3.7.5, the SUS is a quick and easy way to measure the usability of a system. In this study, the SUS was administered after each scenario. Participants were asked to evaluate the system, with a focus on the visualization of the system. The result of the SUS is a score between 0 (low perceived usability) and 100 (high perceived usability).

4.5.1 Descriptive Statistics

Table 7 presents the means and standard deviations of both groups across all four visualization scenarios. Figure 32 visualizes these findings. Across all scenarios, gamers consistently assigned higher SUS scores than non-gamers, with the most significant gap in the stereoscopic HMD scenario. Notably, scenarios with stereoscopic depth information received higher rankings compared to those without. According to the adjective ratings, direct view for both groups and stereoscopic HMD for gamers received a "good" rating, while the remaining scenarios received an "ok" rating. These results show that visualization with stereoscopic depth information is perceived as more usable than visualization without stereoscopic depth information. Additionally, scenarios without stereoscopic depth information exhibit a higher standard deviation, indicating bigger differences between the participants' ratings.

Table 7 Overview of means and standard deviation of SUS data

Scenario	Mean Score and Standard Deviation
Direct view	Gamer: M = 81.10 , SD = 12.93 Non-gamer: M = 79.89, SD = 12.20
Stereoscopic HMD	Gamer: M = 80.58, SD = 12.88 Non-gamer: M = 73.57, SD = 14.94
Monoscopic HMD	Gamer: M = 68.00, SD = 21.04 Non-gamer: M = 65.75, SD = 19.59
Flat screen display	Gamer: M = 63.90, SD = 19.40 Non-gamer: M = 60.57, SD = 16.61

4.5.2 Inferential Statistics

Assumptions

To conduct the ANOVA, first the SUS score was analyzed for **normal distribution**. A Shapiro-Wilk Test conducted for each group for all four scenarios showed a significant deviation from normal distribution for gamers in direct view and with the monoscopic HMD. Results of the Shapiro-Wilk Test are presented in Table 8, where significant deviations were marked with *. A visual examination of the Q-Q plot shows no extreme outliers (Figure 33). The data is considered to be normally distributed.

Furthermore, **variance homogeneity** was investigated. The Levene's test showed no significant results for direct view ($F(1,57) = 0.667$, $p = 0.418$), stereoscopic HMD ($F(1,57) = 0.696$, $p = 0.408$), monoscopic HMD ($F(1,57) = 0.133$, $p = 0.717$), and the flat screen display ($F(1,57) = 0.871$, $p = 0.355$). Therefore, variance homogeneity can be assumed. Additionally, **Covariance homogeneity** was investigated. The Box's M-test for homogeneity of covariance matrices was conducted but did not find a significant effect ($F(1,57) = 0.307$, $p = 0.579$), which indicates covariance homogeneity.

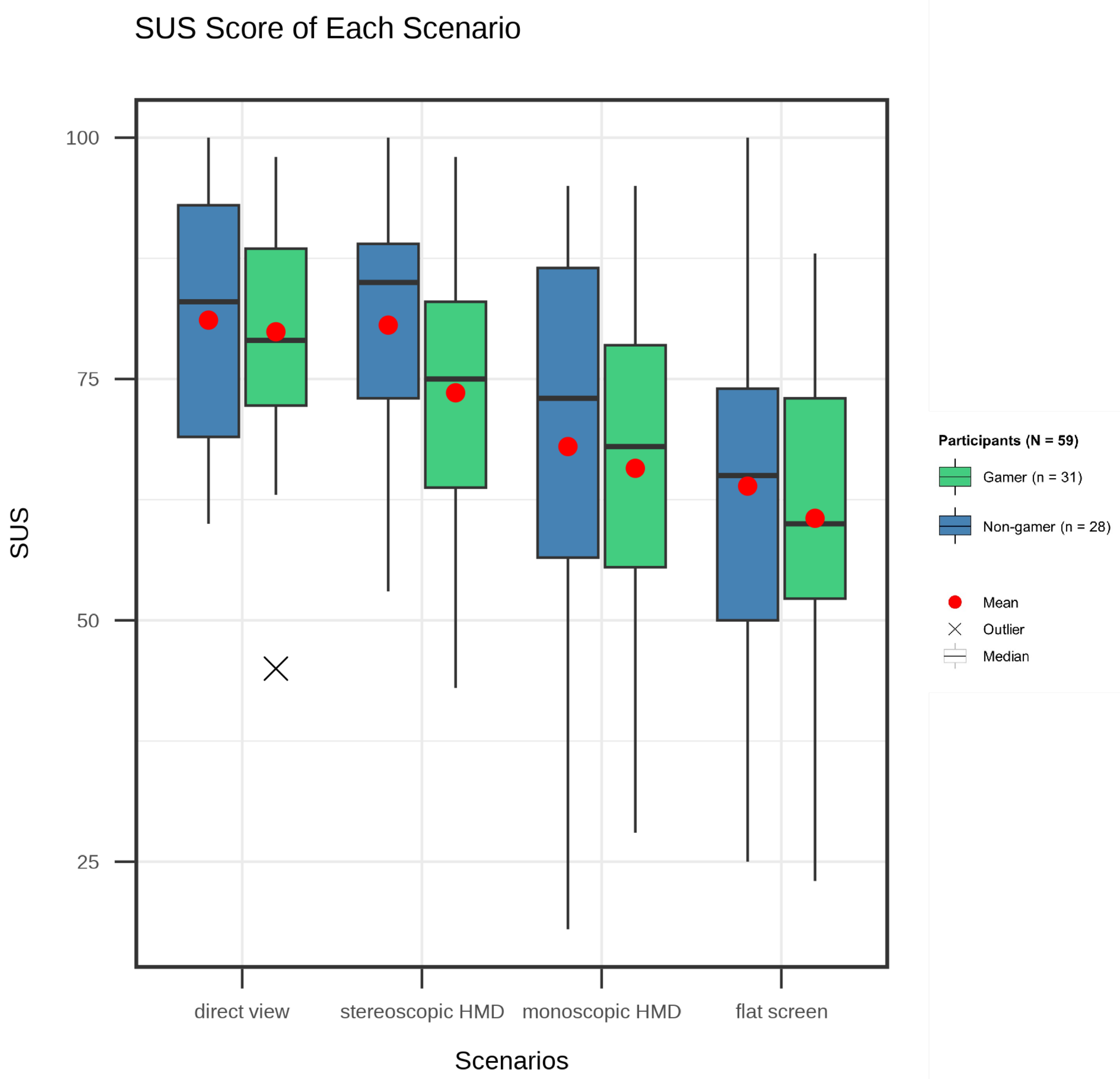


Figure 32 Total SUS of each scenario

Table 8 Overview of results of the Shapiro-Wilk Test on SUS data

Scenario	**Shapiro-Wilk Test**
Direct view	Gamer: W =0.927, p = 0.036* Non-gamer: W = 0.952, p = 0.220
Stereoscopic HMD	Gamer: W = 0.945, p = 0.117 Non-gamer: W = 0.968, p = 0.532
Monoscopic HMD	Gamer: W = 0.904, p = 0.009* Non-gamer: W = 0.941, p = 0.118
Flat screen display	Gamer: W = 0.976, p = 0.696 Non-gamer: W = 0.959, p = 0.321

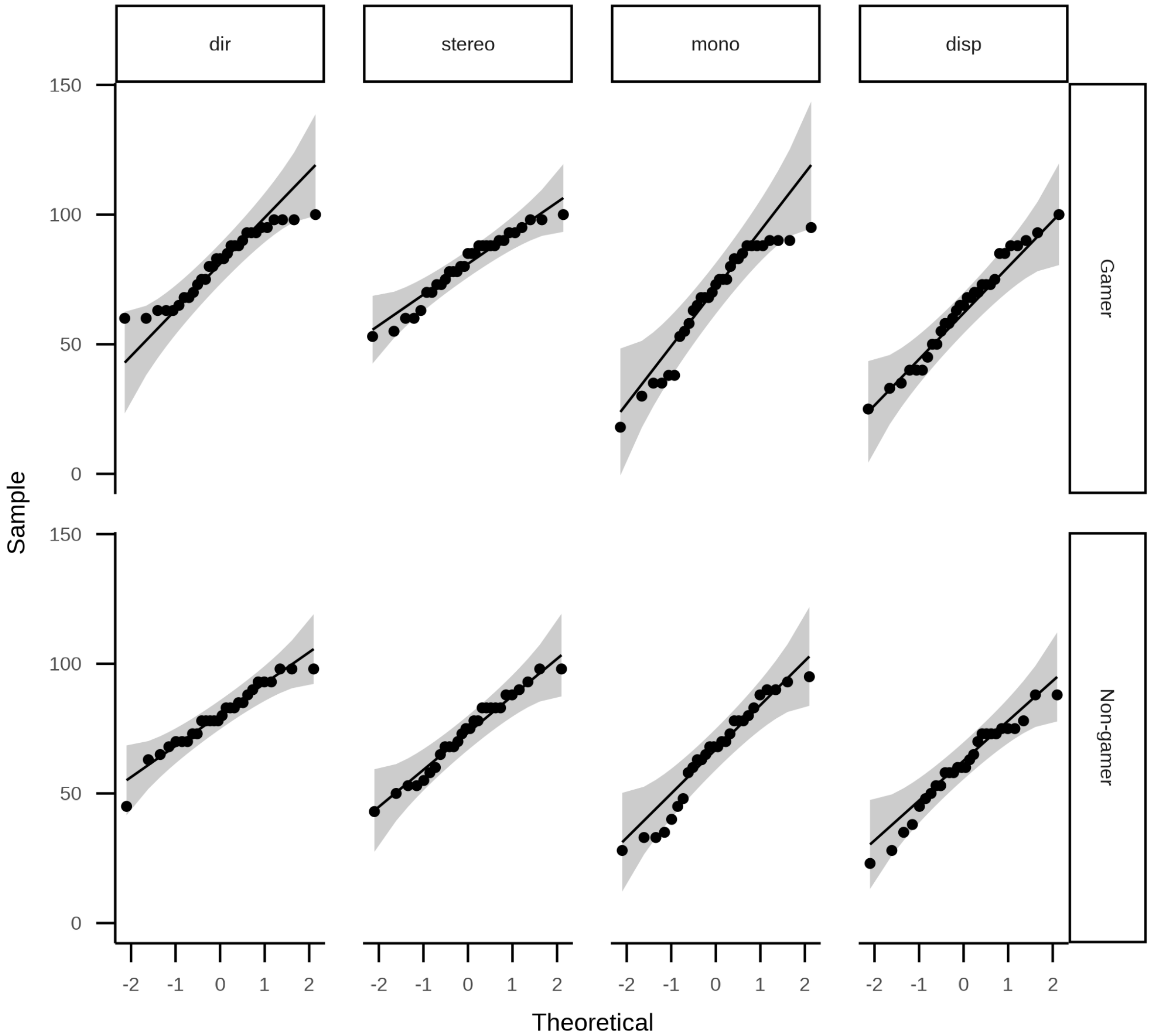


Figure 33 Q-Q plot of TCT data

ANOVA

A two-factorial mixed-design ANOVA was conducted to compare the effect of the four different visualization types on the SUS score. The analysis revealed that there was no statistically significant interaction between the effects of the group belonging (gamer and non-gamer) and the visualization scenario (direct view, stereoscopic HMD, monoscopic HMD, and flat screen display) ($F(2.36, 134.74) = 0.503$, $p = 0.636$). Simple main effects analysis showed that the group did not have a statistically significant effect on SUS ($F(1, 57) = 1.308$, $p = 0.258$). However, the scenario did have a statistically significant effect on the SUS score ($p < 0.001$). Since the assumption of sphericity was not met, a Greenhouse-Geisser correction was applied to the resulting values.

Post-Hoc Tests

After the analysis, a pairwise t-test was applied to reveal significant differences between scenarios. Therefore, a t-test was applied to the SUS data. The comparison between direct view and stereoscopic HMD did not show a significant result, indicating no big differences between those scenarios. The same is true for the pairwise comparison between monoscopic HMD and the scenario with a flat screen display. However, all other comparisons showed significant results, indicating significant differences (as shown in Table 9). This finding shows that there are significant differences in the SUS scores between scenarios with and without stereoscopic depth information. With a value of η = 0.063, the effect size is rather small.

Table 9 Results of pairwise T-test of SUS data

Scenario	t-value and significance
Direct view - Stereoscopic HMD	$t = 1.89$, $p = 0.064$
Direct view - Monoscopic HMD	$t = 4.92$, $p < 0.001$*
Direct view - Flat screen display	$t = 8.31$, $p < 0.001$*
Stereoscopic HMD - Monoscopic HMD	$t = 4.30$, $p < 0.001$*
Stereoscopic HMD - Flat screen display	$t = 5.71$, $p < 0.001$*
Monoscopic HMD - Flat screen display	$t = 1.49$, $p = 0.142$

4.5.3 Summary of Total SUS Score

The interaction plot in Figure 34 summarizes the findings of the prior analysis. The figure illustrates the mean SUS scores of all scenarios between the groups. It shows the difference between scenarios with and without stereoscopic depth information, with a bigger difference between the monoscopic HMD and the flat screen display than between the stereoscopic HMD and direct view. The strong similarity to horizontal lines with the scenarios without stereoscopic depth information indicates a non-significant effect of the group on SUS score. However, the lines between the means of the scenarios with stereoscopic depth information are not parallel, hinting at an influence of the group. As a result, gamers perceive stereoscopic HMD just as usable as the direct view, while non-gammers perceived direct view as significantly more usable. During the scenario with the flat screen display, participants had the lowest mean SUS score and, therefore, the worst perceived usability. Generally, the visualization scenario has a significantly bigger influence on the perceived usability than group belonging.

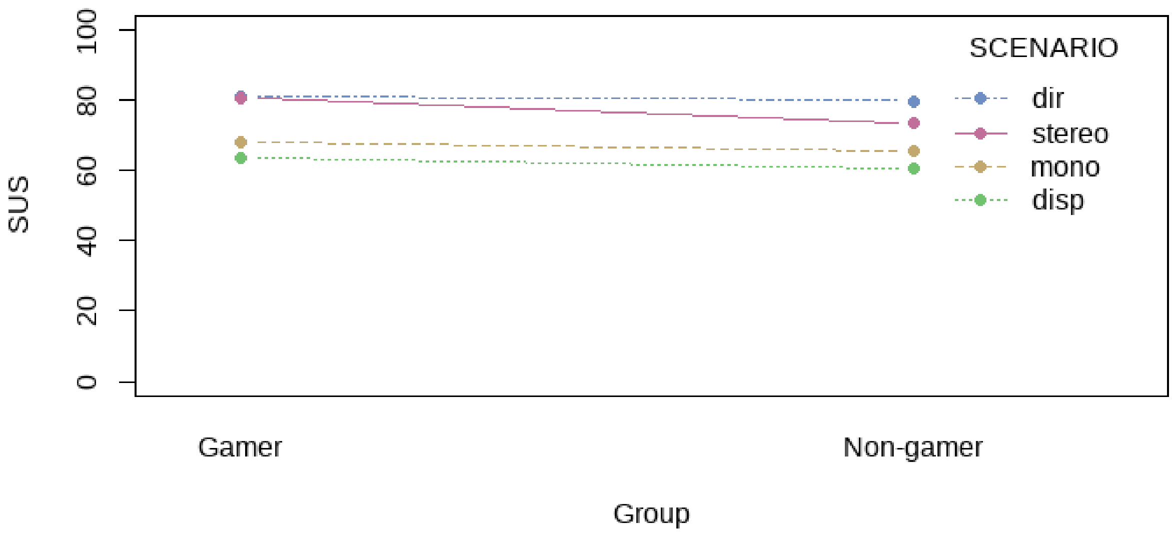


Figure 34 Interaction plot between both groups of the means of the SUS scores in all four scenarios

4.5.4 Results of Interview Questions

At the end of the experiment, all participants were asked final interview questions relating to their experience of the different types of visualization and the teleoperated system. The first was intended to find out if the participant recognized a difference between the two scenarios with the HMD (Figure 35). Participants were asked, "Did you experience any differences between the two scenarios with the HMDs?". 4 participants reported not recognizing a difference. All others identified a difference. 13 participants just reported experiencing a difference without being able to specify the effect more concretely. Another 13 attributed better operation to one scenario being 2D and the other 3D, while another 13 found one scenario to be advantageous due to depth perception. Both of these answers describe the difference correctly. The other participants claimed to have recognized other differences between scenarios: 10 attributed better operation to a better camera perspective, 7 experienced the camera to be closer, 2 reported better resolution, and 1 reported to have seen different colors.

In the second question, the participants were asked to rank the four scenarios from easiest to hardest (Figure 36). Of the 59 participants, 31 found direct view to be the easiest (24 stereoscopic HMD, 2 monoscopic HMD, and 2 flat screen display). In second place in the ranking was stereoscopic HMD with 27 (18 direct view, 11 monoscopic HMD, and 3 flat screen display). The flat screen display with 22 votes and monoscopic HMD with 21 votes were considered equally hard in the third place (9 direct view, and 7 stereoscopic HMD). The flat screen display was reported as the hardest scenario by 32 of the participants (25 monoscopic HMD, 1 direct view, and 1 stereoscopic HMD).

The final two interview questions gave the participants the opportunity to voice their suggestions for improvement, first on the visualization and then on the teleoperated system. An overview of the suggestions can be found in Figure 37 and Figure 38 with the size of the circles representing the number

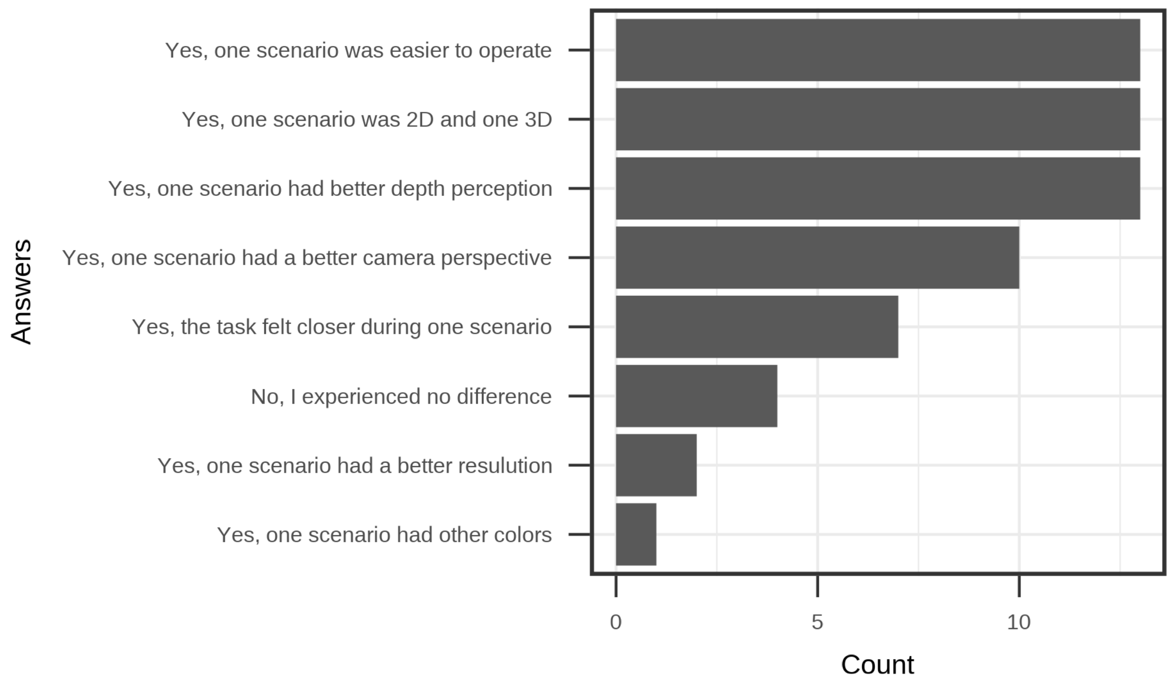


Figure 35 Answers of participants to the question whether they recognized a difference between the two scenarios with the HMD

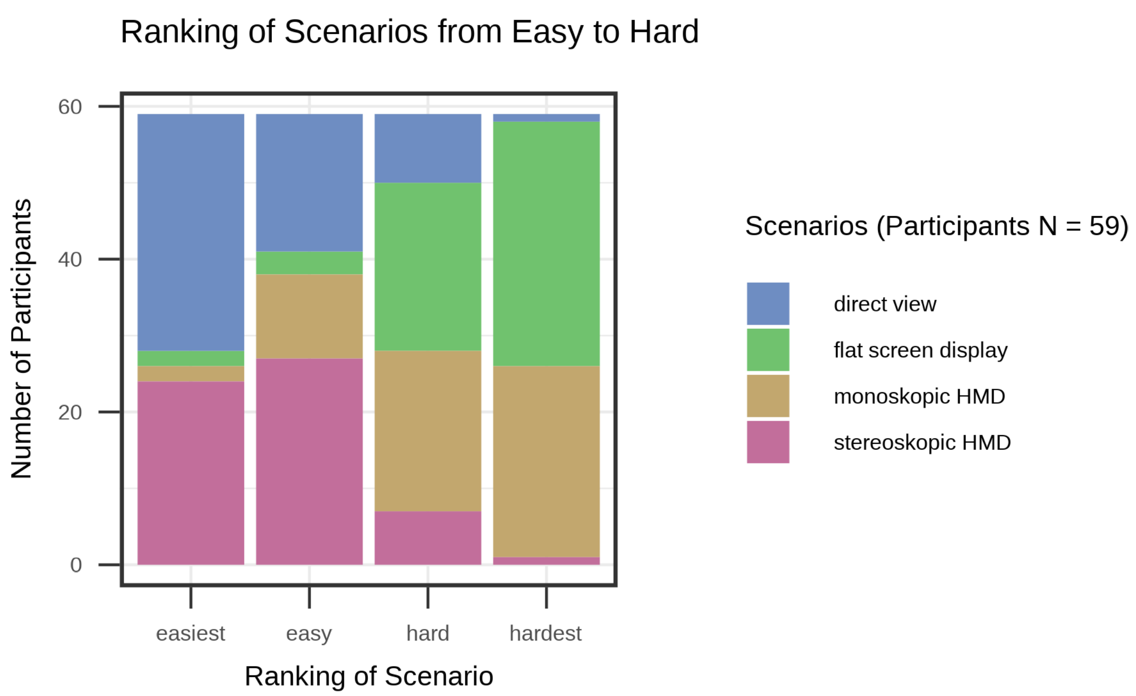


Figure 36 The ranking of scenarios from easiest to hardest

of participants suggesting the item. Key suggestions made by multiple participants regarding visualization were more camera perspectives, a better resolution, better lighting, and laser-projected guides.

Considering the teleoperated system, participants most frequently suggested better usability of the gripper, less resistance while moving the robot, disabling the automatic stop function of the robot, and the possibility to manipulate on a finer scale.

4.6 Other Observations

Beyond the measured data reported and evaluated in the previous sections, some additional observations made by the study administrator during the study are noteworthy. During the study, three participants reported slight discomfort while wearing an HMD due to simulator sickness. A break was offered to them but all three participants assured that the discomfort was tolerable and finished the scenario.
Moreover, one effect some participants experienced was an inverse feeling during teleoperation, meaning that they would expect the robot arm to mirror their movement by moving in the opposite direction. Nine participants reported while moving the leader robot to the right, they would expect the follower to move left and vice versa. The same was true for forward and back movement. This effect was not recorded systematically.
In addition to these observations, the participant without stereo vision can give interesting indications on the effect of the dimensionality and the HMD device. The following table presents the participants TCT, NASA-TLX, and SUS.

Table 10 TCT, NASA-TLX, and SUS of each scenario of the person without stereo vision

	Direct view	**Stereoscopic HMD**	**Monoscopic HMD**	**Flat screen display**
TCT [sec]	460	782	608	313
NASA-TLX score	49	46	66	26
SUS score	85	80	78	85

This participant completed the scenarios in the following order: direct view, monoscopic HMD, stereoscopic HMD, and flat screen display. They reported to have experienced no difference between the two scenarios with the HMD. Throughout all three measures, this participant's data does not fit into the patterns explained in this chapter. Only the values of TCT and NASA-TLX in the scenario with the flat screen display stand out with above-average performance and workload. This might be connected to the order of the scenarios, with the flat screen display as the last one. They experienced no significant difference in usability between all four scenarios. Although the data of this participant without stereo vision can give helpful indications, it is only one data point and any interpretation needs to be performed with caution. The results of the participant without stereo vision confirm the importance of depth perception during teleoperation. Moreover, they illustrate the learning effect from scenario to scenario. With more data points a difference between the devices might also be detected.

All results presented in this chapter will be explained and set into context in the following chapter.

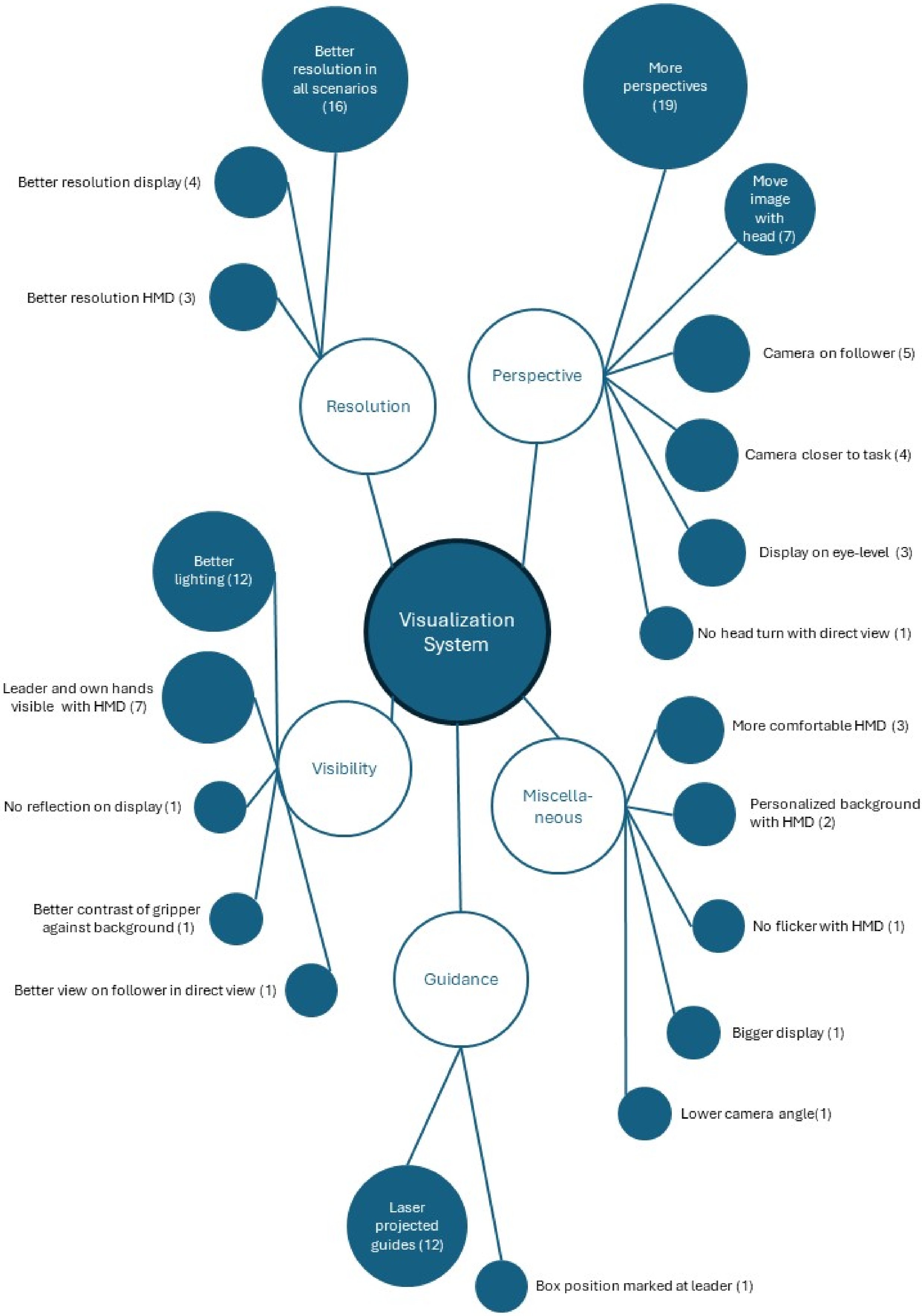


Figure 37 Improvements suggested by participants for the visualization system

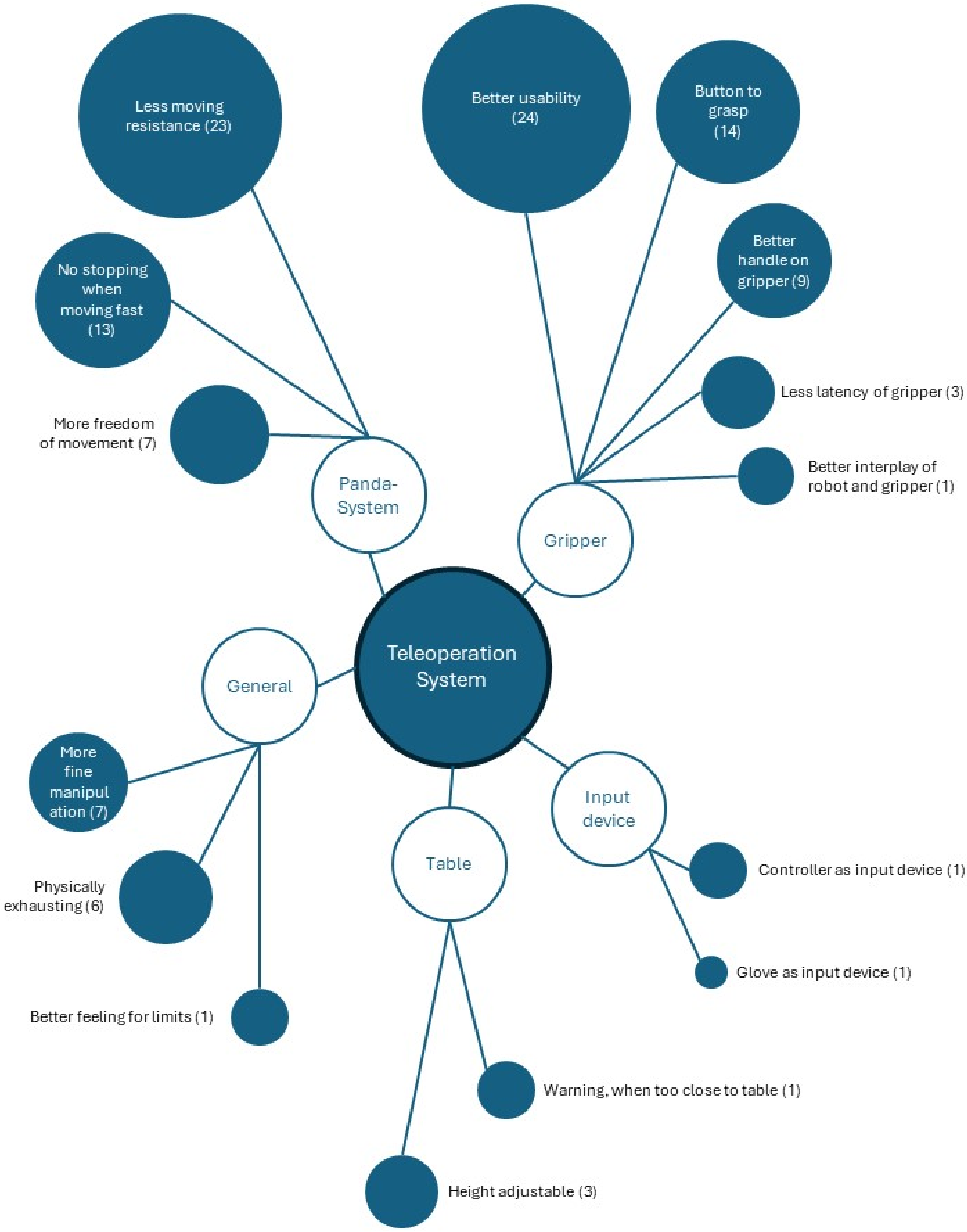


Figure 38 Improvements suggested by participants for the teleoperation system

5 Discussion

The main results of this study reveal improved performance, decreased workload, and a higher perceived usability for visualization with stereoscopic depth information compared to visualization without. However, the study shows no significant difference between gamers and non-gamers when performing teleoperated tasks. In summary, one of the hypotheses examined in this thesis was confirmed, while the other two were rejected.

1. There is no significant difference in the performance of expert operators in operating the teleoperated system between stereoscopic and monoscopic displays.
   FALSE, there is a significant difference in the performance of experts in operating the teleoperated system. Depth perception is the main influencing factor. Expert operators perform better with visualization with stereoscopic depth information (direct view and stereoscopic HMD) than without stereoscopic depth information (monoscopic HMD and 2D-screen).
2. Non-expert operators perform better with a stereoscopic display compared to a monoscopic display.
   TRUE, non-expert operators performed better in scenarios with stereoscopic depth information compared to scenarios without.
3. The workload is higher for expert and non-expert operators while wearing an HMD.
   FALSE, depth perception is the main influencing factor on workload, not the HMD device.

In this chapter, the findings of this study are discussed and contextualized in order to answer the research questions. First, the differences between the findings of the four different visualization scenarios are elaborated, with a focus on each aspect individually: performance, workload, and perceived usability. Subsequently, two possible explanations for the differences between gamers and non-gamers are presented. In addition, the differences in handling the four different shapes used in the task of this study will be discussed. Finally, the limitations of this study will be addressed for a transparent interpretation of the results.

5.1 Differences Between Visualization Methods in Operator Performance and Workload

The first research question referred to the operator performance and workload, namely how the differences between the investigated types of visualization can be quantified considering operator performance and workload on the operator and how big those differences are. The main significant effect found in this study was the differences between scenarios. Scenarios with stereoscopic depth information (direct view, stereoscopic HMD) produced better results for the performance, workload, and perceived usability than scenarios without stereoscopic depth information (flat screen display, monoscopic HMD). Between all scenarios, with direct view, participants showed the highest performance, the lowest workload, and the best perceived usability.

This finding coincides with de Boer et al. (2023), who found that direct manipulation (manual assembly with hands) without a visualization device produces the best results regarding performance compared to using input devices and visualization devices. In particular, de Boer et al. (2023) argue that direct manipulation does not have latency or bad resolution and that participants can adjust the perspective and gain additional secondary visual cues, like motion parallax cues, for depth perception with head movement. All of these factors contribute to improved performance and reduced workload. In teleoperated systems, however, direct view often cannot be implemented since there is a barrier between the operator and the remote site. Hence, a well-designed visualization of the remote site is required for an effective execution of the teleoperated task.

For designing visualization for teleoperation, the direct view scenario can still provide valuable insights. de Boer et al. (2023) argue that if typical constraints like latency, bad resolution, or a stationary viewpoint are reduced or eliminated in the visualization devices (HMD and flat screen display) by technological improvements, operators will perform better and experience less workload with visualization devices compared to direct view as well.

When designing visualization for teleoperation, one important choice is the decision between monoscopic and stereoscopic displays. Although statistical analysis did not find significant differences between the two monoscopic (flat screen display compared to monoscopic HMD) as well as between the two stereoscopic displays (direct view compared to the stereoscopic HMD), the interaction diagrams of TCT (Figure 20), the NASA-TLX score (Figure 31), and the SUS score (Figure 34) can indicate potential towards future investigations. In particular, **the monoscopic HMD showed improved performance, a lower workload, and a higher-perceived usability than the flat screen display for both gamers and non-gamers**. This result is notable given that the only difference between the two visualization scenarios is the type of device, while the dimensionality, resolution, and frame rate are the same. In line with the statistical analysis, participants considered the monoscopic HMD easier to work with when asked to rank the scenarios in the final interview questions. Multiple participants explained that they preferred the monoscopic HMD because it is closer to the face, thus improving visual perception and limiting distractions from the environment. This preference might be explained by a more immersive experience supporting the performance and decreasing the workload of participants.

5.1.1 Improved Performance in Scenarios with Stereoscopic Depth Information

Above all, the results of this study reveal an improved performance in scenarios with stereoscopic depth information (direct view and stereoscopic HMD) than without stereoscopic depth information (monoscopic HMD and 2D-screen). For example, the performance measurements using the TCT in this study coincide with a prior study by Prinz and Bengler (2023) using the same equipment but performing a different task. Prinz and Bengler (2023) found higher TCTs with the flat screen display configuration compared to direct view in a between-subjects design. This effect can also be observed in the within-subjects design of this study.

Further, related studies confirm the finding of improved performance with stereoscopic displays over monoscopic displays (de Boer et al., 2023; Maciaś et al., 2020; Triantafyllidis et al., 2020). Generally, this improved performance is attributed to depth perception. Similarly, a higher accuracy can be observed in scenarios with stereoscopic depth information compared to scenarios without. The findings of this study show, that in scenarios with direct view and stereoscopic HMD participants needed fewer grab attempts and fewer corrections to complete the task, indicating higher precision. These findings are in line with results by de Boer et al. (2023), which reported more failed grab attempts in scenarios without stereoscopic depth information compared to scenarios with stereoscopic depth information. Furthermore, Triantafyllidis et al. (2020) reported a significantly higher position accuracy in scenarios with stereoscopic depth information, which is comparable to the results of corrections of this study.

During the scenarios with monoscopic visualization, participants often performed additional movements to correct the position of the shapes after release. For example, they gently nudged the shapes with the gripper to grab or correct the position of the shape. Additionally, some participants reported to have used the shadow cast by the gripper for orientation. This shows how **participants relied especially on secondary cues during gripping and correction when stereo vision was not possible**. Therefore, the grab attempts and corrections increased in scenarios with a monoscopic display. In conclusion, when choosing a visualization method for teleoperation, a device with stereoscopic depth information is superior due to depth perception improving the performance.

5.1.2 Reduced Workload in Scenarios with Stereoscopic Depth Information

The results of the NASA-TLX are similar to the performance results. There is no significant difference between gamers and non-gamers. However, a significant difference was found between scenarios. **The scenarios with stereoscopic depth information were rated with a lower NASA-TLX score than scenarios without stereoscopic depth information** and therefore, they pose a lower workload. This finding agrees with Triantafyllidis et al. (2020) where a significantly lower workload was observed with the VR set-up compared to a monocular display. They attributed the higher workload with the flat screen display to higher amounts of induced vection (the illusion of self-motion in VR with HMD (Triantafyllidis et al., 2020)). However, they state that further investigation is necessary for more founded conclusions. In combination with the results of the study in this thesis, their findings can be explained by the difference in dimensionality. **Participants experience less workload with visualization with stereoscopic depth information** rather than increased vection. Conversely, the findings of the study of this thesis contradict the findings of Brooks et al. (2017). They reported higher levels of mental effort, physical effort, and discomfort with a stereoscopic HMD compared to a flat screen display. However, they investigated a combination of a navigation and a manipulation task. This combination requires additional effort by the operator. Moreover, they used a more elaborate HMD-system with head tracking that translated into camera movement. Thus, in addition to the search task, participants also needed to navigate in three-dimensional space, which might add to the workload. Such elaborate HMD systems have evolved since the study was conducted in 2017 and might show different results with modern technology.

Further investigation of each of the NASA-TLX dimensions reveals interesting results. The **mental workload** reflects the tendencies of the overall NASA-TLX score: Participants reported a lower workload in scenarios with stereoscopic depth information. Only in the dimension of mental workload gamers experienced a lower workload than non-gamers. This might be attributed to gamers dealing differently with challenging situations than non-gamers. Gamers might see the task of the study as a challenging game and experience a lower workload since they are used to such situations during gaming. However, non-gamers might experience the study task rather as test, which explains the increased workload.

The **physical workload**, on the other hand, shows little to no influence on the overall score. The physical workload is low in all scenarios, with no difference between groups. This might be due to the short time of the trials, with no participant taking more than 15 min for a trial. However, in an application scenario with teleoperation in assembly, operators would be required to use the system for a longer amount of time, possibly a whole 8 h shift. The workload would be different with longer operation times. Additionally, most participants were relatively young and physically healthy, with a mean age of about 26 years. Thus, they were little affected by the physical demands of the task. However, after the trials, many participants reported some exhaustion in their hands and fingers due to the gripper operation. An improved gripper design of the teleoperated system might reduce the physical demands on the operator.

Temporal workload reflects the trend of a better workload of scenarios with stereoscopic depth information compared to scenarios without. Overall, the workload score was low throughout all scenarios and all groups. The flat screen display scenario for gamers stands out with a higher score. This might be attributed to the display recording. While recording the task from ZED-view using Windows Game Bar, the recording software shows a counter of how long the recording is going. This was visible on the flat screen display in the upper right corner. Gamers might have been especially affected due to feeling challenged by the recording timer and, therefore, reported increased temporal demand.

Performance and effort reflect the overall score and show no extraordinary tendencies. **Frustration** shows a particularly low frustration score in direct view compared to other scenarios. Moreover, gamers report a particularly high frustration score for the flat screen display scenario. This might also be related to the record time showing in the corner, as explained in the previous section. Overall, gamers report the same or higher frustration scores compared to non-gamers. This finding contradicts Illing et al. (2020), who reports lower frustration levels with experts. They attribute lower frustration levels to the expert operators' familiarity with the investigated kind of control. However, the experts in the study by Illing et al. (2020) were not gamers but expert teleoperators who were trained on the investigated system. This gives the teleoperation experts an advantage over gamers who have to transfer their gaming skills to the teleoperated system. Schmidt et al. (2014) report lower frustration levels in a telepresence unit (consisting of a stereoscopic HMD, sound feedback, and force feedback). They explain low frustration levels with the telepresence unit with multimodal feedback for the operator. The operator's frustration is low because they receive support through feedback from different channels. Multimodal feedback might also explain low frustration levels during the study of this thesis. During all scenarios, the operators received **support through haptic feedback of the robot system and acoustic feedback of the shapes falling into the box. This support reduced the frustration level.**

5.1.3 Better Usability Rating in Scenarios with Stereoscopic Depth Information

An investigation of the SUS score can give indications about the perceived usability of a system. Overall, gamers gave a slightly better SUS rating than non-gamers. This effect might be explained by the mindset of gamers. Gamers' attitudes towards the teleoperation and visualization system might be more relaxed since they experience the study as a game. Their familiarity with challenging games might influence the perceived usability. The prior study by Prinz and Bengler (2023) with the same teleoperation system did not find a significant difference between direct view and using a flat screen display for visualization in a between study design. Compared to the study of this thesis, Prinz and Bengler (2023) found a similar SUS score with the flat screen display scenario, but the SUS score of the direct view in the study of this thesis was higher in comparison, resulting in a significant difference between the two scenarios. This can be attributed to the different study designs. In a direct comparison, participants might experience a more distinct difference between the scenarios than in a between-study design. Similarly to the study by Triantafyllidis et al. (2020), the study of this thesis also found a distinct difference between scenarios with and without stereoscopic depth information. The findings of de Boer et al. (2023) agree with these results. **Higher SUS scores can be clearly attributed to depth perception improving the process of manipulation, resulting in better-perceived usability**.

5.2 Differences Between Gamers and Non-gamers

The results of this study can help answer the second research question, whether or not there are differences between expert and non-expert operators in performance and workload for different visualization methods. As reported in Chapter 2.3, gamers in this thesis are considered experts in teleoperation, whereas non-gamers are classified as non-experts. However, **no significant difference between gamers and non-gamers** was discovered in the study of this thesis. Two possible explanations for this effect are conceivable.

The first plausible explanation for no significant difference relates to the generally high technical affinity of the participants. Gamers and non-gamers were equally distributed in the sample. Yet, about 80 % either work or study at TUM and therefore have a technical background. Nenna and Gamberini (2022) and Gomer and Pagano (2011) attribute better performance of gamers to increased spatial abilities, improved skills of handling input devices, and more trust in technology. The qualities can reasonably be assumed for TUM students and employees as well due to their technical education and work. Hence, by this definition, most participants can be considered experts, regardless of their gaming habits. The results of the ATI score support this argument. No significant difference was revealed between the ATI score of gamers and non-gamers, implying equal affinity towards technology in both groups. Moreover, the mean ATI score for gamers and non-gamer was above-average, indicating above-average affinity towards technology, according to Franke et al. (2019). **Thus, due to their technological background, a majority of the participants in this study exhibit qualities that lead to expert-level teleoperation skills (spatial abilities, skills in handling input devices, and trust in technology) regardless of their gaming abilities.**

Similarly, Brooks et al. (2017) did not find a significant difference between gamers and non-gamers in performance and workload during a teleoperated manipulation task. Their participants were recruited at the "Defence Science and Technology Group" so it can be reasonably assumed that most have a technical background leading to improved teleoperation skills. Following this argumentation, all participants would have been considered experts regardless of their gaming abilities, which supports the explanation above. However, the results from Brooks et al. (2017) and this thesis contradict the findings of Illing et al. (2020), who found a significant difference between experts and non-experts. However, Illing et al. (2020) recruited trained teleoperation experts who were experienced with the system under investigation. Thus, the difference between experts and non-experts was much more distinct in their study. Due to their familiarity with the system, teleoperation experts inherently performed better and experienced less workload during teleoperation. In conclusion, **the categorization of experts by gamers and non-gamers, as applied in this thesis, does not reflect the expert levels in teleoperation well**.

A second plausible explanation for no significant difference in the performance and workload experienced by gamers and non-gamers in this study relates to the design of the teleoperative control interface. In contrast to this study, Nenna and Gamberini (2022) and Brizzi et al. (2018) both found significant differences between gamers and non-gamers. However, they also list limitations, where the difference is less pronounced. For example, Nenna and Gamberini (2022) found more significant differences in the workload and performance with a controller as an input device than with physical actions (gesture control). Schmidt et al. (2014) supports the finding that controllers are less intuitive input devices than input devices with the same degree of freedom as the output device. The study conducted for this thesis used an intuitive teleoperation setup where the input device (leader) was identical to the output device (follower). Therefore, the operation of the teleoperated system was more intuitive than with a controller. In addition, Brizzi et al. (2018) found no difference between groups in scenarios with feedback (supporting guides projected in Augmented Reality) compared to scenarios without feedback. They conclude that guides, support, and feedback compensate the differences between gamers and non-gamers. The setup used during the study of this thesis provided force feedback and auditive feedback, which supported the operator. In conclusion, an intuitive input device and support through feedback can reduce or even eliminate the differences between gamers and non-gamers. Therefore, **different skill levels might be compensated by an intuitive and immersive system design**. However, these two possible explanations need to be further verified by future studies. A more detailed outlook can be found in the conclusion chapter.

Although the statistical analysis in this thesis did not find a significant difference between gamers and non-gamers, small differences could be discovered by investigating descriptive statistics. In general, these results can give first impressions on possible effects. However, they should be interpreted with caution. That is, these findings should only be considered as pointers toward future investigations rather than tangible research findings. **Gamers were found to complete the task with lower TCTs** and. Therefore, they completed the trial faster throughout all scenarios. This might be attributed to **better skills in handling input devices** and therefore faster and more precise movement. The robot movement data was also collected during this study (see Table 1) and may be evaluated in future analyses to support or disapprove this explanation. In line with this study, both Nenna and Gamberini (2022) and Brizzi et al. (2018) found increased TCTs with gamers. Brizzi et al. (2018) attribute these shorter operation times to gamers' improved skills in utilizing virtual visual cues, judging distances, and finding effective strategies of motion in virtual scenarios.

5.3 Differences in Handling the Shapes During the Task

In addition to the research questions, some findings regarding the shapes of the task are noteworthy. During the trial, each shape had unique challenges which impacted the operator's performance. Some shapes resulted in notable differences in the operators' TCTs, grab attempts, and corrections. The **left cube** was the first moved shape, which might explain the operators' higher TCTs, more grab attempts, and more corrections. This cube was used for calibration to find the right distance to operate, especially in monoscopic scenarios. The **right cube**, in comparison, showed lower TCTs, supporting the explanation that the left cube had higher TCTs due to the calibration and not the shape itself. The right cube showed similar TCTs to the **cylinder**, which supports results from Triantafyllidis et al. (2020). They found higher rates of successful shape placement with cubes than cylinders.

The **triangle** showed significantly higher TCTs than all other shapes on both sides. This can be explained by the shape. The triangle can only be grasped by the tip at one side and the hypotenuse at the other. If the gripper is not on the tip exactly, it slips on the sides. Rotationally symmetric shapes like cylinders or cubes with more grasp area are more forgiving in this regard.

The **semicircle** also showed increased TCT, although not as high as the triangle. Once the semicircle tipped over, it was hard to bring it back into a position to move it into the box, resulting in higher TCTs. Additionally, the semicircle had smaller tolerances (2 mm) than the triangle (5 mm) between the shape and the box hole. However, the semicircle is more forgiving towards inaccuracy than the triangle since it does not need to be gripped exactly at the tip.

5.4 Limitations

Although this study produced valuable results for applications and further research, some limitations should be noted. The four key limitations relate to the composition of participants, the functionality of the gripper, the task design, and the subjective measures of data collection. These limitations are further discussed in the following.

5.4.1 Composition of Participants

The participants pose the most influential limitations of this study. As explained before in this chapter (Chapter 5.2), **categorizing only gamers as experts was insufficient to represent expert teleoperators**. Even most participants categorized as non-gamers could be considered experts due to their technical background. Originally, the distinction between experts and non-experts was made to be able to transfer the findings of experts to teleoperation experts in assembly in industrial settings in contrast to novices. If the results of this study can be transferred to an industrial setting, it must be determined which explanation of a non-significant effect between gamers and non-gamers is true: the technical background leading to improved teleoperation or intuitive system design leading to level performance and workload (Chapter 5.2). If all participants can be considered experts, the results are transferable since teleoperators in the industry are experts. If the non-significant result between gamers and non-gamers is due to the intuitive and supportive design, the results might not be transferable. Which explanation is accurate needs to be identified in further investigations.

An additional limitation regarding participants was the **gender distribution**. Most of the gamers were male (5 female, 26 male) and most of the non-gamers female (17 female and 11 male). Nenna and Gamberini (2022) reports gender effects on operation time, with males outperforming females. However, this gender effect was only observed with a controller as an input device, not with physical action (gesture control). Since the setup in the study of this thesis is similarly intuitive as physical action, it can be reasonably assumed that gender effects are minimized. Furthermore, the categorization by expert level is more relevant than by gender for the study of this thesis.

5.4.2 Gripper Functionality

The biggest limitation was the functionality of the gripper of the teleoperated system. It is hard to use and has significant latency. The participants repeatedly reported difficulties with operating the gripper in their answers to the final questions. These factors likely influenced the perceived usability of the system. However, since this study employed a within-study design, all participants experienced the same limitations throughout all scenarios. Therefore, the effect of the gripper influenced all dependent factors in the same way.

However, the gripper also produced a reoccurring technical error, which could not be resolved within the time of this thesis: It would close around a shape (mostly the right cube) but not grasp it. In most cases, after a restart of the gripper system, the participant was able to continue. However, in some cases, the system required multiple restarts. If the system did not work even after several restarts, the participants were advised to continue with the next shape. This led to missing values, which were later calculated by extrapolating from values of other scenarios, as shown in Chapter 4.2. That these values have been extrapolated should be kept in mind when interpreting the results.

Additionally, when this error occurred, participants experienced frustration, which likely influenced their performance and workload. The performance suffered from an interruption of the flow and the NASA-TLX records frustration as one of the dimensions. These interruptions influenced the performance and the workload of participants. No pattern could be detected if the error was influenced by either the group belonging or the visualization method. It seemed to be more dependent on the personal operation style of each individual. To avoid these limitations posed by the gripper system in future studies with this system, these technical problems with the gripper system need to be fixed and the usability needs to be improved for future research.

5.4.3 Task Design

Although the task is deliberately chosen to be easily understandable and a pick-and-place task, it is not entirely representative of assembly. Assembly often requires high precision and consists of a bigger variation of manipulation steps. However, the teleoperation system does not allow for higher precision without force feedback in the gripper. If the technical system is improved to facilitate more accuracy, a task more closely representing industrial assembly can be investigated.

5.4.4 Subjective Measures in Data Collection

Another limitation is the method of data collection for measuring the workload. Although the NASA-TLX is a widely used, standardized, and validated questionnaire, it records the subjective workload. For the NASA-TLX to be accurate, participants need accurate self-evaluation skills, which are influenced by personal qualities. Overall, this subjective workload rating the comparability between subjects. In addition to the subjective NASA-TLX data, objective workload data was collected during the experiments using the Empatica E4 wristband. The wristband measured blood volume pulse, electrical properties of the skin, peripheral skin temperature, and motion-based activity, from which the objective workload can be derived. However, an analysis of the data collected by the Empatica E4 wristband was outside of the scope of this thesis. It will be analyzed at a later point in time to derive additional findings regarding the objective workload and compare these results to the subjective workload data of this thesis.

6 Conclusion and Outlook

The findings presented in this thesis offer novel perspectives on the human factors influencing teleoperation in assembly settings. Current research mainly focuses on technical improvements of the teleoperated system. However, to establish a secure and sustainable workplace for teleoperation operators, the workload and subjective preference measures also need to be considered apart from performance measures during the design of a teleoperated workplace. The results of this thesis contribute to a differentiated decision-making process for a visualization method that enhances performance, lowers the workload, and also supports the personal preference of the operator.

Overall, the most significant finding of this study is that depth perception is the biggest factor in improving performance, lowering workload, and increasing perceived usability. However, small non-significant effects hint towards the device as an influencing factor with different influences between expert and non-expert operators. If the dimensionality or the device is more influential on the performance and the workload of the operator can give indications on where to direct research and development efforts: into improving the visualization device or enhancing depth perception. This effect should be further investigated in future research to give a more differentiated overview of which visualization affects the performance and workload of the operator in the most beneficial way.

In order to enhance depth perception, the task and environment should be investigated and improved. The study showed depth perception to be the most influential factor for performance, workload, and usability. However, providing more pronounced secondary visual cues like shadows, guiding lines for perspective, or others might improve monoscopic displays to a point where they could compete with stereoscopic displays. In this case, opera tors could use improved monoscopic displays without the additional workload of a stereoscopic display.

In the future, new groupings to represent expert and non-expert operators should be considered for future investigations. The participants' technological background and prior experiences should be considered rather than their gaming habits. This will lead to a better distinction between experts for teleoperation and non-experts. Additionally, the differences between groups that were not significant in this study, might be more pronounced with the right participants. This could lead to better advice on what visualization suits experts or non-experts. In addition, a better-suited grouping might clarify if the non-significant effect between gamers and non-gamers can be attributed to an intuitive design. In this case, a different grouping would find a non-significant effect as well.

Additionally, a longer wearing time should be investigated. During this study, participants only used each visualization device for a maximum 15 min. However, at a workplace in industrial assembly, the system would need to be used for longer amounts of time, possibly multiple hours. The performance and the workload would both be affected by longer use time. Especially the HMDs would lead to more fatigue for the eyes since they would be looking at the same distance for too long, as well as physical fatigue of wearing the device on the head for longer times. In conclusion, the long-term effects of each visualization method should be investigated.

This study, together with future research as suggested before, can help improve the working situation of assembly workers by increasing their productivity while keeping the workload low. These investigations can help industrial companies evaluate their workplaces and create them in a way that suits and supports the workers.

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Acronyms

Appendix

Appendix A : Study Guide

Studienablauf

Generell machen:

- Backup Fragebogen auf Papier
- Backup Einverständniserklärung auf Papier

☐ Etwas zu tun
- Etwas zu sagen/erklären

Zeit [min]	Stichwort	Versuchsleitung	Proband*in
Setup			
60	Aufbau	☐ Licht an, durchlässige Rollos runter ☐ Teleoperation starten ☐ Excel-Protokoll: Daten anlegen ☐ iPad: Fragebogen und Einverständniserklärung vorbereiten ☐ Task zurücksetzen: Bauernhofspiel und Formenbox ☐ ZED-Kamera für Versuch hinstellen ☐ iPad-Kamera für Aufzeichnung vorbereiten ☐ Abschirmung vorbereiten ☐ Kabel vorbereiten und anschließen: HMD (USB + HDMI), Oculus Sensor (USB), Kamera (USB)	-
Begrüßung			
2	Hallo und Infos	• Hallo und herzlich willkommen. Vielen Dank, dass du dir Zeit für diesen Versuch nimmst. • Wir untersuchen in dieser Studie wie die Visualisierung während der Teleoperation aussehen kann. Ich erkläre gleich mehr dazu. • Das sind die teleoperativen Roboter. Wenn man den ersten Roboter hier bewegt, dann kopiert der zweite Roboter seine Bewegungen. So kann man dort drüben eine Aufgabe bearbeiten, indem man hier den Roboter bewegt. • Man setzt Teleoperation ein, wenn man etwas aus der Ferne bedienen will (unter Wasser, im Weltraum) oder keinen direkten Kontakt mit dem Bauteil haben kann (radioaktives Material).	zuhören

		• Wir untersuchen den Einsatz in der Montage. Deshalb wirst du einige montageähnliche Aufgaben bekommen. • Insbesondere untersuchen wir die Visualisierung, also wie der zweite Roboter beim Bediener angezeigt wird. Dabei vergleichen wir verschiedene Visualisierungsarten. • Du bekommst am Anfang etwas Zeit, dich mit dem System vertraut zu machen und mit den Robotern Teleoperation auszuprobieren. Dann füllst du den Anfangsfragebogen aus. Dann durchläufst du 4 Szenarien mit vier verschiedenen Visualisierungsarten, in denen du eine einfache Aufgabe mit dem teleoperativen System bearbeitest. Nach jedem Szenario füllst du einen Fragebogen aus, während ich das nächste Szenario vorbereite. Zum Schluss gibt es ein paar Abschlussfragen und ein kleines Dankeschön von mir.	
3	Einwilligungserklärung und Datenschutz	☐ Kontrollieren, ob überall unterschrieben	Lesen und unterschreiben
2	Voraussetzungen	☐ Überprüfen: • Sicht: Lang-Stereotest • Schwanger	Auskunft geben
2	ZED-Kamera	☐ Kamera auf Körperhöhe einstellen	Neben Kamera hinstellen
Einführung			
	Roboter erklären	• Der Roboter bewegt sich in Echtzeit • Jedes Gelenk und Endeffektor bewegen lassen • Notstopp erklären ☐ Wenn zu schnell bewegt - Stopp - Zurücktreten und in Startposition verfahren -> ausprobieren • Nicht an die Grenzen der Beweglichkeit -> stoppt manchmal • Endeffektor ist träge und klemmt manchmal • Endeffektor hat etwas Latenz/ist träge	Zuhören und ausprobieren
	HMD erklären (Wenn das passende Szenario kommt)	☐ Zeigen, wie man die Brille aufsetzt (insbesondere mit Brille): erst Brille an Gesicht ansetzen und dann Halterung über den Kopf ziehen, Mit Klettverschlüssen kann die Größe eingestellt werden ☐ Linse einstellen, bis das Bild scharf ist • Bescheid geben, falls Übelkeit	Zuhören und ausprobieren
	Empatica Armband	• Armband zeichnet Bewegung, Hautleitwiderstand (Schwitzen), Hauttemperatur und Herzfrequenz auf.	Zuhören und aufsetzen

		• Das braucht man, um Belastung objektiv zu messen ☐ Aufsetzen zeigen: soll eng anliegen (nicht zu fest) unter Handgelenkknochen. • Wenn man auf den Knopf drückt, dann wird eine Markierung in der Aufzeichnung gesetzt. Das erleichtert mir später die Datenauswertung. Das machen wir am Anfang und am Ende von jedem Szenario. Ich sage dir Bescheid, wenn du drücken sollst. • (Falls man keine Gesundheitsdaten aufzeichnen möchte, kann man auch weglassen)	
3	mit System vertraut machen	Beobachten, Fragen beantworten, bei Bedarf eingreifen	Mit System vertraut machen und Testaufgabe (Bauernhof) bearbeiten
3	Demografischer Fragebogen, Umbau	Proband*in zu Tablet führen und demografischen Fragebogen geben Umbau: ☐ Ergebnis von Lang-Test eintragen ☐ Task wechseln ☐ Datenaufzeichnung starten: ☐ Empatica Armband ☐ Video Proband:in iPad ☐ Video ZED-Kamera über Laptop ☐ Bewegungsdaten von Roboter	Demografischen Fragebogen ausfüllen
1	Task erklären	In den kommenden 4 Szenarios: Formen in Box reintun -> Mit Würfel links anfangen und dann nach hinten (Würfel, Zylinder, Halbkreis, Dreiceck) und dann die rechte Seite genauso von vorne nach hinten (Würfel, Zylinder, Halbkreis, Dreiceck) Wichtig: Es wird das System bewertet und nicht die Leistung des Nutzers	zuhören
Szenario 1/2/3/4			
2	Vorbereitung	☐ Roboter in Startposition fahren ☐ Bildschirmaufzeichnung für Roboter-video starten ☐ Anfang: Empatica Eventmarker ☐ Start Skripte für Aufzeichnung der Roboterbewegung	
5	Durchführung	☐ Checken, ob alle Messungen laufen ☐ Proband*in beobachten, ggf. eingreifen ☐ Ende: Empatica Eventmarker ☐ Stopp Skripte für Aufzeichnung der Roboterbewegung	Aufgabe ausführen

2	Fragebogen/Umbau	„Während du den Fragebogen ausfüllst, baue ich für das nächste Szenario um“ ☐ Bildschirmaufzeichnung stoppen ☐ Die Aufgabe in Ausgangszustand bringen ☐ Abschirmung hin/weg ☐ Bildschirm hin/weg ☐ Richtige Kabel anschließen	Fragebogen ausfüllen
	Pause?	Fragen, ob Pause nötig	
Verabschiedung			
2	NASA-TLX Wertung	Warten	Fragebogen ausfüllen
2	Abschlussfragen	☐ Interviewfragen aus Fragebogen stellen	Fragen beantworten
2	Aufzeichnung stoppen	☐ Datenaufzeichnungen stoppen: • Empatica Armband • iPad Video • Bildschirmaufzeichnung • Roboterbewegung	
1	Dankeschön	• Danke sagen • Fragen, ob die Person informiert werden will • Süßigkeiten als Dankeschön	Verabschiedung Letzte Fragen
Nachbereitung			
20	Nachbereitung	☐ Im Protokoll (Excel) ggf. Ereignisse markieren ☐ Überprüfen, ob Daten alle aufgezeichnet und ggf. speichern: ○ Bildschirmaufzeichnung für Robotervideo ○ Roboter Bewegungsdaten ○ Empatica ○ iPad Video ○ Exceltabelle mit Protokolldaten ○ Einverständniserklärung ☐ Armband, HMD und Roboter desinfizieren ☐ Geräte zum Laden anschließen: 2 iPads, iPad Stift, Empatica ☐ Aufräumen	

Sonstige Texte für Situationen zwischendurch

- Mit HMD Roboter finden: Achtung, ich nehme dich am Unterarm und führe dich zum Roboter
- Restart der Roboter mit HMD: Erzählen was passiert -> Der Roboter startet gerade neu, er fährt in Startposition, die Greifer starten neu,…
- Ich bewege mich, wenn Proband HMD aufhat: Achtung, ich komme in deine Richtung, ich laufe zum Roboter,…

Szenario 1: Direkte Sicht

- ☐ Abschirmung: nein
- ☐ Visualisierung: direkt
- ☐ Kamera: nein
- ☐ Anschlüsse: keine
- ☐ Software: keine

Szenario 2: Bildschirm

- ☐ Abschirmung: ja
- ☐ Visualisierung: Bildschirm
- ☐ Kamera: ja
- ☐ Anschlüsse: HDMI-Bildschirm, USB-ZED
- ☐ Software: Display.exe, Laptopbild auf Bildschirm duplizieren

Szenario 3: HMD mono

- ☐ Abschirmung: ja
- ☐ Visualisierung: HMD
- ☐ Kamera: ja
- ☐ Anschlüsse: HDMI-Oculus, USB-Oculus, USB-Oculussensor, USB-ZED
- ☐ Software: Mono.exe

Szenario 4: HMD stereo

- ☐ Abschirmung: ja
- ☐ Visualisierung: HMD
- ☐ Kamera: ja
- ☐ Anschlüsse: HDMI-Oculus, USB-Oculus, USB-Oculussensor, USB-ZED
- ☐ Software: Stereo.exe

Appendix B : Questionnaire

Visualisierung während Teleoperation

In dieser Umfrage sind 65 Fragen enthalten.

Personenbezogene Daten

Bitte geben Sie den Code an, den sie zur Anonymisierung von der Studienleitung bekommen haben: *

Bitte geben Sie Ihre Antwort hier ein:

Dies ist eine Frage-Hilfetext.

Wie alt sind Sie? *

In dieses Feld dürfen nur Zahlen eingegeben werden.
Bitte geben Sie Ihre Antwort hier ein:

Was ist Ihr Geschlecht? *

Bitte wählen Sie eine der folgenden Antworten:
Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Weiblich
- ◯ Männlich
- ◯ Divers

Benötigen Sie eine Sehhilfe für die Sicht in die Ferne (Kurzsichtigkeit) und/oder für die Bildschirmarbeit (Weitsichtigkeit)? *

Bitte wählen Sie eine der folgenden Antworten:
Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Ja, für die Ferne
- ◯ Ja, für die Bildschirmarbeit
- ◯ Ja, für beides
- ◯ Nein

Wie viel Erfahrung haben Sie mit Head-mounted Displays wie VR-Brillen oder AR-Brillen (Beispiel siehe unten)?

*

Bitte wählen Sie eine der folgenden Antworten:
Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Keine Erfahrung
- ◯ Wenig Erfahrung
- ◯ Einigermaßen viel Erfahrung
- ◯ Ziemlich viel Erfahrung
- ◯ Extrem viel Erfahrung

Wie viel Vorerfahrung haben Sie mit ferngesteuerten Geräten (Drohne, ferngesteuertes Auto, etc.)? *

Bitte wählen Sie eine der folgenden Antworten:
Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Keine Erfahrung
- ◯ Wenig Erfahrung
- ◯ Einigermaßen viel Erfahrung
- ◯ Ziemlich viel Erfahrung
- ◯ Extrem viel Erfahrung

Welche technischen Vorerfahrungen besitzen Sie? Geben Sie an, wie sehr Sie den folgenden Aussagen zustimmen. *

Bitte wählen Sie die zutreffende Antwort für jeden Punkt aus:

	stimmt gar nicht	stimmt weitgehend nicht	stimmt eher nicht	stimmt eher	stimmt weitgehend	stimmt völlig
Ich beschäftige mich gerne genauer mit technischen Systemen.	○	○	○	○	○	○
Ich probiere gerne die Funktionen neuer technischer Systeme aus.	○	○	○	○	○	○
In erster Linie beschäftige ich mich mit technischen Systemen, weil ich muss.	○	○	○	○	○	○
Wenn ich ein neues technisches System vor mir habe, probiere ich es intensiv aus.	○	○	○	○	○	○
Ich verbringe sehr gerne Zeit mit dem Kennenlernen eines neuen technischen Systems.	○	○	○	○	○	○
Es genügt mir, dass ein technisches System funktioniert, mir ist es egal, wie oder warum.	○	○	○	○	○	○
Ich versuche zu verstehen, wie ein technisches System genau funktioniert.	○	○	○	○	○	○
Es genügt mir, die Grundfunktionen eines technischen Systems zu kennen.	○	○	○	○	○	○
Ich versuche, die Möglichkeiten eines technischen Systems vollständig auszunutzen.	○	○	○	○	○	○

1= stimmt gar nicht, 6= stimmt völlig

Wie häufig spielen Sie Computerspiele? *

Bitte wählen Sie eine der folgenden Antworten:
Bitte wählen Sie nur eine der folgenden Antworten aus:

- ○ Nie
- ○ Selten
- ○ Gelegentlich
- ○ Regelmäßig
- ○ Oft

Wie viele Stunden spielen Sie Computerspiele durchschnittlich in der Woche? *

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
Antwort war NICHT 'Nie' bei Frage ' [G01Q07]' (Wie häufig spielen Sie Computerspiele?)

Bitte geben Sie Ihre Antwort hier ein:

Welche Computerspiele spielen Sie am häufigsten? Geben Sie an, welchen Kategorien Ihre 3-5 meistgespielten Computerspiele angehören.

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
((G01Q07.NAOK != "AO01"))

Wählen Sie alle zutreffenden Optionen
Bitte wählen Sie alle zutreffenden Antworten aus:

- ☐ **Shooter** (z.B. Counterstrike, Call of Duty, Fortnite)
- ☐ **Sandbox** (z.B. Minecraft, Terraria, Starbound)
- ☐ **Action adventure** (z.B. Zelda, The Witcher, Assassin's Creed)
- ☐ **Simulation** (z.B. Cities: Skylines, Flight simulator, farming simulator, SIMS)
- ☐ **MOBA** (Multiplayer online battle arena) (z.B. League of Legends, Dota 2, Vainglory)
- ☐ **Sport** (z.B. FIFA, MBA, Madden)
- ☐ **Racing** (z.B. Forza, iRacing, Trackmania)
- ☐ **Strategie** (z.B. StarCraft, Age of Empires, Civilization)
- ☐ **Puzzle** (z.B. Sudoku, candy crush)
- ☐ **Fighting** (z.B. Tekken, Mortal Combat, Street Fighter)
- ☐ **Action Platform** (z.B. Super Mario, Little Big Planet, Cuphead)
- ☐ **Online Brettspiele** (z.B. Schach, Monopoly, Uno)
- ☐ Sonstiges:

Auf welchem Gerät spielen Sie diese Spiele?

Bitte ordnen Sie die genannten Geräte nach dem folgenden Schema:

> am häufigsten verwendet
> ...
> ...
> am seltesten verwendet

*

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
((G01Q07.NAOK != "AO01"))

Alle Ihre Antworten müssen unterschiedlich sein, und müssen zugeordnet sein.
Bitte wählen Sie maximal 4 Antworten.
Bitte nummerieren Sie jede Box in der Reihenfolge Ihrer Präferenz, beginnen mit 1 bis 4

[ ] PC / Laptop
[ ] Konsole
[ ] Smartphone / Handy / Tablet
[ ] anderes Endgerägt (bitte in Textfeld angeben)

Geben Sie an, welches sonstige Gerät Sie verwenden (falls notwendig).

Beantworten Sie diese Frage nur, wenn folgende Bedingungen erfüllt sind:
((G01Q07.NAOK != "AO01"))

Bitte geben Sie Ihre Antwort hier ein:

Vielen Dank, dieser Teil der Umfrage ist hiermit abgeschlossen. Bitte geben Sie der Versuchsleiterin Bescheid, dass Sie fertig sind.

Bitte sehen Sie davon ab auf "weiter" zu klicken.

Szenario 1 (dir)

System-Usability-Scale: Bitte geben Sie Ihre Einschätzung zu den folgenden Fragen. *

Bitte wählen Sie die zutreffende Antwort für jeden Punkt aus:

	1 stimme überhaupt nicht zu	2 stimme nicht zu	3 neutral	4 stimme zu	5 stimme vollständig zu
Ich kann mir sehr gut vorstellen, das System regelmäßig zu nutzen.	○	○	○	○	○
Ich empfinde das System als unnötig komplex.	○	○	○	○	○
Ich empfinde das System als einfach zu nutzen.	○	○	○	○	○
Ich denke, dass ich technischen Support brauchen würde, um das System zu nutzen.	○	○	○	○	○
Ich finde, dass die verschiedenen Funktionen des Systems gut integriert sind.	○	○	○	○	○
Ich finde, dass es im System zu viele Inkonsistenzen gibt.	○	○	○	○	○
Ich kann mir vorstellen, dass die meisten Leute das System schnell zu beherrschen lernen.	○	○	○	○	○
Ich empfinde die Bedienung als sehr umständlich.	○	○	○	○	○
Ich habe mich bei der Nutzung des Systems sehr sicher gefühlt.	○	○	○	○	○
Ich musste eine Menge Dinge lernen, bevor ich mit dem System arbeiten konnte.	○	○	○	○	○

1 = stimme überhaupt nicht zu, 5 = stimme vollständig zu

Mentale Beanspruchung

Wie viel geistige Anstrengung war bei der Informationsaufnahme und -verarbeitung erforderlich (z.B. Denken, Entscheiden, Rechnen, Erinnern, Hinsehen, Suchen...)? War die Aufgabe leicht oder anspruchsvoll, einfach oder komplex, erforderte sie hohe Genauigkeit oder war sie fehlertolerant?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie anstrengend Sie die mentale Belastung empfunden haben.

Körperliche Beanspruchung

Wie viel körperliche Aktivität war erforderlich (z.B. Ziehen, Drücken, Drehen, Steuern, Aktivieren,...)? War die Aufgabe leicht oder schwer, einfach oder anstrengend, erholsam oder mühselig?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie anstrengend Sie die körperliche Belastung empfunden haben.

Zeitliche Beanspruchung

Wie viel Zeitdruck empfanden Sie hinsichtlich der Häufigkeit oder dem Takt, mit dem Aufgaben oder Aufgabenelemente auftraten? War die Abfolge langsam und geruhsam oder schnell und hektisch?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, wie sehr Sie sich unter Zeitdruck gefühlt haben.

Leistung

Wie erfolgreich haben Sie Ihrer Meinung nach die vom Versuchsleiter (oder Ihnen selbst) gesetzten Ziele erreicht? Wie zufrieden waren Sie mit Ihrer Leistung bei der Verfolgung dieser Ziele?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie gut Sie Ihre Leistung empfinden.

Anstrengung

Wie hart mussten sie arbeiten, um die Aufgabenerfüllung zu erreichen?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie sehr Sie sich bei der Aufgabe anstrengen mussten.

Frustration

Wie unsicher, entmutigt, irritiert, gestresst und verärgert (versus sicher, bestätigt, zufrieden, entspannt und zufrieden mit sich selbst) fühlten Sie sich während der Aufgabe?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie frustriert Sie sich durch die Aufgabe gefühlt haben.

Vielen Dank, dieser Teil der Umfrage ist hiermit abgeschlossen. Bitte geben Sie der Versuchsleiterin Bescheid, dass Sie fertig sind.

Bitte sehen Sie davon ab auf "weiter" zu klicken.

Szenario 2 (dis)

System-Usability-Scale: Bitte geben Sie Ihre Einschätzung zu den folgenden Fragen. *

Bitte wählen Sie die zutreffende Antwort für jeden Punkt aus:

	1 stimme überhaupt nicht zu	2 stimme nicht zu	3 neutral	4 stimme zu	5 stimme vollständig zu
Ich kann mir sehr gut vorstellen, das System regelmäßig zu nutzen.	○	○	○	○	○
Ich empfinde das System als unnötig komplex.	○	○	○	○	○
Ich empfinde das System als einfach zu nutzen.	○	○	○	○	○
Ich denke, dass ich technischen Support brauchen würde, um das System zu nutzen.	○	○	○	○	○
Ich finde, dass die verschiedenen Funktionen des Systems gut integriert sind.	○	○	○	○	○
Ich finde, dass es im System zu viele Inkonsistenzen gibt.	○	○	○	○	○
Ich kann mir vorstellen, dass die meisten Leute das System schnell zu beherrschen lernen.	○	○	○	○	○
Ich empfinde die Bedienung als sehr umständlich.	○	○	○	○	○
Ich habe mich bei der Nutzung des Systems sehr sicher gefühlt.	○	○	○	○	○
Ich musste eine Menge Dinge lernen, bevor ich mit dem System arbeiten konnte.	○	○	○	○	○

1 = stimme überhaupt nicht zu, 5 = stimme vollständig zu

Mentale Beanspruchung

Wie viel geistige Anstrengung war bei der Informationsaufnahme und -verarbeitung erforderlich (z.B. Denken, Entscheiden, Rechnen, Erinnern, Hinsehen, Suchen...)? War die Aufgabe leicht oder anspruchsvoll, einfach oder komplex, erforderte sie hohe Genauigkeit oder war sie fehlertolerant? *

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie anstrengend Sie die mentale Belastung empfunden haben.

Körperliche Beanspruchung

Wie viel körperliche Aktivität war erforderlich (z.B. Ziehen, Drücken, Drehen, Steuern, Aktivieren,...)? War die Aufgabe leicht oder schwer, einfach oder anstrengend, erholsam oder mühselig?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie anstrengend Sie die körperliche Belastung empfunden haben.

Zeitliche Beanspruchung

Wie viel Zeitdruck empfanden Sie hinsichtlich der Häufigkeit oder dem Takt, mit dem Aufgaben oder Aufgabenelemente auftraten? War die Abfolge langsam und geruhsam oder schnell und hektisch?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, wie sehr Sie sich unter Zeitdruck gefühlt haben.

Leistung

Wie erfolgreich haben Sie Ihrer Meinung nach die vom Versuchsleiter (oder Ihnen selbst) gesetzten Ziele erreicht? Wie zufrieden waren Sie mit Ihrer Leistung bei der Verfolgung dieser Ziele?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie gut Sie Ihre Leistung empfinden.

Anstrengung

Wie hart mussten sie arbeiten, um die Aufgabenerfüllung zu erreichen?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie sehr Sie sich bei der Aufgabe anstrengen mussten.

Frustration

Wie unsicher, entmutigt, irritiert, gestresst und verärgert (versus sicher, bestätigt, zufrieden, entspannt und zufrieden mit sich selbst) fühlten Sie sich während der Aufgabe?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie frustriert Sie sich durch die Aufgabe gefühlt haben.

Vielen Dank, dieser Teil der Umfrage ist hiermit abgeschlossen. Bitte geben Sie der Versuchsleiterin Bescheid, dass Sie fertig sind.

Bitte sehen Sie davon ab auf "weiter" zu klicken.

Szenario 3 (mo)

System-Usability-Scale: Bitte geben Sie Ihre Einschätzung zu den folgenden Fragen. *

Bitte wählen Sie die zutreffende Antwort für jeden Punkt aus:

	1 stimme überhaupt nicht zu	2 stimme nicht zu	3 neutral	4 stimme zu	5 stimme vollständig zu
Ich kann mir sehr gut vorstellen, das System regelmäßig zu nutzen.	◯	◯	◯	◯	◯
Ich empfinde das System als unnötig komplex.	◯	◯	◯	◯	◯
Ich empfinde das System als einfach zu nutzen.	◯	◯	◯	◯	◯
Ich denke, dass ich technischen Support brauchen würde, um das System zu nutzen.	◯	◯	◯	◯	◯
Ich finde, dass die verschiedenen Funktionen des Systems gut integriert sind.	◯	◯	◯	◯	◯
Ich finde, dass es im System zu viele Inkonsistenzen gibt.	◯	◯	◯	◯	◯
Ich kann mir vorstellen, dass die meisten Leute das System schnell zu beherrschen lernen.	◯	◯	◯	◯	◯
Ich empfinde die Bedienung als sehr umständlich.	◯	◯	◯	◯	◯
Ich habe mich bei der Nutzung des Systems sehr sicher gefühlt.	◯	◯	◯	◯	◯
Ich musste eine Menge Dinge lernen, bevor ich mit dem System arbeiten konnte.	◯	◯	◯	◯	◯

1 = stimme überhaupt nicht zu, 5 = stimme vollständig zu

Mentale Beanspruchung

Wie viel geistige Anstrengung war bei der Informationsaufnahme und -verarbeitung erforderlich (z.B. Denken, Entscheiden, Rechnen, Erinnern, Hinsehen, Suchen...)? War die Aufgabe leicht oder anspruchsvoll, einfach oder komplex, erforderte sie hohe Genauigkeit oder war sie fehlertolerant? *

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie anstrengend Sie die mentale Belastung empfunden haben.

Körperliche Beanspruchung

Wie viel körperliche Aktivität war erforderlich (z.B. Ziehen, Drücken, Drehen, Steuern, Aktivieren,...)? War die Aufgabe leicht oder schwer, einfach oder anstrengend, erholsam oder mühselig?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie anstrengend Sie die körperliche Belastung empfunden haben.

Zeitliche Beanspruchung

Wie viel Zeitdruck empfanden Sie hinsichtlich der Häufigkeit oder dem Takt, mit dem Aufgaben oder Aufgabenelemente auftraten? War die Abfolge langsam und geruhsam oder schnell und hektisch?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, wie sehr Sie sich unter Zeitdruck gefühlt haben.

Leistung

Wie erfolgreich haben Sie Ihrer Meinung nach die vom Versuchsleiter (oder Ihnen selbst) gesetzten Ziele erreicht? Wie zufrieden waren Sie mit Ihrer Leistung bei der Verfolgung dieser Ziele?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie gut Sie Ihre Leistung empfinden.

Anstrengung

Wie hart mussten sie arbeiten, um die Aufgabenerfüllung zu erreichen?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie sehr Sie sich bei der Aufgabe anstrengen mussten.

Frustration

Wie unsicher, entmutigt, irritiert, gestresst und verärgert (versus sicher, bestätigt, zufrieden, entspannt und zufrieden mit sich selbst) fühlten Sie sich während der Aufgabe?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie frustriert Sie sich durch die Aufgabe gefühlt haben.

Vielen Dank, dieser Teil der Umfrage ist hiermit abgeschlossen. Bitte geben Sie der Versuchsleiterin Bescheid, dass Sie fertig sind.

Bitte sehen Sie davon ab auf "weiter" zu klicken.

Szenario 4 (ste)

System-Usability-Scale: Bitte geben Sie Ihre Einschätzung zu den folgenden Fragen. *

Bitte wählen Sie die zutreffende Antwort für jeden Punkt aus:

	1 stimme überhaupt nicht zu	2 stimme nicht zu	3 neutral	4 stimme zu	5 stimme vollständig zu
Ich kann mir sehr gut vorstellen, das System regelmäßig zu nutzen.	○	○	○	○	○
Ich empfinde das System als unnötig komplex.	○	○	○	○	○
Ich empfinde das System als einfach zu nutzen.	○	○	○	○	○
Ich denke, dass ich technischen Support brauchen würde, um das System zu nutzen.	○	○	○	○	○
Ich finde, dass die verschiedenen Funktionen des Systems gut integriert sind.	○	○	○	○	○
Ich finde, dass es im System zu viele Inkonsistenzen gibt.	○	○	○	○	○
Ich kann mir vorstellen, dass die meisten Leute das System schnell zu beherrschen lernen.	○	○	○	○	○
Ich empfinde die Bedienung als sehr umständlich.	○	○	○	○	○
Ich habe mich bei der Nutzung des Systems sehr sicher gefühlt.	○	○	○	○	○
Ich musste eine Menge Dinge lernen, bevor ich mit dem System arbeiten konnte.	○	○	○	○	○

1 = stimme überhaupt nicht zu, 5 = stimme vollständig zu

Mentale Beanspruchung

Wie viel geistige Anstrengung war bei der Informationsaufnahme und -verarbeitung erforderlich (z.B. Denken, Entscheiden, Rechnen, Erinnern, Hinsehen, Suchen...)? War die Aufgabe leicht oder anspruchsvoll, einfach oder komplex, erforderte sie hohe Genauigkeit oder war sie fehlertolerant? *

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie anstrengend Sie die mentale Belastung empfunden haben.

Körperliche Beanspruchung

Wie viel körperliche Aktivität war erforderlich (z.B. Ziehen, Drücken, Drehen, Steuern, Aktivieren,...)? War die Aufgabe leicht oder schwer, einfach oder anstrengend, erholsam oder mühselig?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie anstrengend Sie die körperliche Belastung empfunden haben.

Zeitliche Beanspruchung

Wie viel Zeitdruck empfanden Sie hinsichtlich der Häufigkeit oder dem Takt, mit dem Aufgaben oder Aufgabenelemente auftraten? War die Abfolge langsam und geruhsam oder schnell und hektisch?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, wie sehr Sie sich unter Zeitdruck gefühlt haben.

Leistung

Wie erfolgreich haben Sie Ihrer Meinung nach die vom Versuchsleiter (oder Ihnen selbst) gesetzten Ziele erreicht? Wie zufrieden waren Sie mit Ihrer Leistung bei der Verfolgung dieser Ziele?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie gut Sie Ihre Leistung empfinden.

Anstrengung

Wie hart mussten sie arbeiten, um die Aufgabenerfüllung zu erreichen?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie sehr Sie sich bei der Aufgabe anstrengen mussten.

Frustration

Wie unsicher, entmutigt, irritiert, gestresst und verärgert (versus sicher, bestätigt, zufrieden, entspannt und zufrieden mit sich selbst) fühlten Sie sich während der Aufgabe?

*

Bitte geben Sie Ihre Antwort(en) hier ein:

|

Verwenden Sie den Schieber um anzuzeigen, als wie frustriert Sie sich durch die Aufgabe gefühlt haben.

Vielen Dank, dieser Teil der Umfrage ist hiermit abgeschlossen. Bitte geben Sie der Versuchsleiterin Bescheid, dass Sie fertig sind.

Bitte sehen Sie davon ab auf "weiter" zu klicken.

NASA TLX - Gewichtung

Bitte bewerten Sie Ihre Arbeitsbelastung anhand der folgenden Fragen.

Ihnen wird eine Reihe von Paaren von Themen vorgelegt (zum Beispiel: Anstrengung vs. Geistige Anforderung). Sie werden gebeten, zu wählen, welches der Themen für Ihre Erfahrung der Arbeitsbelastung wichtiger war.

Es gibt 6 Themen:

Geistige Anforderung: Wie viel geistige Anstrengung war bei der Informationsaufnahme und -verarbeitung erforderlich (z.B. Denken, Entscheiden, Rechnen, Erinnern, Hinsehen, Suchen...)? War die Aufgabe leicht oder anspruchsvoll, einfach oder komplex, erforderte sie hohe Genauigkeit oder war sie fehlertolerant?

Körperliche Anforderung: Wie viel körperliche Aktivität war erforderlich (z.B. Ziehen, rücken, Drehen, Steuern, Aktivieren, ...)? War die Aufgabe leicht oder schwer, einfach oder anstrengend, erholsam oder mühselig?

Zeitliche Anfoderung: Wie viel Zeitdruck empfanden Sie hinsichtlich der Häufigkeit oder dem Takt, mit dem Aufgaben oder Aufgabenelemente auftraten? War die Abfolge langsam und geruhsam oder schnell und hektisch?

Leistung: Wie erfolgreich haben Sie Ihrer Meinung nach die vom Versuchsleiter (oder Ihnen selbst) gesetzten Ziele erreicht? Wie zufrieden waren Sie mit Ihrer Leistung bei der Verfolgung dieser Ziele?

Anstrengung: Wie hart mussten sie arbeiten, um Ihren Grad an Aufgabenerfüllung zu erreichen?

Frustration: Wie unsicher, entmutigt, irritiert, gestresst und verärgert (versus sicher, bestätigt, zufrieden, entspannt und zufrieden mit sich selbst) fühlten Sie sich während der Aufgabe?

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Anstrengung
- ◯ Leistung

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Zeitliche Anforderung
- ◯ Frustration

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Zeitliche Anforderung
- ◯ Anstrengung

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Körperliche Anforderung
- ◯ Frustration

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Leistung
- ◯ Frustration

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Körperliche Anforderung
- ◯ Zeitliche Anforderung

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Körperliche Anforderung
- ◯ Leistung

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Zeitliche Anforderung
- ◯ Geistige Anforderung

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Frustration
- ◯ Anstrengung

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Leistung
- ◯ Geistige Anforderung

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Leistung
- ◯ Zeitliche Anforderung

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Geistige Anforderung
- ◯ Körperliche Anforderung

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Geistige Anforderung
- ◯ Anstrengung

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Anstrengung
- ◯ Körperliche Anforderung

Welches Thema war für Ihre Erfahrung der Arbeitsbelastung bei den Aufgaben wichtiger ? *

Bitte wählen Sie nur eine der folgenden Antworten aus:

- ◯ Frustration
- ◯ Geistige Anforderung

Vielen Dank, dieser Teil der Umfrage ist hiermit abgeschlossen. Bitte geben Sie der Versuchsleiterin Bescheid, dass Sie fertig sind.

Bitte sehen Sie davon ab auf "weiter" zu klicken.

Interviewfragen

Vielen Dank, dieser Teil der Umfrage ist hiermit abgeschlossen. Geben Sie der Versuchsleiterin Bescheid, dass Sie fertig sind.
Bitte sehen Sie davon ab, weiter zu klicken.

Ist Ihnen ein Unterschied zwischen den zwei Durchläufen mit der VR-Brille aufgefallen? Wenn ja, welcher?

Bitte geben Sie Ihre Antwort hier ein:

Insgesamt haben Sie die teleoperative Montageaufgabe mit vier verschiedenen Visualisierungsarten gelöst: direkte Sicht, Bildschirm, monoskopische (2D) Sicht mit VR-Brille, stereoskopische (3D) Sicht mit VR-Brille. Mit welcher Visualisierung ist ihnen die Aufgabe am schwersten/leichtesten gefallen? Sortieren sie von leicht nach schwer. *

Bitte nummerieren Sie jede Box in der Reihenfolge Ihrer Präferenz, beginnen mit 1 bis 4

[ ] direkte Sicht

[ ] Bildschirm

[ ] monoskopische Sicht mit VR-Brille

[ ] stereoskopische Sicht mit VR-Brille

Welche Verbesserungsschvorschläge haben Sie für die Visualisierung?

Bitte geben Sie Ihre Antwort hier ein:

Welche Verbesserungsvorschläge haben Sie für das Teleoperative System?

Bitte geben Sie Ihre Antwort hier ein:

10.01.2024 – 13:45
Senden Sie Ihre Umfage ein.
Vielen Dank für die Beantwortung des Fragebogens.

Appendix C : Performance - Task Completion Time

ID	Gamer	cube-l-dir	cylinder-l-dir	semicircle-l-dir	triangle-l-dir	cube-r-dir	cylinder-r-dir	semicircle-r-dir	triangle-r-dir
1380	non-gamer	41	15	155	56	36	29	65	417
2257	non-gamer	24	19	18	49	22	14	13	25
6728	gamer	23	19	16	63	51	13	17	22
8546	non-gamer	19	18	21	21	22	20	20	25
8757	gamer	24	19	41	25	27	18	19	20
6576	non-gamer	45	36	32	69	67	21	39	31
3758	non-gamer	48	17	19	66	27	14	20	21
2720	non-gamer	27	22	27	27	19	17	32	20
6927	non-gamer	25	16	16	19	24	14	126	13
5340	non-gamer	24	14	24	21	14	10	15	46
5341	gamer	16	25	13	21	14	14	12	13
7146	non-gamer	102	27	18	26	21	22	15	28
2729	gamer	39	30	20	23	29	28	28	20
6391	gamer	23	14	19	16	24	27	16	21
3342	gamer	29	16	28	24	19	17	20	24
1835	gamer	18	17	21	37	16	16	21	49
1303	non-gamer	25	27	75	43	22	18	19	29
9318	gamer	18	13	14	18	45	13	87	20
4014	gamer	37	30	28	141	18	15	23	23
7529	gamer	26	27	21	29	19	16	15	19
6847	non-gamer	29	23	16	52	27	24	22	29
4368	gamer	23	20	21	27	23	17	15	33
2600	non-gamer	20	13	15	23	20	14	22	29
4864	non-gamer	18	18	25	58	29	17	19	45
6031	non-gamer	45	24	36	120	91	19	44	81
7859	gamer	42	22	117	40	22	18	48	90
5384	gamer	26	21	36	25	17	11	14	18
3759	non-gamer	29	22	29	25	44	25	21	24
1005	non-gamer	24	27	50	143	42	23	21	24
4077	gamer	15	13	27	22	21	16	34	17
3599	gamer	21	17	23	28	20	15	17	25
6598	gamer	29	24	31	153	32	17	27	33
5795	gamer	28	15	16	26	25	18	16	173
1691	non-gamer	23	26	32	41	28	24	24	40
7922	non-gamer	28	24	20	38	29	22	37	33
1531	gamer	27	18	20	35	24	16	14	15
4999	non-gamer	19	11	16	35	22	34	82	23
2812	gamer	28	23	28	124	31	21	30	32
3318	gamer	71	26	46	191	21	22	20	34
4921	gamer	24	20	21	43	34	19	72	65
6060	gamer	24	25	55	43	57	26	31	33
6557	non-gamer	51	37	34	47	23	20	26	21
9295	non-gamer	14	15	23	18	17	12	11	33
6419	gamer	84	21	23	47	28	15	23	20
4438	gamer	42	38	46	44	72	42	31	38
2463	gamer	19	12	13	15	23	12	54	12
2190	gamer	31	32	29	25	28	19	32	19
8500	gamer	28	43	27	63	59	32	18	23
3077	gamer	49	40	49	43	73	43	26	34
3170	non-gamer	24	20	20	29	61	13	45	22
9202	gamer	81	27	40	21	68	17	25	30
7818	non-gamer	25	17	36	31	53	31	18	32
5569	non-gamer	20	16	15	18	19	12	16	16
8243	non-gamer	56	20	13	46	31	17	12	22
5212	non-gamer	33	16	35	41	35	44	104	142
5336	non-gamer	22	13	33	23	32	16	18	18
7926	gamer	27	20	26	36	29	18	22	41
4993	gamer	18	9	9	85	13	10	18	214
1254	gamer	19	24	20	32	26	17	23	20
2485	non-gamer	70	24	21	60	NA	18	21	27
3915	non-gamer	19	22	22	42	14	41	18	24
7398	non-gamer	17	19	57	17	22	28	17	21
8029	non-gamer	39	25	23	28	21	23	18	25

cube-l-disp	cylinder-l-disp	semicircle-l-disp	triangle-l-disp	cube-r-disp	cylinder-r-disp	semicircle-r-disp	triangle-r-disp
57	21	17	28	29	24	95	71
62	28	20	64	39	26	22	38
106	81	40	88	38	18	24	25
28	36	42	64	40	33	24	109
43	26	60	53	23	19	55	42
67	30	33	37	47	51	31	97
120	18	196	52	140	27	21	200
43	28	67	55	143	33	32	41
50	40	29	27	73	21	25	19
42	28	195	37	19	24	24	21
34	24	34	77	20	15	13	25
19	37	46	66	108	27	191	158
100	22	35	13	20	15	32	22
33	25	40	26	36	52	23	37
50	43	217	60	45	35	25	152
21	17	18	51	9	45	18	41
65	54	84	36	49	51	33	34
26	23	18	23	20	18	16	27
20	50	22	404	102	28	30	21
54	28	29	33	19	18	18	31
32	25	50	110	34	20	20	30
71	35	40	63	55	23	20	173
36	20	20	69	79	33	23	41
40	49	54	19	65	42	30	64
44	68	30	32	69	24	29	17
167	46	136	49	33	31	16	50
30	31	65	28	22	15	32	17
55	32	50	71	64	39	43	41
52	62	26	42	24	25	17	20
32	21	24	21	19	60	25	27
44	41	23	66	54	23	31	43
96	53	90	141	83	97	37	111
51	37	213	41	57	33	34	170
58	44	74	113	67	37	27	33
74	32	74	99	51	26	51	37
32	35	18	53	25	103	94	36
50	28	87	39	55	12	120	16
100	27	24	26	21	33	24	23
31	45	72	57	35	30	32	173
NA	55	65	43	NA	24	29	103
26	17	21	44	34	17	21	46
16	203	210	39	60	81	86	82
29	38	59	48	32	33	35	41
46	77	65	32	70	25	45	45
77	41	54	89	174	61	79	270
106	19	16	31	23	22	13	42
72	30	15	40	33	19	22	49
89	24	25	31	72	27	57	23
79	60	47	48	87	53	67	95
72	92	61	22	30	23	175	27
149	39	23	91	79	35	31	50
115	30	108	60	52	34	20	75
34	24	47	34	32	15	115	48
31	33	23	34	26	25	48	16
83	26	182	43	71	22	35	22
35	22	54	22	45	28	56	54
251	59	29	104	130	31	58	34
28	21	60	68	40	18	24	26
118	89	115	52	40	17	39	21
115	146	37	73	NA	527	113	23
70	32	76	33	23	21	22	116
60	34	28	42	41	31	45	33
138	36	35	78	44	39	32	38

cube-l-mono	cylinder-l-mono	semicircle-l-mono	triangle-l-mono	cube-r-mono	cylinder-r-mono	semicircle-r-mono
37	24	23	66	14	32	12
56	53	54	282	29	23	16
41	24	17	43	51	29	26
100	54	92	47	30	24	108
30	22	23	41	25	23	205
113	48	50	37	77	36	23
30	64	32	43	27	22	16
63	36	27	28	27	28	53
70	47	38	36	53	24	21
221	34	72	31	38	21	27
25	17	16	31	25	14	19
48	18	18	326	42	74	118
47	31	19	42	47	28	28
23	20	30	127	30	25	13
36	22	22	39	89	18	22
49	30	19	25	31	20	30
29	51	20	29	19	20	37
142	24	45	189	67	23	1
25	21	31	39	31	18	33
28	21	18	14	18	16	14
26	17	25	23	53	23	39
66	27	36	598	68	25	18
26	32	21	29	28	23	14
28	27	148	25	41	36	21
89	41	96	29	76	28	120
63	24	1	75	33	22	18
45	32	29	206	129	25	25
54	46	298	30	72	25	79
42	25	42	100	33	32	26
33	39	13	28	32	20	32
43	28	35	19	37	40	63
33	21	30	23	29	35	31
61	31	59	15	47	41	70
42	23	57	78	43	33	37
49	24	64	34	23	19	24
39	29	110	36	29	22	68
22	28	30	17	55	23	27
17	18	29	36	120	31	30
26	133	19	69	29	24	21
112	33	35	51	37	47	40
17	16	20	24	28	17	35
49	36	54	38	41	24	41
16	13	14	12	16	33	25
53	23	65	109	72	34	28
129	67	41	66	48	40	48
20	22	19	15	37	18	15
40	25	93	33	23	16	33
21	33	29	19	24	29	72
42	45	94	66	35	59	80
94	24	65	18	26	30	23
89	33	19	20	89	41	210
33	21	24	86	38	11	36
46	26	111	132	40	22	27
33	16	50	50	23	18	20
32	16	33	162	24	24	36
41	24	21	50	39	40	32
29	16	47	23	45	20	32
22	22	39	63	21	18	50
29	24	48	19	51	33	27
56	34	26	45	NA	29	52
40	26	99	27	47	120	35
35	22	37	71	5	28	15
72	30	64	33	126	59	26

triangle-r-mono	cube-l-stereo	cylinder-l-stereo	semicircle-l-stereo	triangle-l-stereo	cube-r-stereo	cylinder-r-stereo
46	56	90	34	91	24	18
34	41	25	20	24	29	15
58	40	24	25	32	33	56
115	29	23	23	55	22	68
42	25	18	33	32	20	23
33	31	21	18	86	26	35
34	27	17	17	14	41	16
78	29	24	26	27	55	21
38	32	15	16	23	35	17
159	18	16	18	28	17	13
15	58	18	27	102	17	15
27	58	40	38	268	172	78
30	17	13	11	14	19	12
48	27	21	42	22	31	13
24	37	38	21	26	56	21
56	19	16	14	14	13	17
30	30	24	19	20	18	17
161	27	15	15	18	20	21
13	17	22	39	51	16	24
20	18	14	18	28	19	12
20	30	22	26	24	16	27
31	42	21	21	108	56	33
123	43	22	17	27	24	19
82	23	21	32	42	44	60
129	85	16	51	192	124	24
20	29	17	17	25	30	21
31	33	18	28	45	29	16
31	37	34	55	57	44	29
69	34	26	17	73	20	30
29	97	61	26	52	16	12
18	73	23	22	22	28	45
28	33	25	22	42	24	19
49	55	29	19	30	25	22
221	51	19	18	41	27	18
36	59	26	32	45	102	21
50	20	15	17	22	32	23
41	23	22	14	71	20	11
41	24	16	16	95	18	18
20	72	25	21	95	15	15
45	39	22	24	164	50	25
76	20	12	19	33	18	18
37	90	27	44	25	38	19
20	22	16	12	216	22	14
58	34	17	19	40	22	19
69	15	41	35	29	40	22
31	17	20	14	17	29	12
22	22	15	14	68	14	52
21	27	42	38	33	24	20
133	44	28	39	47	24	41
76	56	27	20	66	30	41
34	31	18	27	31	31	82
23	34	22	22	16	29	18
68	20	17	16	28	26	15
23	28	16	15	25	38	17
19	25	24	91	20	23	13
37	26	19	27	58	23	38
47	58	26	31	40	26	23
26	34	15	14	15	16	15
32	26	34	21	19	22	20
36	33	19	18	20	NA	18
29	79	38	36	29	50	49
20	28	49	43	68	11	34
100	30	29	38	28	23	20

semicircle-r-stereo	triangle-r-stereo	left side-dir	right side-dir	left side-disp	right side-disp	left side-mono	right side-mono
14	25	267	547	123	219	150	104
21	91	110	74	174	125	445	102
22	44	121	103	315	105	125	164
46	32	79	87	170	206	293	277
57	32	109	84	182	139	116	295
137	46	182	158	167	226	248	169
19	14	150	82	386	388	169	99
19	17	103	88	193	249	154	186
23	29	76	177	146	138	191	136
45	22	83	85	302	88	358	245
23	18	75	53	169	73	89	73
24	53	173	86	168	484	410	261
219	39	112	105	170	89	139	133
17	21	72	88	124	148	200	116
22	29	97	80	370	257	119	153
20	16	93	102	107	113	123	137
19	18	170	88	239	167	129	106
18	44	63	165	90	81	400	252
27	31	236	79	496	181	116	95
13	17	103	69	144	86	81	68
27	25	120	102	217	104	91	135
26	19	91	88	209	271	727	142
109	40	71	85	145	176	108	188
142	18	119	110	162	201	228	180
230	60	225	235	174	139	255	353
82	25	221	178	398	130	163	93
15	18	108	60	154	86	312	210
36	33	105	114	208	187	428	207
17	23	244	110	182	86	209	160
21	72	77	88	98	131	113	113
21	18	89	77	174	151	125	158
19	23	237	109	380	328	107	123
26	24	85	232	342	294	166	207
35	44	122	116	289	164	200	334
21	141	110	121	279	165	171	102
21	17	100	69	138	258	214	169
21	20	81	161	204	203	97	146
29	41	203	114	177	101	100	222
23	39	334	97	205	270	247	94
15	34	108	190	163	156	231	169
17	70	147	147	108	118	77	156
21	24	169	90	468	258	177	143
93	18	70	73	174	141	55	94
20	22	175	86	220	185	250	192
26	31	170	183	261	584	303	205
15	17	59	101	172	100	76	101
16	15	117	98	157	123	191	94
35	55	161	132	169	179	102	146
22	144	181	176	234	302	247	307
31	27	93	141	247	255	201	155
59	29	169	140	302	195	161	374
40	17	109	134	313	181	164	108
40	39	69	63	139	210	315	157
26	21	135	82	121	115	149	84
29	29	125	325	334	150	243	103
28	35	91	84	133	183	136	148
22	35	109	110	443	253	115	144
14	17	121	255	177	108	146	115
19	33	95	86	374	117	120	143
24	15	175	66	371	663	161	117
81	33	105	97	211	182	192	231
27	33	110	88	164	150	165	68
29	29	115	87	287	153	199	311

left side-stereo	right side-stereo	complete-dir	complete-disp	complete-mono	complete-stereo
271	81	814	342	254	352
110	156	184	299	547	266
121	155	224	420	289	276
130	168	166	376	570	298
108	132	193	321	411	240
156	244	340	393	417	400
75	90	232	774	268	165
106	112	191	442	340	218
86	104	253	284	327	190
80	97	168	390	603	177
205	73	128	242	162	278
404	327	259	652	671	731
55	289	217	259	272	344
112	82	160	272	316	194
122	128	177	627	272	250
63	66	195	220	260	129
93	72	258	406	235	165
75	103	228	171	652	178
129	98	315	677	211	227
78	61	172	230	149	139
102	95	222	321	226	197
192	134	179	480	869	326
109	192	156	321	296	301
118	264	229	363	408	382
344	438	460	313	608	782
88	158	399	528	256	246
124	78	168	240	522	202
183	142	219	395	635	325
150	90	354	268	369	240
236	121	165	229	226	357
140	112	166	325	283	252
122	85	346	708	230	207
133	97	317	636	373	230
129	124	238	453	534	253
162	285	231	444	273	447
74	93	169	396	383	167
130	72	242	407	243	202
151	106	317	278	322	257
213	92	431	475	341	305
249	124	298	319	400	373
84	123	294	226	233	207
186	102	259	726	320	288
266	147	143	315	149	413
110	83	261	405	442	193
120	119	353	845	508	239
68	73	160	272	177	141
119	97	215	280	285	216
140	134	293	348	248	274
158	231	357	536	554	389
169	129	234	502	356	298
107	201	309	497	535	308
94	104	243	494	272	198
81	120	132	349	472	201
84	102	217	236	233	186
160	94	450	484	346	254
130	124	175	316	284	254
155	106	219	696	259	261
78	62	376	285	261	140
100	94	181	491	263	194
90	57	241	1034	278	147
182	213	202	393	423	395
188	105	198	314	233	293
125	101	202	440	510	226

Appendix D : Performance - Grab Attempts

ID	Gamer	cube-l-dir	cylinder-l-dir	semicircle-l-dir	triangle-l-dir	cube-r-dir	cylinder-r-dir	semicircle-r-dir	triangle-r-dir
1380	non-gamer	2	1	2	2	1	2	1	8
2257	non-gamer	1	1	1	1	1	1	1	1
6728	gamer	1	1	1	4	1	1	1	1
8546	non-gamer	1	1	1	1	1	1	1	1
8757	gamer	1	1	1	1	1	1	1	1
6576	non-gamer	1	1	1	2	1	1	1	1
3758	non-gamer	1	1	1	4	1	1	1	2
2720	non-gamer	1	1	1	1	1	1	2	1
6927	non-gamer	1	1	1	1	3	1	1	1
5340	non-gamer	1	1	1	1	1	1	1	3
5341	gamer	1	3	1	1	1	1	1	1
7146	non-gamer	2	1	1	1	1	1	1	2
2729	gamer	2	2	1	1	1	3	1	1
6391	gamer	1	1	1	1	1	3	1	1
3342	gamer	1	1	1	1	1	1	1	1
1835	gamer	1	1	1	2	1	1	1	4
1303	non-gamer	1	1	1	2	1	1	1	1
9318	gamer	1	1	1	1	1	1	3	1
4014	gamer	1	3	1	14	1	1	2	1
7529	gamer	1	1	1	1	1	1	1	1
6847	non-gamer	1	1	1	2	1	2	1	1
4368	gamer	1	1	1	1	1	1	1	2
2600	non-gamer	1	1	1	1	1	1	1	1
4864	non-gamer	1	1	1	3	1	1	1	3
6031	non-gamer	1	1	2	5	1	1	1	1
7859	gamer	1	1	2	1	1	1	2	1
5384	gamer	1	1	1	2	1	1	1	1
3759	non-gamer	1	1	1	1	1	1	1	1
1005	non-gamer	1	1	1	1	1	2	2	1
4077	gamer	1	1	2	1	1	1	3	1
3599	gamer	1	1	1	1	1	1	1	1
6598	gamer	1	1	2	8	1	1	1	1
5795	gamer	1	1	1	1	1	1	1	3
1691	non-gamer	1	1	1	1	1	1	1	2
7922	non-gamer	1	1	1	1	1	1	1	1
1531	gamer	1	1	1	3	1	1	1	1
4999	non-gamer	1	1	1	4	1	1	5	2
2812	gamer	1	1	1	3	1	1	1	1
3318	gamer	1	1	1	6	1	1	1	1
4921	gamer	1	1	1	2	1	1	1	3
6060	gamer	1	2	1	2	1	2	2	1
6557	non-gamer	1	1	1	2	1	1	1	1
9295	non-gamer	1	1	1	1	1	1	1	4
6419	gamer	1	1	1	2	1	1	1	1
4438	gamer	1	1	1	1	1	1	1	1
2463	gamer	1	1	1	1	1	1	1	1
2190	gamer	1	1	1	1	1	1	2	1
8500	gamer	1	2	1	1	1	1	1	1
3077	gamer	1	1	1	2	1	1	1	1
3170	non-gamer	1	1	1	1	1	1	2	2
9202	gamer	1	2	1	1	0	1	1	2
7818	non-gamer	1	1	2	1	4	1	1	2
5569	non-gamer	1	1	1	1	1	1	1	1
8243	non-gamer	1	1	1	1	2	1	1	2
5212	non-gamer	1	1	1	2	3	1	1	3
5336	non-gamer	1	1	1	1	2	1	1	1
7926	gamer	1	1	1	1	1	1	1	2
4993	gamer	1	1	1	5	1	1	1	1
1254	gamer	1	1	1	2	1	1	1	1
2485	non-gamer	1	1	1	2	0	1	1	2
3915	non-gamer	2	1	1	4	0	2	1	1
7398	non-gamer	1	1	1	1	1	1	1	1
8029	non-gamer	1	1	1	1	1	1	1	1

cube-l-disp	cylinder-l-disp	semicircle-l-disp	triangle-l-disp	cube-r-disp	cylinder-r-disp	semicircle-r-disp	triangle-r-disp
2	2	1	2	2	2	2	1
1	1	1	1	3	1	1	1
5	4	2	1	1	1	1	1
1	2	2	3	1	2	1	5
1	1	2	2	1	1	4	1
2	2	1	2	2	3	2	3
1	1	3	3	1	2	1	9
1	1	3	2	1	1	1	3
1	2	2	1	3	1	1	1
1	2	3	2	1	2	1	1
1	2	2	5	1	1	1	2
1	3	4	4	1	1	3	8
1	1	2	1	1	1	3	1
1	1	2	1	1	1	1	1
1	2	5	2	1	1	1	4
1	1	1	2	1	1	1	3
1	2	2	1	2	2	1	2
1	1	1	1	1	1	1	1
1	5	1	5	1	1	1	1
1	1	1	1	1	1	1	2
2	1	1	2	1	1	1	1
2	1	2	2	2	1	1	5
2	1	1	2	1	2	1	2
2	3	3	1	1	2	2	4
2	4	1	2	3	2	3	1
7	1	2	2	2	2	1	4
1	2	2	1	1	1	1	1
1	1	2	1	1	1	1	1
1	3	1	2	1	2	1	1
2	1	3	1	1	1	1	1
2	2	1	2	1	1	1	2
1	1	4	6	1	2	2	5
3	3	10	1	1	3	2	4
1	1	2	5	1	1	1	1
2	1	2	4	1	2	1	2
1	2	1	2	1	4	4	2
1	2	3	3	1	1	6	1
1	2	1	1	1	2	1	1
1	2	1	1	1	2	1	7
0	2	4	2	0	1	1	1
1	1	1	3	1	1	1	2
2	6	8	1	0	2	1	4
2	3	3	3	1	3	2	3
2	1	4	1	1	1	2	2
2	1	2	2	2	2	3	1
1	1	1	2	1	2	1	4
1	3	1	1	1	2	1	4
1	1	1	2	1	1	2	1
1	2	1	1	2	3	3	2
2	2	3	1	1	2	9	1
3	3	1	7	4	2	2	4
1	1	5	3	1	2	1	4
2	1	2	1	2	1	2	1
1	1	1	2	0	1	1	1
3	2	4	2	1	1	1	1
1	1	3	1	2	1	1	3
3	1	1	2	1	1	4	2
1	2	2	4	1	2	1	2
3	1	3	3	1	1	1	1
1	1	1	4	0	1	4	1
2	1	2	2	1	2	1	8
3	2	1	2	1	2	1	2
1	1	1	2	1	1	1	2

cube-l-mono	cylinder-l-mono	semicircle-l-mono	triangle-l-mono	cube-r-mono	cylinder-r-mono	semicircle-r-mono
4	2	1	4	1	3	1
3	3	1	5	1	1	1
1	1	1	2	1	2	1
2	3	2	1	1	1	2
1	1	1	2	1	1	3
2	2	2	1	1	1	1
1	3	1	1	1	1	1
2	1	1	1	1	2	2
1	3	1	2	4	1	1
2	2	3	1	1	1	1
2	1	1	2	2	1	1
2	1	1	15	2	4	4
1	1	1	1	1	2	1
1	1	1	4	1	2	1
1	1	1	2	1	1	1
4	2	1	1	1	1	1
1	3	1	1	1	2	2
1	1	1	2	1	2	1
1	1	1	3	2	1	3
2	2	1	1	1	1	1
1	1	2	1	2	2	1
1	1	2	9	1	1	1
1	3	1	2	1	2	1
1	2	3	1	1	3	1
1	1	6	1	2	1	9
3	1	1	2	2	1	1
1	1	1	11	3	1	1
1	2	2	1	2	1	3
2	2	3	2	1	2	1
3	1	1	1	3	2	2
2	2	2	1	1	1	1
1	1	1	1	2	4	2
3	2	4	1	1	3	4
1	1	2	2	1	1	1
1	1	4	1	1	1	1
1	3	2	2	1	2	5
1	3	2	1	3	2	3
1	1	1	1	1	2	1
1	4	1	3	1	2	1
1	1	1	1	1	2	2
1	1	1	1	1	1	1
3	2	3	1	3	1	2
1	1	1	1	1	3	1
1	1	1	2	4	2	1
1	1	1	1	1	1	1
1	2	1	1	2	1	1
2	2	3	2	1	1	1
1	2	1	1	1	2	2
2	1	2	3	1	3	4
3	1	3	1	2	1	1
3	3	2	1	4	5	2
1	1	1	4	0	1	1
2	2	4	5	1	1	1
1	1	2	5	1	2	1
1	1	2	8	2	2	3
1	1	1	3	2	2	1
1	1	3	1	1	1	1
1	2	2	1	1	1	3
1	2	4	1	1	2	2
2	2	1	2	0	1	2
1	1	3	1	3	1	2
1	1	3	3	1	1	1
3	1	2	2	2	2	1

triangle-r-mono	cube-l-stereo	cylinder-l-stereo	semicircle-l-stereo	triangle-l-stereo	cube-r-stereo	cylinder-r-stereo
1	1	2	1	2	1	1
1	1	1	1	1	1	1
2	1	1	1	1	1	1
5	1	1	1	2	1	2
1	1	1	1	1	1	1
1	1	1	1	2	1	1
2	1	1	1	1	1	1
3	1	1	1	1	4	1
3	1	1	1	1	1	1
6	1	1	1	1	1	1
1	1	1	1	2	1	1
2	2	1	2	5	1	3
1	1	1	1	1	1	1
3	1	2	3	2	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
2	1	1	1	1	1	1
2	1	1	1	1	1	2
1	1	1	3	1	1	2
2	1	1	1	1	1	1
1	1	1	1	1	1	1
2	1	1	1	3	1	1
3	1	1	1	1	2	1
4	1	1	1	2	1	2
5	1	1	3	6	2	1
1	1	1	1	1	1	1
2	1	1	1	2	1	1
1	1	1	1	2	1	1
3	1	1	1	1	1	3
2	2	2	2	8	1	1
1	2	1	1	1	1	4
1	1	1	1	2	1	1
3	1	2	1	2	1	1
2	1	1	1	2	1	1
1	1	1	1	2	1	1
2	1	1	1	1	1	2
4	1	1	1	1	1	1
3	1	1	1	4	1	1
1	1	1	1	3	1	1
2	1	1	1	1	1	1
3	1	1	1	2	1	1
2	1	1	1	1	1	1
2	1	1	1	5	1	1
2	1	1	1	2	1	1
2	1	1	1	1	1	1
3	1	2	1	1	1	1
1	1	1	1	1	1	2
1	1	2	2	1	1	1
6	1	1	1	1	1	2
5	2	1	1	1	1	1
2	1	1	1	2	1	1
1	1	1	1	1	2	1
5	1	1	1	1	1	1
2	2	1	1	1	1	1
1	2	1	1	1	2	1
2	1	1	1	3	1	2
3	1	1	1	1	1	1
2	1	1	1	1	1	1
2	1	2	1	1	1	1
1	2	1	1	1	0	1
2	1	2	1	1	1	2
1	1	3	3	3	1	1
5	1	1	2	1	1	1

semicircle-r-stereo	triangle-r-stereo	left side-dir	right side-dir	left side-disp	right side-disp	left side-mono	right side-mono
1	2	7	12	7	7	11	6
1	2	4	4	4	6	12	4
1	2	7	4	12	4	5	6
2	1	4	4	8	9	8	9
1	1	4	4	6	7	5	6
2	2	5	4	7	10	7	4
1	1	7	5	8	13	6	5
1	1	4	5	7	6	5	8
1	2	4	6	6	6	7	9
1	1	4	6	8	5	8	9
1	1	6	4	10	5	6	5
1	2	5	5	12	13	19	12
2	1	6	6	5	6	4	5
1	1	4	6	5	4	7	7
1	1	4	4	10	7	5	4
1	1	5	7	5	6	8	4
1	1	5	4	6	7	6	7
1	2	4	6	4	4	5	6
1	1	19	5	12	4	6	7
1	1	4	4	4	5	6	5
1	1	5	5	6	4	5	6
1	1	4	5	7	9	13	5
1	2	4	4	6	6	7	7
3	1	6	6	9	9	7	9
3	3	9	4	9	9	9	17
1	1	5	5	12	9	7	5
1	1	5	4	6	4	14	7
1	2	4	4	5	4	6	7
1	2	4	6	7	5	9	7
1	5	5	6	7	4	6	9
1	1	4	4	7	5	7	4
1	1	12	4	12	10	4	9
1	1	4	6	17	10	10	11
1	1	4	5	9	4	6	5
1	1	4	4	9	6	7	4
1	1	6	4	6	11	8	10
1	2	7	9	9	9	7	12
2	2	6	4	5	5	4	7
2	2	9	4	5	11	9	5
1	1	5	6	8	3	4	7
1	5	6	6	6	5	4	6
1	1	5	4	17	7	9	8
5	1	4	7	11	9	4	7
1	1	5	4	8	6	5	9
1	1	4	4	7	8	4	5
1	1	4	4	5	8	5	7
1	1	4	5	6	8	9	4
1	5	5	4	5	5	5	6
1	6	5	4	5	10	8	14
2	2	4	6	8	13	8	9
1	3	5	4	14	12	9	13
2	1	5	8	10	8	7	3
1	2	4	4	6	6	13	8
1	1	4	6	5	3	9	6
2	2	5	8	11	4	12	8
1	2	4	5	6	7	6	7
1	1	4	5	7	8	6	6
1	1	8	4	9	6	6	7
1	2	5	4	10	4	8	7
1	1	5	4	7	6	7	4
2	1	8	4	7	12	6	8
1	3	4	4	8	6	8	4
1	1	4	4	5	5	8	10

left side-stereo	right side-stereo	complete-dir	complete-disp	complete-mono	complete-stereo
6	5	19	14	17	11
4	5	8	10	16	9
4	5	11	16	11	9
5	6	8	17	17	11
4	4	8	13	11	8
5	6	9	17	11	11
4	4	12	21	11	8
4	7	9	13	13	11
4	5	10	12	16	9
4	4	10	13	17	8
5	4	10	15	11	9
10	7	10	25	31	17
4	5	12	11	9	9
8	4	10	9	14	12
4	4	8	17	9	8
4	4	12	11	12	8
4	4	9	13	13	8
4	6	10	8	11	10
6	5	24	16	13	11
4	4	8	9	11	8
4	4	10	10	11	8
6	4	9	16	18	10
4	6	8	12	14	10
5	7	12	18	16	12
11	9	13	18	26	20
4	4	10	21	12	8
5	4	9	10	21	9
5	5	8	9	13	10
4	7	10	12	16	11
14	8	11	11	15	22
5	7	8	12	11	12
5	4	16	22	13	9
6	4	10	27	21	10
5	4	9	13	11	9
5	4	8	15	11	9
4	5	10	17	18	9
4	5	16	18	19	9
7	6	10	10	11	13
6	6	13	16	14	12
4	4	11	11	11	8
5	8	12	11	10	13
4	4	9	24	17	8
8	8	11	20	11	16
5	4	9	14	14	9
4	4	8	15	9	8
5	4	8	13	12	9
4	5	9	14	13	9
6	8	9	10	11	14
4	10	9	15	22	14
5	6	10	21	17	11
5	6	9	26	22	11
4	6	13	18	10	10
4	5	8	12	21	9
5	4	10	8	15	9
5	7	13	15	20	12
6	6	9	13	13	12
4	4	9	15	12	8
4	4	12	15	13	8
5	5	9	14	15	10
5	3	9	13	11	8
5	6	12	19	14	11
10	6	8	14	12	16
5	4	8	10	18	9

Appendix E : Performance - Corrections

ID	Gamer	cube-l-dir	cylinder-l-dir	semicircle-l-dir	triangle-l-dir	cube-r-dir	cylinder-r-dir	semicircle-r-dir	triangle-r-dir
1380	non-gamer	0	0	1	1	1	0	1	1
2257	non-gamer	0	0	0	0	0	0	0	0
6728	gamer	0	0	0	0	0	0	0	0
8546	non-gamer	0	0	0	0	0	0	0	0
8757	gamer	0	0	1	0	0	0	0	0
6576	non-gamer	0	0	0	0	0	0	0	0
3758	non-gamer	1	0	0	0	1	0	1	0
2720	non-gamer	0	0	0	0	0	0	0	0
6927	non-gamer	0	0	0	0	0	0	1	0
5340	non-gamer	0	0	0	0	0	0	0	0
5341	gamer	0	0	0	0	0	0	0	0
7146	non-gamer	1	0	0	1	0	0	0	0
2729	gamer	0	0	0	0	0	0	1	0
6391	gamer	0	0	0	0	0	0	0	0
3342	gamer	0	0	0	0	0	0	0	0
1835	gamer	0	0	0	0	0	0	1	0
1303	non-gamer	0	0	1	0	0	0	0	0
9318	gamer	0	0	0	0	1	0	1	0
4014	gamer	1	0	1	0	0	0	0	0
7529	gamer	0	0	0	0	0	0	0	0
6847	non-gamer	0	0	0	1	0	0	0	0
4368	gamer	0	0	0	0	0	0	0	0
2600	non-gamer	0	0	0	0	0	0	0	0
4864	non-gamer	0	0	0	1	0	0	0	0
6031	non-gamer	0	0	0	1	1	0	1	0
7859	gamer	1	0	1	0	0	0	0	1
5384	gamer	0	0	0	0	0	0	0	0
3759	non-gamer	0	0	0	0	0	0	0	0
1005	non-gamer	0	1	1	1	1	0	0	0
4077	gamer	0	0	0	0	0	0	0	0
3599	gamer	0	0	0	0	0	0	0	0
6598	gamer	0	0	0	1	0	0	0	0
5795	gamer	0	0	0	1	0	0	0	1
1691	non-gamer	0	1	0	1	0	0	0	0
7922	non-gamer	0	0	0	0	0	0	0	0
1531	gamer	0	0	0	0	0	0	0	0
4999	non-gamer	0	0	0	0	0	1	1	0
2812	gamer	0	0	0	1	0	0	0	0
3318	gamer	0	0	1	1	0	0	0	0
4921	gamer	0	0	0	0	0	0	0	0
6060	gamer	0	0	1	0	1	0	0	0
6557	non-gamer	0	0	0	0	0	0	0	0
9295	non-gamer	0	0	1	0	0	0	0	0
6419	gamer	1	0	0	0	0	0	0	0
4438	gamer	0	0	0	0	0	0	0	0
2463	gamer	0	0	0	0	0	0	1	0
2190	gamer	0	0	0	0	0	0	0	0
8500	gamer	0	1	1	1	1	1	0	0
3077	gamer	1	1	0	0	0	0	0	0
3170	non-gamer	0	0	0	0	1	0	1	0
9202	gamer	1	0	1	0	0	0	0	0
7818	non-gamer	0	0	0	0	0	1	0	0
5569	non-gamer	0	0	0	0	0	0	0	0
8243	non-gamer	1	0	0	1	0	0	0	0
5212	non-gamer	0	0	0	0	0	1	1	1
5336	non-gamer	0	0	1	0	0	0	0	0
7926	gamer	0	0	0	0	0	0	0	0
4993	gamer	0	0	0	1	0	0	0	1
1254	gamer	0	0	0	0	0	0	0	0
2485	non-gamer	1	0	0	1	0	0	0	0
3915	non-gamer	0	0	0	0	0	0	0	0
7398	non-gamer	0	0	1	0	0	0	0	0
8029	non-gamer	0	0	0	0	0	0	0	0

cube-l-disp	cylinder-l-disp	semicircle-l-disp	triangle-l-disp	cube-r-disp	cylinder-r-disp	semicircle-r-disp	triangle-r-disp
1	0	1	0	0	0	1	1
0	0	0	1	0	0	0	0
1	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0
1	0	0	0	0	1	0	0
1	1	1	1	1	0	1	1
0	0	0	0	1	0	1	0
0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	0
0	0	0	0	0	0	0	0
0	0	0	0	1	1	1	1
1	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0
0	0	1	1	0	0	0	1
0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0
0	0	0	1	1	1	0	0
1	0	0	0	0	0	0	0
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1	0	0	0	1	1	0	1
1	0	0	1	1	0	1	1
0	0	0	0	0	0	0	0
1	0	1	0	0	0	1	0
0	0	0	1	0	1	1	0
1	0	1	0	1	0	1	0
1	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	1
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0	0	1	0	0	0	0	0
0	1	1	0	1	0	1	0
0	0	0	0	1	0	0	1
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1	0	0	1	0	0	0	0
1	0	0	0	1	1	1	0
1	1	1	0	1	1	0	1
1	1	0	0	0	0	1	0
1	0	0	0	0	0	0	0
1	0	0	1	1	0	0	0
0	0	1	0	0	0	1	1
0	0	0	0	0	0	1	0
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0	0	0	0	1	0	0	0
1	0	0	1	1	0	0	0
0	0	1	0	1	0	0	0
1	0	1	0	0	0	0	0
1	1	1	0	0	0	1	0
0	0	1	0	0	0	1	0
0	0	0	0	0	0	0	0
1	0	0	0	0	1	0	0

cube-l-mono	cylinder-l-mono	semicircle-l-mono	triangle-l-mono	cube-r-mono	cylinder-r-mono	semicircle-r-mono
0	0	0	1	0	1	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
1	0	1	0	0	0	1
0	0	0	0	0	0	1
1	1	0	0	1	0	0
0	0	0	1	0	1	1
0	0	0	0	0	0	0
1	0	0	0	0	0	0
1	0	1	1	1	0	1
0	0	0	0	0	0	0
1	0	0	1	1	1	1
0	1	0	1	1	0	0
0	0	0	1	0	0	0
0	0	0	0	1	0	0
0	1	0	0	1	0	1
0	0	0	0	0	0	1
1	0	0	1	1	0	0
0	0	1	0	1	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	1
0	0	1	1	0	0	0
0	0	0	0	0	0	0
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0	0	1	1	0	0	0
0	1	0	0	0	0	0
0	0	0	0	0	1	1
0	0	0	0	0	0	0
0	1	1	0	1	1	1
0	0	0	1	0	0	0
0	0	1	0	0	0	1
0	0	1	0	0	0	0
0	0	0	0	1	0	0
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0	0	1	0	0	0	0
0	0	1	0	0	0	1
0	1	1	0	1	1	1
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0	0	0	0	0	0	1
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0	0	0	1	0	0	0
0	0	0	0	1	1	1
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0	0	0	1	1	0	1
0	0	0	0	1	0	0
1	0	1	1	0	1	1
0	0	1	0	0	1	0
0	0	0	1	0	0	0
0	0	0	0	1	0	0

triangle-r-mono	cube-l-stereo	cylinder-l-stereo	semicircle-l-stereo	triangle-l-stereo	cube-r-stereo	cylinder-r-stereo
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0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	0	0	0	1	0	0
1	0	0	0	0	1	1
0	0	0	0	0	0	0
0	0	0	0	0	1	0
1	0	0	0	1	0	0
0	1	0	0	0	0	0
1	1	1	1	1	1	1
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	0	0	0	0	1	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
1	0	0	0	0	0	0
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0	0	0	0	0	0	0
0	0	0	0	0	0	1
0	0	0	0	1	0	1
1	1	0	0	0	0	0
1	0	0	0	0	1	1
1	1	0	0	1	1	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
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0	0	0	0	0	0	0
1	1	0	0	0	0	1
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0	0	1	1	0	0	0
0	0	0	1	0	0	1
0	0	0	0	1	0	1
0	0	0	1	1	1	0
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0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	0	0	0	0	0	0
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0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	1	0	0	0	1	0
0	0	0	0	1	0	0
0	0	0	0	0	0	0

semicircle-r-stereo	triangle-r-stereo
1	0
0	0
0	0
0	0
0	0
1	0
1	0
0	0
0	0
1	0
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0	0
0	0
0	0
0	0
1	0
0	0
0	0

Appendix F : Workload - NASA Task Load Index

		tally weights						dir
ID	Gamer	mental.tally	physical.tally	temporal.tally	performance.tally	effort.tally	frustration.tally	mental.dir
1380	non-gamer	3	1	0	5	2	4	210
2257	non-gamer	4	0	3	2	1	5	120
6728	gamer	3	1	0	5	2	4	12
8546	non-gamer	5	1	1	4	1	3	30
8757	gamer	4	2	0	1	3	5	168
6576	non-gamer	5	0	2	3	3	2	100
3758	non-gamer	4	0	2	5	1	3	172
2720	non-gamer	3	1	0	5	2	4	21
6927	non-gamer	4	5	2	1	1	2	48
5340	non-gamer	2	2	2	2	3	4	20
5341	gamer	4	2	1	4	3	1	40
7146	non-gamer	2	0	3	4	3	3	80
2729	gamer	4	1	3	5	2	0	80
6391	gamer	4	0	1	5	3	2	76
3342	gamer	2	0	5	4	1	3	68
1835	gamer	2	5	0	2	4	2	8
1303	non-gamer	4	0	3	2	5	1	200
9318	gamer	5	3	1	2	3	1	130
4014	gamer	0	4	3	1	5	2	0
7529	gamer	2	4	2	0	3	4	140
6847	non-gamer	5	2	1	0	3	4	310
4368	gamer	3	1	2	2	2	5	90
2600	non-gamer	2	0	3	4	1	5	10
4864	non-gamer	4	0	1	3	3	4	120
6031	non-gamer	3	0	3	5	1	3	120
7859	gamer	3	0	3	2	2	5	90
5384	gamer	4	0	2	3	1	5	40
3759	non-gamer	4	2	3	1	0	5	0
1005	non-gamer	5	0	1	3	4	2	50
4077	gamer	4	0	5	3	1	2	80
3599	gamer	2	3	0	5	2	3	0
6598	gamer	2	3	0	1	4	5	40
5795	gamer	3	0	3	5	1	3	90
1691	non-gamer	5	2	0	1	3	4	95
7922	non-gamer	3	1	4	5	2	0	75
1531	gamer	3	1	0	3	3	5	30
4999	non-gamer	1	0	3	3	3	5	39
2812	gamer	0	1	5	2	3	4	0
3318	gamer	2	1	1	4	2	5	40
4921	gamer	2	5	3	3	2	0	90
6060	gamer	2	0	3	5	1	4	2
6557	non-gamer	2	3	0	1	5	4	8
9295	non-gamer	5	1	4	2	2	1	70
6419	gamer	3	5	0	2	1	4	195
4438	gamer	3	1	3	5	1	2	75
2463	gamer	0	3	4	5	2	1	0
2190	gamer	4	0	2	5	1	3	144
8500	gamer	4	0	1	4	2	4	240
3077	gamer	4	1	1	2	2	5	128
3170	non-gamer	3	1	2	4	3	2	18
9202	gamer	5	4	2	1	3	0	300
7818	non-gamer	5	1	2	4	3	0	325
5569	non-gamer	3	0	2	5	4	1	60
8243	non-gamer	5	3	0	1	2	4	350
5212	non-gamer	2	2	0	3	3	5	44
5336	non-gamer	1	5	2	3	4	0	16
7926	gamer	3	0	2	4	1	5	9
4993	gamer	3	0	4	5	1	2	108
1254	gamer	2	1	0	5	4	3	60
2485	non-gamer	3	4	0	1	3	4	156
3915	non-gamer	5	3	0	2	4	1	310
7398	non-gamer	5	0	2	4	2	2	150
8029	non-gamer	4	1	2	0	3	5	80

					disp		
physical.dir	**temporal.dir**	**performance.dir**	**effort.dir**	**frustration.dir**	**mental.disp**	**physical.disp**	**temporal.disp**
65	0	300	140	320	30	30	0
0	150	100	28	200	200	0	150
14	0	15	14	16	45	15	0
10	0	8	3	0	125	30	10
128	0	14	108	40	264	118	0
0	128	0	63	16	105	0	60
0	52	20	31	30	288	0	142
18	0	25	20	24	165	55	0
40	18	27	10	0	164	115	58
40	10	4	30	24	80	80	40
66	18	360	63	14	236	62	50
0	135	280	150	117	96	0	183
20	210	150	100	0	120	40	60
0	25	90	51	36	104	0	50
0	75	360	15	15	148	0	330
345	0	82	236	26	90	350	0
0	120	100	125	20	280	0	180
75	13	16	30	10	50	12	5
120	90	31	300	80	0	124	219
140	0	0	39	0	150	48	0
30	43	0	90	0	335	22	21
20	0	20	40	0	240	60	180
0	105	40	14	30	78	0	27
0	35	270	105	140	140	0	45
0	195	325	25	75	90	0	84
0	150	120	130	275	225	0	180
0	0	30	3	0	12	0	16
10	15	9	0	0	24	6	6
0	3	24	40	20	100	0	6
0	95	240	25	20	88	0	100
6	0	0	0	0	30	30	0
150	0	40	120	125	120	180	0
0	60	125	25	60	180	0	180
60	0	7	48	60	200	44	0
20	80	425	40	0	90	25	60
21	0	6	39	30	39	21	0
0	156	0	117	190	83	0	300
78	440	200	201	260	0	70	225
30	70	100	20	25	120	20	20
350	120	225	80	0	130	375	180
0	3	45	4	20	10	0	30
15	0	0	25	0	40	30	0
28	0	138	44	11	350	30	160
250	0	40	60	100	210	300	0
5	45	50	10	10	75	5	15
114	156	425	80	8	0	210	284
0	58	305	20	90	316	0	140
0	50	280	120	260	280	0	60
53	56	80	78	300	320	43	6
7	16	80	30	22	15	15	14
280	110	10	165	0	350	240	170
20	0	52	66	0	300	22	16
0	50	0	20	0	120	0	40
90	0	70	80	240	375	90	0
48	0	63	96	75	132	46	0
175	80	15	284	0	16	310	126
0	4	0	3	0	270	0	100
0	296	295	27	116	120	0	140
5	0	150	120	150	120	10	0
256	0	30	177	140	171	248	0
138	0	58	232	19	430	219	0
0	38	112	96	42	315	0	52
25	20	0	45	30	100	15	40

			mono				
performance.disp	**effort.disp**	**frustration.disp**	**mental.mono**	**physical.mono**	**temporal.mono**	**performance.mono**	**effort.mono**
450	40	120	90	40	0	375	80
84	50	325	300	0	225	70	60
105	34	40	30	15	0	100	20
36	25	12	300	20	15	100	15
19	114	150	316	128	0	68	204
93	48	60	275	0	130	90	120
400	84	276	164	0	60	95	19
325	100	260	90	20	0	50	50
39	9	0	132	35	0	34	7
60	120	60	140	112	60	80	165
360	123	51	88	72	41	360	60
132	171	192	130	0	219	160	180
75	60	0	120	10	180	125	40
120	93	48	316	0	78	120	204
308	65	216	122	0	265	160	57
100	256	78	0	375	0	70	220
130	200	55	220	0	129	80	125
10	6	2	375	267	25	20	180
50	350	160	0	44	33	19	55
0	219	172	94	76	0	0	126
0	84	92	375	44	26	0	162
80	140	500	300	40	200	180	200
44	10	115	66	0	30	52	27
225	135	160	180	0	60	195	165
80	38	99	210	0	210	325	60
100	140	350	165	0	120	150	90
0	20	5	200	0	20	210	25
3	0	25	84	32	36	14	0
60	160	20	5	0	3	9	20
210	15	40	40	0	100	210	15
100	30	51	20	30	0	100	10
65	240	300	60	90	0	20	120
200	40	120	90	0	90	75	50
9	66	88	185	40	0	45	96
350	70	0	75	20	80	400	50
72	87	75	72	21	0	117	141
15	195	500	37	0	171	0	156
180	165	244	0	91	400	120	225
120	110	275	50	10	55	80	30
180	140	0	130	425	195	240	120
125	6	60	20	0	0	100	5
20	75	244	0	15	0	0	15
60	80	55	95	18	72	36	30
70	50	220	195	300	0	70	60
150	10	20	90	5	45	75	20
165	84	69	0	135	240	285	110
375	50	120	144	0	48	345	23
160	140	240	260	0	50	120	130
162	126	420	256	58	61	180	152
128	51	134	114	38	148	76	99
20	300	0	400	300	180	70	240
144	120	0	130	22	16	32	48
50	240	15	150	0	40	400	200
65	130	280	300	90	0	70	70
213	216	335	104	146	0	117	141
51	212	0	64	355	114	78	280
172	78	500	15	0	20	40	10
315	34	118	198	0	168	110	17
375	280	240	20	5	0	150	120
70	177	248	111	292	0	42	132
6	284	29	335	204	0	40	288
124	120	40	280	0	88	204	128
0	105	100	140	15	40	0	120

	stereo					
frustration.mono	**mental.stereo**	**physical.stereo**	**temporal.stereo**	**performance.stereo**	**effort.stereo**	**frustration.stereo**
160	165	60	0	350	120	280
475	260	0	204	80	50	300
28	30	16	0	25	10	0
12	215	15	5	68	21	0
300	292	120	0	15	195	50
60	345	0	96	219	195	100
75	120	0	20	80	35	45
40	60	22	0	40	84	20
50	52	170	0	19	13	0
92	40	20	20	20	45	32
11	120	80	50	360	60	0
219	130	0	210	200	195	225
0	160	40	180	100	60	0
138	288	0	34	65	174	60
90	52	0	160	48	44	60
88	8	165	0	52	100	4
24	160	0	90	40	125	22
52	20	30	0	8	12	0
40	0	40	45	20	100	30
136	98	92	0	0	51	96
164	105	42	22	0	78	0
500	165	60	60	60	50	150
150	70	0	36	64	20	75
220	80	0	40	225	180	160
180	180	0	180	200	45	90
165	60	0	60	170	90	100
50	100	0	20	15	10	0
210	48	40	18	16	0	5
8	15	0	0	0	20	0
30	80	0	165	180	30	50
90	4	24	0	50	10	18
100	60	90	0	20	120	125
120	60	0	60	50	20	30
116	120	40	0	8	75	48
0	75	30	80	400	40	0
130	15	21	0	12	24	25
280	55	0	159	0	183	335
240	0	76	215	150	165	140
75	20	20	60	40	20	90
0	140	425	135	210	120	0
72	52	0	45	25	20	80
12	8	15	0	0	0	20
18	200	30	76	84	78	42
220	105	300	0	30	35	100
20	75	5	45	50	10	20
47	0	162	144	400	90	36
36	64	0	60	380	14	18
220	280	0	60	160	140	260
380	240	31	17	134	62	320
60	225	77	146	32	252	144
0	225	220	100	60	165	0
0	100	24	24	48	30	0
75	150	0	40	25	100	5
140	375	90	0	60	120	160
120	32	108	0	75	57	75
0	32	265	68	39	228	0
15	45	0	12	80	16	40
38	57	0	96	95	13	0
105	10	5	0	50	40	15
232	174	296	0	10	180	92
34	420	222	0	36	348	67
76	405	0	110	312	136	130
150	40	15	20	0	30	25

NASA-TLX scores total

NASA_TLX_score_dir	NASA_TLX_score_disp	NASA_TLX_score_mono	NASA_TLX_score_stereo
69,00	44,67	49,67	65,00
39,87	53,93	75,33	59,60
4,73	15,93	12,87	5,40
3,40	15,87	30,80	21,60
30,53	44,33	67,73	44,80
20,47	24,40	45,00	63,67
20,33	79,33	27,53	20,00
7,20	60,33	16,67	15,07
9,53	25,67	17,20	16,93
8,53	29,33	43,27	11,80
37,40	58,80	42,13	44,67
50,80	51,60	60,53	64,00
37,33	23,67	31,67	36,00
18,53	27,67	57,07	41,40
35,53	71,13	46,27	24,27
46,47	58,27	50,20	21,93
37,67	56,33	38,53	29,13
18,27	5,67	61,27	4,67
41,40	60,20	12,73	15,67
21,27	39,27	28,80	22,47
31,53	36,93	51,40	16,47
11,33	80,00	94,67	36,33
13,27	18,27	21,67	17,67
44,67	47,00	54,67	45,67
49,33	26,07	65,67	46,33
51,00	66,33	46,00	32,00
4,87	3,53	33,67	9,67
2,27	4,27	25,07	8,47
9,13	23,07	3,00	2,33
30,67	30,20	26,33	33,67
0,40	16,07	16,67	7,07
31,67	60,33	26,00	27,67
24,00	48,00	28,33	14,67
18,00	27,13	32,13	19,40
42,67	39,67	41,67	41,67
8,40	19,60	32,07	6,47
33,47	72,87	42,93	48,80
78,60	58,93	71,73	49,73
19,00	44,33	20,00	16,67
57,67	67,00	74,00	68,67
4,93	15,40	13,13	14,80
3,20	27,27	2,80	2,87
19,40	49,00	17,93	34,00
43,00	56,67	56,33	38,00
13,00	18,33	17,00	13,67
52,20	54,13	54,47	55,47
41,13	66,73	39,73	35,73
63,33	58,67	52,00	60,00
46,33	71,80	72,47	53,60
11,53	23,80	35,67	58,40
57,67	72,00	79,33	51,33
30,87	40,13	16,53	15,07
8,67	31,00	57,67	21,33
55,33	62,67	44,67	53,67
21,73	62,80	41,87	23,13
38,00	47,67	59,40	42,13
1,07	74,67	6,67	12,87
56,13	48,47	35,40	17,40
32,33	68,33	26,67	8,00
50,60	60,93	53,93	50,13
50,47	64,53	60,07	72,87
29,20	43,40	51,73	72,87
13,33	24,00	31,00	8,67

Appendix G : System Usability Scale

		dir										disp	
ID	Gamer	Q1_dir	Q2_dir	Q3_dir	Q4_dir	Q5_dir	Q6_dir	Q7_dir	Q8_dir	Q9_dir	Q10_dir	Q1_disp	Q2_disp
1380	non-gamer	2	3	2	2	2	2	1	4	4	2	4	2
2257	non-gamer	3	1	3	2	3	2	4	3	4	1	3	3
6728	gamer	4	1	5	3	4	1	5	1	5	1	4	2
8546	non-gamer	5	1	5	1	5	2	5	1	5	1	2	1
8757	gamer	3	2	4	1	4	1	3	1	4	1	3	4
6576	non-gamer	4	2	5	2	4	2	5	5	4	5	4	2
3758	non-gamer	5	1	5	2	4	1	4	1	4	2	1	4
2720	non-gamer	4	1	5	1	4	2	5	1	5	1	4	3
6927	non-gamer	5	1	5	1	4	4	4	1	4	1	4	2
5340	non-gamer	5	3	5	1	3	2	4	2	4	2	4	2
5341	gamer	5	1	5	1	5	2	5	1	5	1	4	1
7146	non-gamer	4	2	3	3	4	1	4	2	3	2	3	2
2729	gamer	4	2	4	4	4	1	4	2	4	2	3	2
6391	gamer	4	2	4	1	4	1	4	1	4	2	3	2
3342	gamer	5	1	5	1	4	1	5	1	5	1	2	1
1835	gamer	4	2	5	3	3	1	5	1	4	1	2	2
1303	non-gamer	5	2	4	1	3	2	4	2	4	2	2	2
9318	gamer	4	2	5	1	5	1	5	3	4	1	5	1
4014	gamer	3	3	3	2	3	2	4	4	4	2	3	3
7529	gamer	3	1	4	2	3	4	4	2	4	2	3	2
6847	non-gamer	4	1	3	1	4	1	4	2	5	1	3	2
4368	gamer	5	1	5	1	5	1	5	1	5	1	2	1
2600	non-gamer	4	1	4	2	4	2	5	1	4	2	2	5
4864	non-gamer	5	1	5	2	5	2	5	2	5	1	3	3
6031	non-gamer	4	1	5	2	4	2	5	2	4	1	4	2
7859	gamer	3	1	4	4	4	2	4	2	2	2	2	3
5384	gamer	5	1	5	1	3	1	5	2	5	1	5	1
3759	non-gamer	5	1	5	2	5	1	5	1	5	1	5	1
1005	non-gamer	4	2	4	2	4	2	4	2	4	1	2	4
4077	gamer	5	2	4	1	4	1	4	2	4	1	2	2
3599	gamer	5	1	5	1	5	1	5	2	5	1	3	2
6598	gamer	3	2	4	4	4	4	3	2	4	2	3	3
5795	gamer	3	2	4	4	4	2	4	2	4	4	2	3
1691	non-gamer	4	3	5	2	4	2	5	2	5	1	3	1
7922	non-gamer	4	2	4	1	4	2	4	2	4	2	2	4
1531	gamer	4	1	4	2	4	2	5	1	5	1	4	1
4999	non-gamer	4	2	4	2	3	2	4	2	4	2	2	2
2812	gamer	4	2	3	4	4	4	5	2	3	2	4	2
3318	gamer	5	1	4	2	5	2	5	2	4	3	5	2
4921	gamer	4	1	2	2	4	2	4	2	5	2	3	3
6060	gamer	5	1	4	2	5	1	4	1	5	1	4	1
6557	non-gamer	5	1	5	1	5	1	5	2	5	1	4	3
9295	non-gamer	5	2	5	2	5	2	5	2	5	1	3	2
6419	gamer	5	1	2	1	5	1	4	1	4	1	4	1
4438	gamer	5	1	5	1	4	2	5	1	5	1	4	1
2463	gamer	4	1	5	1	4	2	5	1	5	1	2	4
2190	gamer	3	1	2	1	3	3	4	4	3	1	2	2
8500	gamer	4	1	5	2	4	3	5	2	4	2	4	1
3077	gamer	4	3	4	1	3	2	5	2	4	2	1	4
3170	non-gamer	4	3	4	1	4	2	5	2	4	2	3	2
9202	gamer	4	2	4	2	4	3	4	2	4	4	4	2
7818	non-gamer	4	2	3	1	3	1	3	2	4	2	2	4
5569	non-gamer	3	2	4	3	5	1	5	1	4	2	4	2
8243	non-gamer	3	2	3	2	4	2	3	2	2	2	2	2
5212	non-gamer	4	2	4	2	3	3	4	2	4	2	2	4
5336	non-gamer	4	2	4	1	2	4	3	2	5	1	2	3
7926	gamer	5	1	5	1	5	1	4	1	5	2	1	2
4993	gamer	4	1	4	2	4	1	4	3	4	3	2	2
1254	gamer	4	2	4	4	4	2	4	3	4	1	3	3
2485	non-gamer	4	2	4	2	4	2	4	2	4	1	1	3
3915	non-gamer	4	2	4	2	4	2	4	4	3	2	3	2
7398	non-gamer	5	1	4	1	3	2	4	2	5	2	5	2
8029	non-gamer	5	1	5	1	4	1	4	1	4	1	2	2

								mono			
Q3_disp	**Q4_disp**	**Q5_disp**	**Q6_disp**	**Q7_disp**	**Q8_disp**	**Q9_disp**	**Q10_disp**	**Q1_mono**	**Q2_mono**	**Q3_mono**	**Q4_mono**
3	2	4	2	4	2	4	1	4	2	5	2
3	3	3	2	4	3	3	2	1	3	1	4
4	3	4	3	4	2	5	1	4	1	4	3
4	2	4	2	5	2	5	2	4	1	5	2
3	2	4	3	3	3	3	1	2	4	1	2
4	4	4	2	4	4	4	4	4	2	3	3
2	5	2	3	2	4	1	3	4	3	4	4
3	1	3	4	4	4	4	1	3	2	4	1
4	1	4	2	4	2	4	4	3	2	4	1
4	2	3	2	4	3	4	2	3	3	3	2
4	2	4	3	4	2	3	3	4	1	5	1
3	2	4	2	4	3	3	2	3	1	3	3
4	3	4	2	4	2	4	2	4	2	4	3
4	1	4	2	4	3	3	1	2	4	2	2
3	1	3	1	4	3	2	1	4	1	4	1
2	3	3	1	4	4	4	1	3	2	4	3
3	2	3	2	4	2	2	2	4	2	4	2
5	1	5	1	5	1	5	1	3	2	2	1
2	2	3	3	2	2	3	3	4	1	5	1
2	3	3	4	2	5	2	4	4	1	3	2
4	2	4	2	4	2	5	2	3	3	3	2
2	1	2	2	2	4	1	3	1	4	1	1
2	2	2	3	2	4	2	2	3	2	2	2
4	2	4	2	5	2	4	2	4	3	4	3
4	2	4	1	5	1	4	1	4	3	4	3
2	4	3	2	4	4	2	4	3	3	3	4
5	1	3	1	5	3	5	1	5	1	5	1
5	2	4	3	4	1	5	1	5	1	5	1
2	2	2	4	3	4	2	2	5	1	4	2
4	2	3	2	4	2	5	1	4	2	4	2
3	2	2	2	4	3	3	1	4	3	3	2
2	4	2	3	2	4	2	4	4	1	4	2
4	4	4	2	4	4	3	4	4	2	4	3
3	2	2	2	3	3	5	2	2	2	2	2
3	1	4	3	3	4	3	2	4	2	4	1
4	2	4	2	5	1	5	1	3	2	3	2
2	2	3	4	5	4	2	2	3	2	4	2
4	3	4	2	4	3	3	2	2	3	2	3
2	4	2	2	2	2	4	2	4	2	4	2
2	3	4	3	3	3	3	3	4	3	4	2
4	1	5	1	5	1	4	1	4	1	5	2
4	1	4	1	5	1	5	1	5	1	4	1
2	2	4	2	3	2	2	2	4	2	5	2
4	1	5	1	4	2	4	1	4	1	5	1
4	1	3	2	5	1	4	1	4	1	5	1
5	1	2	2	5	2	5	1	2	4	2	1
2	2	2	4	2	2	2	4	3	1	3	2
4	1	5	1	5	4	4	1	4	2	5	1
1	1	2	3	2	5	1	4	2	5	2	1
3	2	3	3	4	3	2	2	2	4	2	2
2	3	4	2	4	1	4	4	2	4	2	2
2	1	2	2	2	4	4	2	4	1	4	1
4	3	4	2	4	2	4	2	2	3	2	3
2	2	3	2	2	4	2	3	3	2	4	2
1	2	2	4	2	5	1	2	4	2	4	2
3	1	1	4	3	2	5	3	1	3	1	1
2	1	2	4	2	4	2	2	5	1	5	1
3	2	3	2	4	2	4	2	4	2	3	3
3	2	3	2	3	4	2	1	4	3	3	1
2	2	2	2	3	4	2	1	2	3	2	2
3	2	3	2	3	4	3	2	3	2	2	1
4	2	2	2	4	2	5	2	4	2	4	1
4	2	4	1	4	2	3	1	2	3	2	3

						stereo				
Q5_mono	Q6_mono	Q7_mono	Q8_mono	Q9_mono	Q10_mono	Q1_stereo	Q2_stereo	Q3_stereo	Q4_stereo	Q5_stereo
4	2	4	2	4	2	3	2	4	3	4
2	3	3	4	3	3	2	1	5	1	4
4	1	5	1	5	1	4	1	5	3	4
4	2	5	1	5	1	4	1	5	2	4
2	2	2	4	1	4	3	1	4	1	3
4	2	4	4	3	4	3	3	3	3	4
4	2	4	2	4	2	5	1	4	2	5
4	4	5	2	5	1	4	1	4	1	4
3	1	5	1	4	1	4	1	4	1	4
3	4	2	4	3	2	4	3	4	2	5
5	2	5	1	5	1	4	1	4	2	4
4	2	4	3	2	2	3	1	2	4	4
4	2	4	1	4	2	4	2	4	3	4
2	4	2	4	2	1	2	3	2	2	4
4	1	5	1	4	1	4	1	4	1	5
2	1	4	3	4	1	5	1	5	3	4
3	2	4	2	3	2	4	1	4	1	4
2	2	4	1	4	1	5	1	5	1	5
5	2	5	4	5	2	4	2	4	2	4
4	3	4	2	4	1	4	1	5	2	3
4	2	4	2	4	2	4	2	4	2	4
1	3	1	5	1	5	4	2	4	1	4
2	2	4	2	4	2	2	3	4	2	3
4	3	4	2	4	2	4	2	4	3	4
4	1	4	1	5	2	4	2	4	3	4
4	2	4	3	3	2	3	1	4	4	4
4	2	5	3	3	2	5	1	5	1	3
3	1	5	2	5	2	1	1	5	4	4
5	2	5	1	5	1	5	1	5	2	5
4	2	4	1	5	2	4	1	4	2	4
3	3	4	3	4	1	4	1	4	1	4
4	1	4	2	4	1	4	2	4	2	4
4	2	4	4	4	4	4	2	4	4	4
2	4	2	3	4	3	4	2	4	2	3
4	2	4	2	4	2	4	2	4	1	4
4	2	4	1	5	2	4	1	5	1	5
3	1	4	3	3	3	2	3	4	3	3
3	4	3	4	2	4	4	3	4	3	3
4	2	2	2	2	1	5	1	5	2	5
4	2	3	2	4	2	4	3	4	3	4
4	2	4	1	5	1	3	2	3	1	4
5	1	4	1	5	1	5	1	5	1	5
4	2	5	2	4	2	4	2	4	2	4
4	1	4	1	4	1	5	1	5	1	5
4	2	5	2	4	1	5	1	5	1	4
2	4	4	4	5	1	5	2	5	1	4
4	4	2	2	3	4	4	2	4	1	5
5	1	5	2	4	1	2	2	4	2	4
2	2	2	4	2	4	2	3	4	1	3
2	4	2	4	1	4	3	2	4	2	3
4	4	2	3	2	4	4	2	3	4	4
4	1	4	2	5	1	4	2	5	1	4
4	4	2	3	2	3	3	2	3	3	4
4	2	4	2	3	2	3	2	3	2	4
3	2	4	2	4	2	4	2	4	2	4
1	4	2	4	3	3	2	3	4	1	2
4	2	4	2	4	1	4	1	4	1	4
3	2	4	3	5	2	5	1	5	2	5
4	1	4	3	3	1	4	1	5	1	4
4	2	4	2	2	1	1	4	3	2	3
3	2	4	4	4	2	2	2	3	2	3
3	3	2	4	4	3	2	2	4	2	3
2	5	2	4	2	1	4	1	5	1	5

Q6_stereo	Q7_stereo	Q8_stereo	Q9_stereo	Q10_stereo	SUS.Score.dir	SUS.Score.disp	SUS.Score.mono	SUS.Score.stereo
2	3	2	4	2	45	75	78	68
2	5	2	4	1	70	58	33	83
2	5	1	5	1	90	75	88	88
2	5	1	5	2	98	78	90	88
2	5	2	4	2	80	58	30	78
3	3	3	3	3	65	60	58	53
1	4	1	5	2	88	23	68	90
3	4	2	5	1	93	63	78	83
1	5	2	4	1	85	73	83	88
2	4	3	4	2	78	70	48	73
2	5	1	5	1	98	70	95	88
2	4	2	2	2	70	65	63	60
2	4	2	4	2	73	70	75	73
2	3	4	2	1	83	73	38	53
4	5	1	5	1	98	68	90	88
1	5	2	5	1	83	60	68	90
2	4	2	4	1	78	60	70	83
1	5	2	5	1	88	100	70	98
2	4	4	5	2	60	50	85	73
2	5	2	5	1	68	35	75	85
2	4	2	4	2	85	75	68	75
1	4	1	4	1	100	45	18	85
2	5	2	4	2	83	35	63	68
2	5	1	5	1	93	73	68	83
1	4	2	5	1	85	85	78	80
2	4	2	4	2	65	40	58	70
1	5	3	5	1	93	90	83	90
1	5	2	5	1	98	88	90	78
1	4	2	5	1	78	38	93	93
3	5	2	4	2	85	73	80	78
1	5	2	4	1	98	63	65	88
2	4	2	4	2	60	33	83	75
2	4	4	4	4	63	50	63	60
4	4	2	4	2	83	65	45	68
2	4	2	4	2	78	53	78	78
1	5	1	5	1	88	88	75	98
2	4	3	4	3	73	50	65	58
3	4	3	4	3	63	68	35	60
2	4	1	2	1	83	58	68	85
3	3	3	4	3	75	50	70	60
1	3	2	3	2	93	93	88	70
1	5	1	5	2	98	88	95	98
2	4	2	2	2	90	60	80	70
1	5	1	5	1	88	88	90	100
2	5	1	5	1	95	85	88	95
1	5	2	5	1	93	73	53	93
1	5	5	5	2	63	40	55	80
1	5	2	4	1	80	85	90	78
1	4	3	2	2	75	25	35	63
2	1	4	1	5	78	58	28	43
3	3	2	3	4	68	65	38	55
2	4	2	4	1	73	48	88	83
2	3	3	3	2	80	73	40	60
2	3	2	3	2	63	45	70	65
2	4	2	4	2	70	28	73	75
4	4	3	4	3	70	53	33	55
3	4	2	4	1	95	40	88	80
2	4	2	5	2	75	65	68	88
1	5	1	4	1	70	55	73	93
2	4	4	2	1	78	45	60	50
3	4	3	2	4	68	58	63	50
3	2	4	3	2	83	75	60	53
1	5	1	5	1	93	73	35	98

Appendix H : Affinity for Technology Interaction Questionnaire

ID	Gamer	Rating Q1	Rating Q2	Rating Q3	Rating Q4	Rating Q5	Rating Q6	Rating Q7	Rating Q8	Rating Q9	Mean
1380	non-gamer	4	6	6	6	6	6	5	3	6	5,33
2257	non-gamer	4	4	5	3	3	6	4	4	4	4,11
6728	gamer	6	5	3	5	4	5	5	2	5	4,44
8546	non-gamer	3	4	4	4	4	5	5	3	4	4,00
8757	gamer	6	6	6	6	6	5	6	6	6	5,89
6576	non-gamer	4	5	4	3	5	3	3	2	5	3,78
3758	non-gamer	4	6	3	3	4	3	6	4	6	4,33
2720	non-gamer	5	5	6	4	4	4	4	5	5	4,67
6927	non-gamer	3	6	5	4	5	4	4	5	6	4,67
5340	non-gamer	3	4	4	6	6	4	6	4	4	4,56
5341	gamer	6	6	5	6	6	5	6	5	6	5,67
7146	non-gamer	4	4	5	5	4	5	4	4	4	4,33
2729	gamer	4	5	6	5	5	5	5	6	5	5,11
6391	gamer	6	5	5	5	5	5	5	5	5	5,11
3342	gamer	5	6	6	5	6	5	5	4	6	5,33
1835	gamer	4	6	5	6	6	5	5	5	6	5,33
1303	non-gamer	5	6	5	5	5	4	4	3	6	4,78
9318	gamer	6	6	2	6	6	4	6	4	6	5,11
4014	gamer	4	4	5	4	4	6	4	3	4	4,22
7529	gamer	6	6	6	4	3	5	4	5	6	5,00
6847	non-gamer	6	6	4	5	4	4	5	4	6	4,89
4368	gamer	6	4	6	6	5	6	6	5	4	5,33
2600	non-gamer	4	3	2	3	2	3	4	3	3	3,00
4864	non-gamer	1	3	6	3	1	3	3	3	3	2,89
6031	non-gamer	3	3	5	4	3	5	3	2	3	3,44
7859	gamer	5	6	4	5	3	4	4	4	6	4,56
5384	gamer	5	6	5	6	5	4	4	4	6	5,00
3759	non-gamer	5	6	5	5	5	4	5	4	6	5,00
1005	non-gamer	5	5	4	6	5	5	5	5	5	5,00
4077	gamer	5	5	2	4	4	5	5	4	5	4,33
3599	gamer	4	5	6	5	4	5	4	5	5	4,78
6598	gamer	2	2	2	3	3	2	2	2	2	2,22
5795	gamer	6	6	3	6	5	5	5	4	6	5,11
1691	non-gamer	6	6	4	5	6	4	6	4	6	5,22
7922	non-gamer	5	5	4	4	4	5	5	5	5	4,67
1531	gamer	5	6	4	5	4	6	6	4	6	5,11
4999	non-gamer	4	5	6	3	3	4	4	4	5	4,22
2812	gamer	4	5	4	5	4	5	5	4	5	4,56
3318	gamer	5	4	4	5	5	4	6	4	4	4,56
4921	gamer	5	4	2	5	4	4	6	3	4	4,11
6060	gamer	6	6	6	6	5	2	6	5	6	5,33
6557	non-gamer	3	6	4	4	5	3	4	4	6	4,33
9295	non-gamer	5	6	5	5	4	5	5	4	6	5,00
6419	gamer	6	6	4	5	5	5	5	5	6	5,22
4438	gamer	4	4	6	4	5	4	5	5	4	4,56
2463	gamer	5	5	3	4	4	4	4	4	5	4,22
2190	gamer	5	5	4	5	6	4	6	3	5	4,78
8500	gamer	6	6	3	5	5	4	5	3	6	4,78
3077	gamer	5	5	5	4	3	4	5	4	5	4,44
3170	non-gamer	6	6	6	6	6	5	6	6	6	5,89
9202	gamer	5	6	6	6	6	2	6	3	6	5,11
7818	non-gamer	5	6	4	5	4	5	4	4	6	4,78
5569	non-gamer	5	6	5	4	4	4	5	5	6	4,89
8243	non-gamer	6	6	4	5	5	5	5	5	6	5,22
5212	non-gamer	6	6	6	6	5	5	6	5	6	5,67
5336	non-gamer	6	6	5	6	6	6	6	5	6	5,78
7926	gamer	5	6	4	4	6	6	5	4	6	5,11
4993	gamer	6	6	5	5	5	4	5	5	6	5,22
1254	gamer	6	6	2	5	5	3	3	3	6	4,33
2485	non-gamer	5	5	4	5	4	4	5	5	5	4,67
3915	non-gamer	4	4	3	3	3	3	3	3	4	3,33
7398	non-gamer	5	6	5	5	5	5	3	3	6	4,78
8029	non-gamer	6	6	4	5	5	5	5	5	6	5,22

Appendix I : Demographic Questionnaire and Final Interview Questions

ID	Gamer	Alter	Geschlecht	Sehhilfe	Erfahrung HMD	Erfahrung remote
1380	non-gamer	24	Weiblich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
2257	non-gamer	25	Weiblich	Ja, fuer die Bildschirmarbeit	Keine Erfahrung	Wenig Erfahrung
6728	gamer	26	Maennlich	Nein	Wenig Erfahrung	Einigermaßen viel Erfahrung
8546	non-gamer	25	Weiblich	Nein	Keine Erfahrung	Wenig Erfahrung
8757	gamer	25	Maennlich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
6576	non-gamer	28	Weiblich	Ja, fuer die Ferne	Keine Erfahrung	Keine Erfahrung
3758	non-gamer	23	Weiblich	Ja, fuer die Ferne	Keine Erfahrung	Keine Erfahrung
2720	non-gamer	24	Weiblich	Nein	Wenig Erfahrung	Keine Erfahrung
6927	non-gamer	35	Maennlich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
5340	non-gamer	20	Weiblich	Ja, fuer die Bildschirmarbeit	Wenig Erfahrung	Keine Erfahrung
5341	gamer	25	Maennlich	Nein	Ziemlich viel Erfahrung	Ziemlich viel Erfahrung
7146	non-gamer	24	Weiblich	Nein	Keine Erfahrung	Keine Erfahrung
2729	gamer	21	Maennlich	Ja, fuer die Ferne	Wenig Erfahrung	Einigermaßen viel Erfahrung
6391	gamer	25	Maennlich	Nein	Wenig Erfahrung	Einigermaßen viel Erfahrung
3342	gamer	27	Maennlich	Ja, fuer die Ferne	Wenig Erfahrung	Einigermaßen viel Erfahrung
1835	gamer	28	Maennlich	Nein	Einigermaßen viel Erfahrung	Wenig Erfahrung
1303	non-gamer	23	Weiblich	Nein	Wenig Erfahrung	Keine Erfahrung
9318	gamer	27	Maennlich	Ja, fuer die Ferne	Wenig Erfahrung	Einigermaßen viel Erfahrung
4014	gamer	24	Maennlich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
7529	gamer	23	Maennlich	Nein	Wenig Erfahrung	Wenig Erfahrung
6847	non-gamer	24	Maennlich	Nein	Wenig Erfahrung	Einigermaßen viel Erfahrung
4368	gamer	18	Maennlich	Ja, fuer die Ferne	Einigermaßen viel Erfahrung	Einigermaßen viel Erfahrung
2600	non-gamer	21	Weiblich	Ja, fuer die Ferne	Keine Erfahrung	Wenig Erfahrung
4864	non-gamer	24	Maennlich	Nein	Keine Erfahrung	Keine Erfahrung
6031	non-gamer	18	Maennlich	Ja, fuer beides	Keine Erfahrung	Wenig Erfahrung
7859	gamer	27	Weiblich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
5384	gamer	33	Maennlich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
3759	non-gamer	21	Maennlich	Nein	Keine Erfahrung	Wenig Erfahrung
1005	non-gamer	24	Weiblich	Ja, fuer die Ferne	Keine Erfahrung	Wenig Erfahrung
4077	gamer	20	Maennlich	Nein	Wenig Erfahrung	Wenig Erfahrung
3599	gamer	28	Maennlich	Nein	Keine Erfahrung	Einigermaßen viel Erfahrung
6598	gamer	29	Weiblich	Nein	Keine Erfahrung	Wenig Erfahrung
5795	gamer	28	Weiblich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
1691	non-gamer	20	Maennlich	Nein	Wenig Erfahrung	Wenig Erfahrung
7922	non-gamer	26	Weiblich	Nein	Wenig Erfahrung	Wenig Erfahrung
1531	gamer	26	Maennlich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
4999	non-gamer	26	Weiblich	Ja, fuer die Ferne	Keine Erfahrung	Wenig Erfahrung
2812	gamer	22	Maennlich	Nein	Wenig Erfahrung	Einigermaßen viel Erfahrung
3318	gamer	27	Maennlich	Ja, fuer die Bildschirmarbeit	Wenig Erfahrung	Wenig Erfahrung
4921	gamer	30	Maennlich	Ja, fuer die Bildschirmarbeit	Einigermaßen viel Erfahrung	Keine Erfahrung
6060	gamer	28	Maennlich	Nein	Wenig Erfahrung	Einigermaßen viel Erfahrung
6557	non-gamer	27	Weiblich	Ja, fuer beides	Wenig Erfahrung	Keine Erfahrung
9295	non-gamer	26	Weiblich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
6419	gamer	27	Maennlich	Ja, fuer die Ferne	Extrem viel Erfahrung	Wenig Erfahrung
4438	gamer	32	Weiblich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
2463	gamer	25	Maennlich	Nein	Ziemlich viel Erfahrung	Einigermaßen viel Erfahrung
2190	gamer	20	Maennlich	Nein	Wenig Erfahrung	Wenig Erfahrung
8500	gamer	25	Maennlich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
3077	gamer	21	Maennlich	Nein	Keine Erfahrung	Wenig Erfahrung
3170	non-gamer	31	Maennlich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
9202	gamer	23	Maennlich	Ja, fuer die Ferne	Keine Erfahrung	Wenig Erfahrung
7818	non-gamer	29	Weiblich	Ja, fuer die Ferne	Einigermaßen viel Erfahrung	Wenig Erfahrung
5569	non-gamer	22	Weiblich	Nein	Wenig Erfahrung	Wenig Erfahrung
8243	non-gamer	32	Maennlich	Ja, fuer die Ferne	Einigermaßen viel Erfahrung	Einigermaßen viel Erfahrung
5212	non-gamer	22	Maennlich	Nein	Wenig Erfahrung	Wenig Erfahrung
5336	non-gamer	65	Maennlich	Ja, fuer beides	Wenig Erfahrung	Wenig Erfahrung
7926	gamer	27	Maennlich	Ja, fuer die Ferne	Wenig Erfahrung	Wenig Erfahrung
4993	gamer	28	Maennlich	Ja, fuer die Ferne	Ziemlich viel Erfahrung	Einigermaßen viel Erfahrung
1254	gamer	26	Weiblich	Ja, fuer die Ferne	Keine Erfahrung	Wenig Erfahrung
2485	non-gamer	29	Weiblich	Ja, fuer die Ferne	Extrem viel Erfahrung	Wenig Erfahrung
3915	non-gamer	30	Weiblich	Ja, fuer die Ferne	Wenig Erfahrung	Keine Erfahrung
7398	non-gamer	31	Maennlich	Nein	Wenig Erfahrung	Wenig Erfahrung
8029	non-gamer	29	Maennlich	Nein	Wenig Erfahrung	Einigermaßen viel Erfahrung

Häufigkeit Computerspiele	Gaming h/Woche	Shooter	Sandbox	Action adventure	Simulation	MOBA	Sport	Racing
Selten	0	Nein	Nein	Nein	Nein	Nein	Ja	Nein
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Oft	25	Ja	Ja	Ja	Nein	Nein	Nein	Nein
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gelegentlich	1	Nein	Ja	Nein	Nein	Nein	Nein	Nein
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Selten	0	Nein	Nein	Nein	Nein	Nein	Nein	Nein
Selten	0,4	Nein	Nein	Nein	Nein	Nein	Nein	Nein
Regelmaeßig	6	Ja	Ja	Ja	Ja	Nein	Nein	Ja
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Regelmaeßig	4	Ja	Ja	Ja	Ja	Nein	Nein	Nein
Gelegentlich	4	Ja	Ja	Nein	Nein	Nein	Nein	Nein
Regelmaeßig	8	Ja	Ja	Nein	Ja	Nein	Nein	Nein
Gelegentlich	4	Ja	Nein	Nein	Ja	Nein	Nein	Ja
Selten	1	Nein	Nein	Nein	Nein	Nein	Nein	Nein
Gelegentlich	1	Ja	Ja	Ja	Nein	Nein	Nein	Ja
Gelegentlich	1	Nein	Nein	Ja	Nein	Nein	Ja	Ja
Oft	7	Ja	Nein	Ja	Ja	Ja	Nein	Nein
Selten	0	Nein	Ja	Nein	Nein	Nein	Nein	Nein
Selten	1	Ja	Ja	Ja	Ja	Nein	Nein	Nein
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gelegentlich	6	Nein	Ja	Ja	Nein	Nein	Nein	Nein
Oft	28	Nein	Ja	Ja	Ja	Nein	Nein	Nein
Selten	0	Ja	Nein	Nein	Nein	Nein	Nein	Nein
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Selten	1	Nein	Nein	Nein	Nein	Nein	Ja	Nein
Oft	6	Nein	Nein	Nein	Nein	Ja	Nein	Ja
Selten	1	Nein	Nein	Nein	Nein	Nein	Nein	Nein
Selten	1	Nein	Nein	Nein	Nein	Ja	Nein	Nein
Selten	0,5	Nein	Ja	Nein	Nein	Nein	Nein	Nein
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gelegentlich	1	Ja	Ja	Nein	Ja	Nein	Nein	Nein
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gelegentlich	15	Nein	Nein	Nein	Ja	Nein	Nein	Nein
Selten	3	Ja	Nein	Nein	Nein	Nein	Nein	Nein
Regelmaeßig	6	Nein	Ja	Nein	Ja	Nein	Nein	Nein
Regelmaeßig	3	Ja	Nein	Nein	Nein	Nein	Ja	Nein
Selten	0,1	Nein	Nein	Nein	Nein	Nein	Nein	Nein
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Regelmaeßig	4	Nein	Nein	Ja	Nein	Ja	Nein	Nein
Gelegentlich	7	Ja	Nein	Ja	Nein	Nein	Nein	Nein
Oft	14	Ja	Nein	Nein	Ja	Nein	Ja	Ja
Oft	6	Ja	Nein	Nein	Nein	Nein	Nein	Nein
Regelmaeßig	6	Nein	Nein	Nein	Nein	Nein	Ja	Nein
Regelmaeßig	5	Ja	Ja	Nein	Ja	Nein	Nein	Nein
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Oft	14	Nein	Ja	Nein	Nein	Nein	Nein	Nein
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gelegentlich	2	Nein	Nein	Nein	Nein	Nein	Nein	Nein
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gelegentlich	3	Nein	Nein	Ja	Nein	Nein	Nein	Nein
Gelegentlich	1	Ja	Nein	Nein	Nein	Nein	Nein	Nein
Gelegentlich	5	Nein	Nein	Nein	Nein	Nein	Nein	Nein
Selten	0	Nein	Nein	Nein	Ja	Nein	Nein	Nein
Selten	0,1	Nein	Nein	Nein	Ja	Nein	Nein	Nein
Nie		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Selten	0,5	Ja	Ja	Nein	Nein	Nein	Nein	Nein

Strategie	Puzzle	Fighting	Action Platform	Online Brettspiele	Sonstiges	1. Gerät
Nein	Ja	Nein	Ja	Nein		Konsole
N/A	N/A	N/A	N/A	N/A		
Ja	Nein	Nein	Nein	Ja		PC / Laptop
N/A	N/A	N/A	N/A	N/A		
Ja	Nein	Nein	Ja	Nein		PC / Laptop
N/A	N/A	N/A	N/A	N/A		
N/A	N/A	N/A	N/A	N/A		
N/A	N/A	N/A	N/A	N/A		
Ja	Nein	Nein	Nein	Nein		PC / Laptop
Nein	Ja	Nein	Ja	Ja		Smartphone / Handy / Tablet
Ja	Nein	Nein	Ja	Ja		PC / Laptop
N/A	N/A	N/A	N/A	N/A		
Nein	Nein	Nein	Ja	Ja		PC / Laptop
Nein	Nein	Nein	Nein	Nein		PC / Laptop
Nein	Nein	Nein	Nein	Nein		PC / Laptop
Nein	Nein	Nein	Nein	Nein		PC / Laptop
Nein	Ja	Nein	Nein	Nein		Smartphone / Handy / Tablet
Nein	Ja	Nein	Nein	Nein		PC / Laptop
Nein	Nein	Nein	Nein	Nein		Konsole
Ja	Nein	Nein	Nein	Nein		PC / Laptop
Ja	Nein	Nein	Nein	Ja		Smartphone / Handy / Tablet
Ja	Nein	Nein	Nein	Ja		PC / Laptop
N/A	N/A	N/A	N/A	N/A		
N/A	N/A	N/A	N/A	N/A		
N/A	N/A	N/A	N/A	N/A		
Nein	Ja	Nein	Ja	Nein		PC / Laptop
Ja	Nein	Nein	Ja	Nein		PC / Laptop
Ja	Ja	Nein	Nein	Nein		Smartphone / Handy / Tablet
N/A	N/A	N/A	N/A	N/A		
Nein	Nein	Nein	Nein	Nein		Konsole
Ja	Nein	Nein	Ja	Nein		Konsole
Nein	Ja	Nein	Ja	Nein		Smartphone / Handy / Tablet
Nein	Ja	Nein	Ja	Ja		Konsole
Ja	Nein	Nein	Nein	Nein		PC / Laptop
N/A	N/A	N/A	N/A	N/A		
Ja	Nein	Nein	Nein	Nein		PC / Laptop
N/A	N/A	N/A	N/A	N/A		
Ja	Nein	Nein	Nein	Ja		Smartphone / Handy / Tablet
Ja	Nein	Nein	Nein	Nein		Smartphone / Handy / Tablet
Ja	Nein	Nein	Nein	Nein		PC / Laptop
Nein	Nein	Nein	Nein	Nein		Konsole
Ja	Nein	Nein	Nein	Ja	cooking games like overcooked	Smartphone / Handy / Tablet
N/A	N/A	N/A	N/A	N/A		
Nein	Nein	Nein	Ja	Nein		PC / Laptop
Nein	Ja	Nein	Ja	Ja		Smartphone / Handy / Tablet
Nein	Nein	Nein	Nein	Nein		PC / Laptop
Ja	Nein	Nein	Nein	Ja		PC / Laptop
Nein	Nein	Nein	Nein	Ja		PC / Laptop
Nein	Ja	Nein	Nein	Nein		Smartphone / Handy / Tablet
N/A	N/A	N/A	N/A	N/A		
Ja	Nein	Nein	Nein	Ja	Karte	PC / Laptop
N/A	N/A	N/A	N/A	N/A		
Nein	Ja	Nein	Nein	Nein		Smartphone / Handy / Tablet
N/A	N/A	N/A	N/A	N/A		
N/A	N/A	N/A	N/A	N/A		
N/A	N/A	N/A	N/A	N/A		
Nein	Nein	Nein	Nein	Nein		PC / Laptop
Ja	Nein	Nein	Ja	Ja		PC / Laptop
Ja	Ja	Nein	Nein	Ja		Smartphone / Handy / Tablet
Nein	Ja	Nein	Nein	Nein		PC / Laptop
Nein	Nein	Nein	Nein	Nein		PC / Laptop
N/A	N/A	N/A	N/A	N/A		
Nein	Nein	Nein	Nein	Nein		PC / Laptop

2. Gerät	3. Gerät	4. Gerät
Smartphone / Handy / Tablet	PC / Laptop	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)	Konsole
Konsole	anderes Endgeraegt (bitte in Textfeld angeben)	Smartphone / Handy / Tablet
PC / Laptop	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
PC / Laptop	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
PC / Laptop	anderes Endgeraegt (bitte in Textfeld angeben)	Smartphone / Handy / Tablet
Konsole	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
PC / Laptop	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
PC / Laptop	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	PC / Laptop	anderes Endgeraegt (bitte in Textfeld angeben)
PC / Laptop	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	PC / Laptop	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	PC / Laptop	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
PC / Laptop	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	PC / Laptop	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	PC / Laptop	anderes Endgeraegt (bitte in Textfeld angeben)
PC / Laptop	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	PC / Laptop	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
PC / Laptop	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
PC / Laptop	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
PC / Laptop	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)
Konsole	Smartphone / Handy / Tablet	anderes Endgeraegt (bitte in Textfeld angeben)
Smartphone / Handy / Tablet	Konsole	anderes Endgeraegt (bitte in Textfeld angeben)

Sonstiges Gerät
keins
Nintendo DS
Nur pc
keine konsole
Keine Konsole
Wer einen Computer hat, braucht keine anderen Geraete im Leben! ;P
keine
kein handy
kein pc
nur pc, handy
Ohne Konsole
keine konsole
keine konsole
VR Brille
kein handy
nur PC

Unterschied 2D/3D	Ranking 1
Weiter und naher Blick von oben besser	monoskopische Sicht mit VR-Brille
3d 2 D_ kein tilfengefuehl	stereoskopische Sicht mit VR-Brille
Ja zweite schlechter - raeumliches sehen	direkte Sicht
Nein	direkte Sicht
Ja - tiefenwahrnehing Mono schwer	stereoskopische Sicht mit VR-Brille
Enger und weiter - es hat besser geklappt 2- schaerfer	direkte Sicht
Beim zweiten leichter	direkte Sicht
Ja - zweite schaerfer - viel einfacher - raeumlich besser	direkte Sicht
Erste weiter wey-zweite naeher	direkte Sicht
Ja erste 2d - schwierig einzuschaetzen - zweite 3d	direkte Sicht
Ja - aber nicht klar was - zweite fluessiger	direkte Sicht
Beim zweite mal konnte man besser	direkte Sicht
Manchmal geflackert - im Nachhinein - zweite leichter	stereoskopische Sicht mit VR-Brille
Ja-eine hatte keine Tiefe	direkte Sicht
Beim zweiten Mal Kopf drehen - Kamera naher	stereoskopische Sicht mit VR-Brille
Ja - 2d us, 3d	stereoskopische Sicht mit VR-Brille
Am Anfang nein - dann bessere Einschaetzung	direkte Sicht
Ja - erste 2d sehr anstrengend - schlechter als Display _ 3d besser als live - intuitiv	stereoskopische Sicht mit VR-Brille
Ja - zweite 3d - einfacher	stereoskopische Sicht mit VR-Brille
Beim zweiten 2d	stereoskopische Sicht mit VR-Brille
Ja- zweite 3d	stereoskopische Sicht mit VR-Brille
Ja - zweite besser - Kamera Perspektive	direkte Sicht
Ja - Aufloesung? - zweite schwer -	direkte Sicht
Ja-etwas anders - zweite Mal groeber	direkte Sicht
Nein	monoskopische Sicht mit VR-Brille
Winkel - Perspektive -	stereoskopische Sicht mit VR-Brille
Erste war schwieriger	Bildschirm
Nein - bisschen leichter	direkte Sicht
Ju weiter wer	stereoskopische Sicht mit VR-Brille
Nein	direkte Sicht
Ja - zweite schwerer - nicht so raeumlich	direkte Sicht
Nein. evtl. eine leicht abgeaenderte Perspektive	stereoskopische Sicht mit VR-Brille
Nein - zweite besser	stereoskopische Sicht mit VR-Brille
Ja-stereosichte	direkte Sicht
Nein- nur anders - zweite schlechter gesehen	direkte Sicht
Ja- 3d Sicht besser - Beleuchtung? - mehr Sicherheit	direkte Sicht
Ner nein - zweite besser	direkte Sicht
Ja - zweite bessere Tiefen Einschaetzung	direkte Sicht
Ja - Winkel anders-erste besser	stereoskopische Sicht mit VR-Brille
Ja - zweite besser - Bild bewegt - depth Perzeption	direkte Sicht
Nein - zweite besser	stereoskopische Sicht mit VR-Brille
Ja - aber was? 3d-gefuehl besser	stereoskopische Sicht mit VR-Brille
Zweite leichter_l) das was mono)	direkte Sicht
Ja - eine flach bildschirm-zweite 3d raeumlich	stereoskopische Sicht mit VR-Brille
Am Anfang ja - aber nicht konkret	stereoskopische Sicht mit VR-Brille
Zweite Mur 2d	direkte Sicht
Ja - depth Perzeption	stereoskopische Sicht mit VR-Brille
Nicht - zweite einfacher (mono) - anderes Gefuehl	direkte Sicht
Ja - 2d 3d	stereoskopische Sicht mit VR-Brille
kein Unterschied	direkte Sicht
Ja - naher bei stereo-leichter - bessere	direkte Sicht
Kein großer-andere Perspektive - naeher	stereoskopische Sicht mit VR-Brille
Ja-stereo besser raeumlich einschaetzen	direkte Sicht
Nein-perspektive anders	monoskopische Sicht mit VR-Brille
Farbe anders	stereoskopische Sicht mit VR-Brille
Ja - kanarawinkel - 3d	direkte Sicht
Ja - 3d sehen bei mono	direkte Sicht
Ja 3d 2d	stereoskopische Sicht mit VR-Brille
Ja - schwieriger-perspektive - man sieht weiter	stereoskopische Sicht mit VR-Brille
Ja - zweite gekippter Hintergrund - schwindelig	direkte Sicht
Nicht explizit - Winkel	direkte Sicht
Ja Perspektive	Bildschirm
Ja - Tiefen Wahrnehmung anders	direkte Sicht

Ranking 2	Ranking 3	Ranking 4
Bildschirm	stereoskopische Sicht mit VR-Brille	direkte Sicht
direkte Sicht	Bildschirm	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
direkte Sicht	Bildschirm	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
monoskopische Sicht mit VR-Brille	stereoskopische Sicht mit VR-Brille	Bildschirm
direkte Sicht	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
direkte Sicht	monoskopische Sicht mit VR-Brille	Bildschirm
direkte Sicht	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
Bildschirm	direkte Sicht	monoskopische Sicht mit VR-Brille
monoskopische Sicht mit VR-Brille	direkte Sicht	Bildschirm
direkte Sicht	Bildschirm	monoskopische Sicht mit VR-Brille
direkte Sicht	Bildschirm	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	direkte Sicht	Bildschirm
monoskopische Sicht mit VR-Brille	direkte Sicht	Bildschirm
direkte Sicht	stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
monoskopische Sicht mit VR-Brille	direkte Sicht	Bildschirm
monoskopische Sicht mit VR-Brille	Bildschirm	stereoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
monoskopische Sicht mit VR-Brille	direkte Sicht	Bildschirm
direkte Sicht	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
monoskopische Sicht mit VR-Brille	direkte Sicht	Bildschirm
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
direkte Sicht	monoskopische Sicht mit VR-Brille	Bildschirm
direkte Sicht	monoskopische Sicht mit VR-Brille	Bildschirm
monoskopische Sicht mit VR-Brille	stereoskopische Sicht mit VR-Brille	Bildschirm
direkte Sicht	Bildschirm	monoskopische Sicht mit VR-Brille
direkte Sicht	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
monoskopische Sicht mit VR-Brille	direkte Sicht	Bildschirm
monoskopische Sicht mit VR-Brille	stereoskopische Sicht mit VR-Brille	Bildschirm
direkte Sicht	Bildschirm	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
monoskopische Sicht mit VR-Brille	direkte Sicht	Bildschirm
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	direkte Sicht	Bildschirm
direkte Sicht	monoskopische Sicht mit VR-Brille	Bildschirm
Bildschirm	stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille
monoskopische Sicht mit VR-Brille	stereoskopische Sicht mit VR-Brille	Bildschirm
direkte Sicht	monoskopische Sicht mit VR-Brille	Bildschirm
direkte Sicht	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille	Bildschirm
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille
direkte Sicht	stereoskopische Sicht mit VR-Brille	monoskopische Sicht mit VR-Brille
stereoskopische Sicht mit VR-Brille	Bildschirm	monoskopische Sicht mit VR-Brille

Verbesserungsvorschläge Visualisierung
Mehr Licht Schatten hilft i Display auf Augenhoehe statt Seite - Brille gut - Display bessere Aufloesung
Belichtung besser - Loch finden
Aufloesung besser
Aufloesung besser
Roboter blockiert Sicht - Schaerfe - Aufloesung - mehr Licht - mehr Kontrast
Schatten besser darstellen
Greifer dunkel - schlecht zu erkennen
Darstellung ans Sicht von Roboter
Andere Winkel sehen
Hoehere Aufloesung - 90 Hz - Display passt - Latenz gut
Interessant i wenn Kamera bewegt mit Kopf - verschiedene Winkel - hohe Aufloesung
Hiohere Aufloesung _ Display spiegelt
Mehr Schatten
Freie Kamera Perspektive - mehrere Winkel - Tilt Control _ schaerfere Aufloesung
Winkel schwierig _ Naehe hilft
Kopf mitbewegen
Display -verschiedene Winkel; 3d echt gut
Aufloesung - guter Kontrast _ diffuses Licht aus anderem Winkel _ manchmal T Bilder flackern
Perspektive wichtig - Display rechts-links Problem
Hoehere Aufloesung - Brille Maße _physisch
Heuere Aufloesung - mehrere Sichten
Schatten nicht gut sichtbar bei Display - HMD bessere Aufloesung - Winkel bei direkte Sicht anders
3d besser
Augmented Gitter fuer Bewegung _ Schatten um Bewegung besser wahrnehmen zu koennen - so wie parkhilfe Piep
Laser als Hilfe - Schatten hilfreich
Brille schaerfer
Bessere Aufloesung
Brille-markierung fuer Tiefe
Mehr Kameras - vr Darstellung - fuer Bewegung und Perspektive - Position der Box auf malen - hoehere Aufloesung -Laser Linien fuer Greifer
Bildschirm sehr schlecht - andere Perspektive
Geblockte Sicht bei Brille - unscharf
Haende + Leader sehen
Roboter sehen hilft bei Bildschirm - hoehere Aufloesung - Bild folgt Kopf Bewegung - Perspektive von Roboter
Perspektive gut _ Gefuehl von Leader bei Brille
Bessere Qualitaet - Licht schlecht zu sehen _ Kamera mit bewegen - mono anstrengend - direkt Roboter lockerer _ Brille auf Bille gut - Aufloesung besser - Display Kopf dreht anstrengend
Eingeblendete Positionierung in Brille - Kantenerkennung
Hein
Greifer prediction
Vr _ schwarzer Rand doof - vielleicht Ar - personalisiert
Perspektive wichtig - Entfernung ueber Schatten
Display unscharf - vr gut
2d Brille nutzbar-schatten - mehr kumeraunsichten - naher am Greifer
Bildschirm andere Perspektive - vr Brille direkt vor dir - Kamera am Greifer - Anzeige von Winkel von Greifer
Perspektive - Ego Perspektive einfacher? - Projektion de tiefeninformation - Greifer verdeckt
Winkel von Kamera unguenstig _ Kamera au Roboter - eigenes System sehen fuer ausrichten _ Greifer senkrecht
Perspektive wichtig - schwitzen schwierig in Brille - bessere Sicht Winkel _ schwierig richtigen Winkel zum Fassen _ Display vor Augen
Sicht drehen- Perspektive anpassen - ur-brille Hohe _ waehrenddessen einstellen
Display Position schwierig _ Greifer Pfeile zur Greifen fuer Ar
Perspektive Draufsicht
Brille, dass man eigene Haende sieht
Bessere Beleuchtung - mehrere Lichter
Mehr Perspektiven bei Display - groeßerer Bildschirm - Zoom rein
Projektionen Position - Feller anzeige
Display verschiedene Ansichten - bewegte Kamera - bessere Aufloesung - Brille anstrengend - schwarz in vr-brille in andere Farbe
Hohe der Tischplatte unterschiedlich - Hoehe der Kamera hoher als Koerpergroeße -l
Nicht direkt draufgeschaut - Ursache fuer inverses Gefuehl - 3d Raster einblenden - gut 1:1
Mehr Licht fuer Schatten - hoehere Aufloesung - Unwohlsein
Bessere Aufloesung

Verbesserungsvorschläge Robotersystem
Greifer besserer Griff - Koerper zu sehr bewegt - Brille Haende a sichtbar - direkt Vertrauen
Greifer schwer zu bedienen - keine Fluessige Bewegung - zusammen Spiel Panda und Greifer
Aut Dauer anstrengend fuer Schultern und Kraft
Gut en bedienen
Hoher Widerstand _ Griff besser - ergonomischer
Manchmal viel Widerstand - Bedienung nicht schwer
Blockieren nicht so schnell
Viel widerstand - Bewegung nicht frei
Greifer schwergaengig _ Blockieren nervig
Greifer klemmen frustrierend - einfach zu bedienen
Greifer ohne Latenz - manchmal grobmotorisch - weniger Widerstand _ Kontakte bei Greifer besser
Greifer Latenz beseitigen - Blockieren nervig
Greifer mit Knopf loesen - zwei Griffe um Kopf von Roboter zu bewegen - mit der Zeit Widerstand gespuert
Aufgaben ablandig - Dreieck schwer - Greifer besser
Greifer _ ergonomischer - geringere Widerstaende
Greifer gewoehnnngsbedhirftig
Hat ueberraschend gut geklappt - bis aut Greifer - Force Feedback gut
Ich zu schwell -' - Grenzen Gefuehl gefehlt - Greifer schwierig
Greifer verbessern - Hand verkrampft _ Bedienung r nervig - Force Feedback schwammig - Wider stand im Arm _ feine Bewegung schwer - mehrachsig schwer
Greifer Unterschied schwer - Latenz ok
Greifer bleibt stecken - stoppen? - Widerstand
Bewegung noch unten unangenehm - bessere Griffe
Greifer Klemmen schwer - verlangsamt alles - Force Feedback gut
Mehr Drehung - Winkel
Abstuerze - fixen - Greifer besser handeln - mehr beweghy
Knuepfe bei Greifer _ anstrengend Greifer zu bedienen
Greifer sehr schlecht
Bisschen schneller
Leichter offnen und schließen - weit ausziehen Widerstand
Greifer unangenehm Zn bedienen
Generell gut - Greifer Zwischenstufen gut am Anfang - aber dann binar besser - Drehung mehr
Greifer Force Feedback - ordentliche Griffe wegen Widerstand - volle Drehung _ ertasten cool
Greifer anstrengend - Knopf stattdessen
Greifer unergononich - eckig und komisch - große Widerstand
Zu langsam -mehr Beweglichkeit _ bisschen anstrengend
Zuverlaessiger _ Greifer zu hart und scharf _ bessere Range of motion
Winkel schwierig - Greifer anstrengend
Roboter schwer -viel Widerstand - Man erwartet was leichtes - Greifer Fehler bloed
Greifen mit Knopf - anstrengend
Greifer anstrengend - Button
Winkel dort zu schwell blockiert _l Greifer zu schwell blockiert - Griff besser - ergonomischer
Zu viel Widerstand mit Bewegung
ueberrascht wie gut bei anderen Formen greift - feinjustierny schwierig
Widerstand zu groß - feine Bewegungen nicht moeglich
Einfach zu bedienen - Controller ausprobieren
Greifer weniger Widerstand - Blockieren doof - alles etwas hoeher
Widerstand zu groß fuer feine Bewegung
Latenzen Problem
Zu viel Kraft - manchmal zu viel Widerstand
Umstaendlich umgreifen zum breiter schließen - besser mit Knopf - Griff angenehm
Greifer verklemmt - sonst gut
Statt Roboter Greifer Handschuh
Reiter besser bedienbar - Klemmen - Force Feedback - Winkel gut Greifer - eine Hand bedienen
Gleichmaeßiger Widerstand _ Greifer mehr Zwischenstufen - Knopf
Widerstand -Greifer mit Knopf und slider _ viel Widerstand - breiter passt nicht zu Task -Fehler dort - rumfahren Intrige
Unangenehm zu greifen an Daumen - ein anderer Griff _ Kissen Polster - viel Greif Kraft - viel Widerstand in der Bewegung _ Roboter verknoten - Knopf bei Roboter - Hand Position aendern schwierig - Anbau - aut Dover unangenehm
Knopf fuer Greifer - zu viel Kraft
Physisch schwer - Greifer schwierig fuer Winkel Greifer gut - Knopf
Greifer mit Knopf - mehrere Knoepfe - Blockieren doof - Sensor wenn nah un Tisch
Umgreifen anstrengend - knopf-runder Griff - Schieberegler

Appendix J : Q-Q Plots for NASA-TLX Dimensions

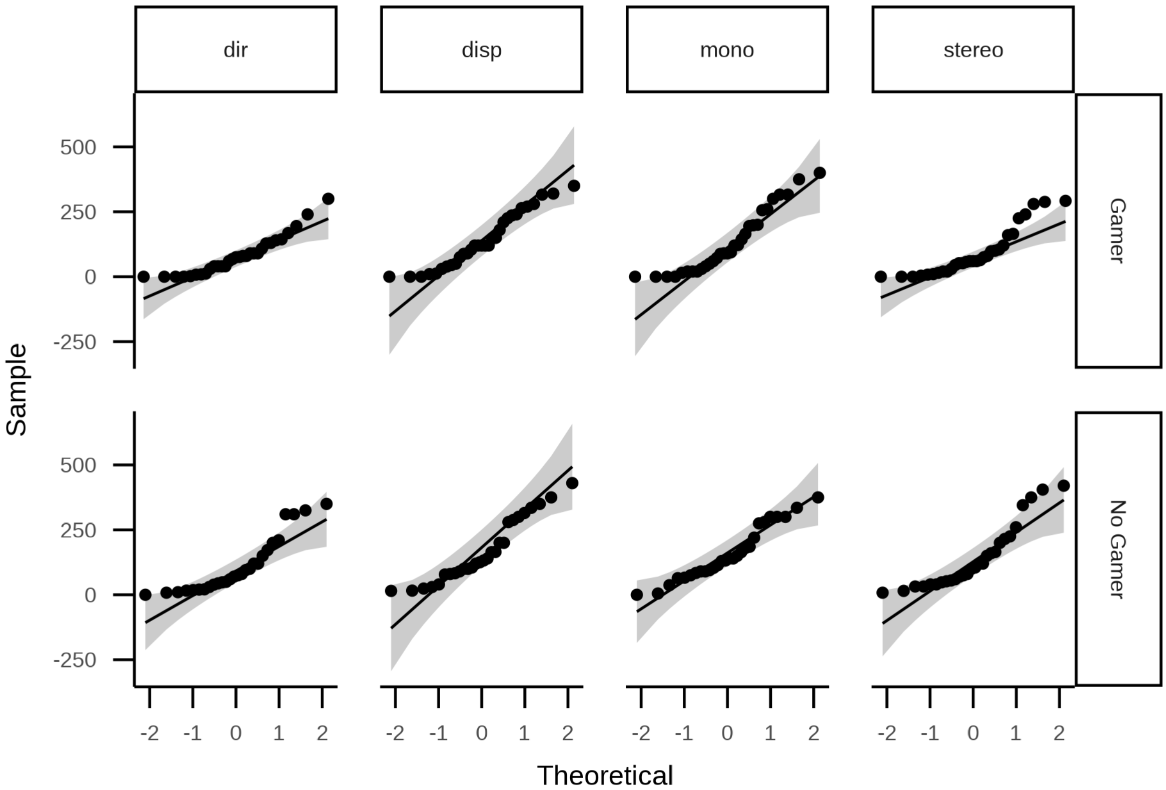

Figure Appendix J.1 Q-Q plot of NASA-TLX score of mental dimension

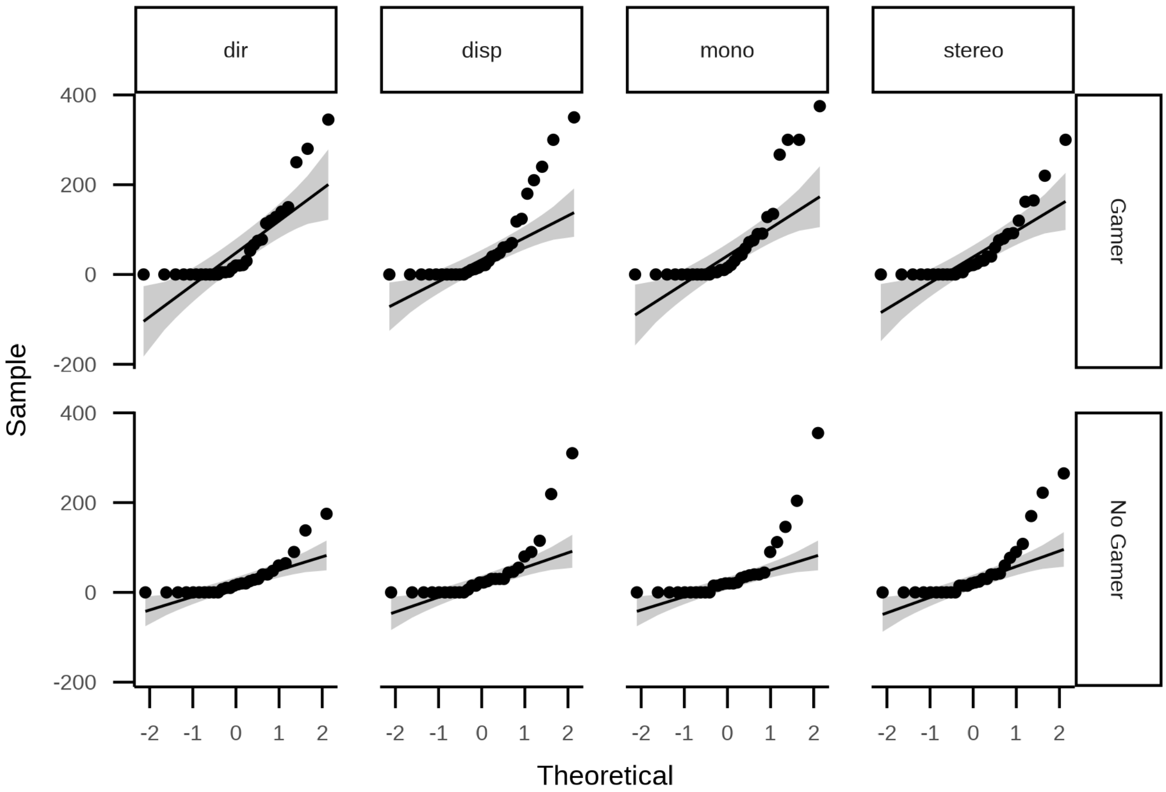

Figure Appendix J.2 Q-Q plot of NASA-TLX score of physical dimension

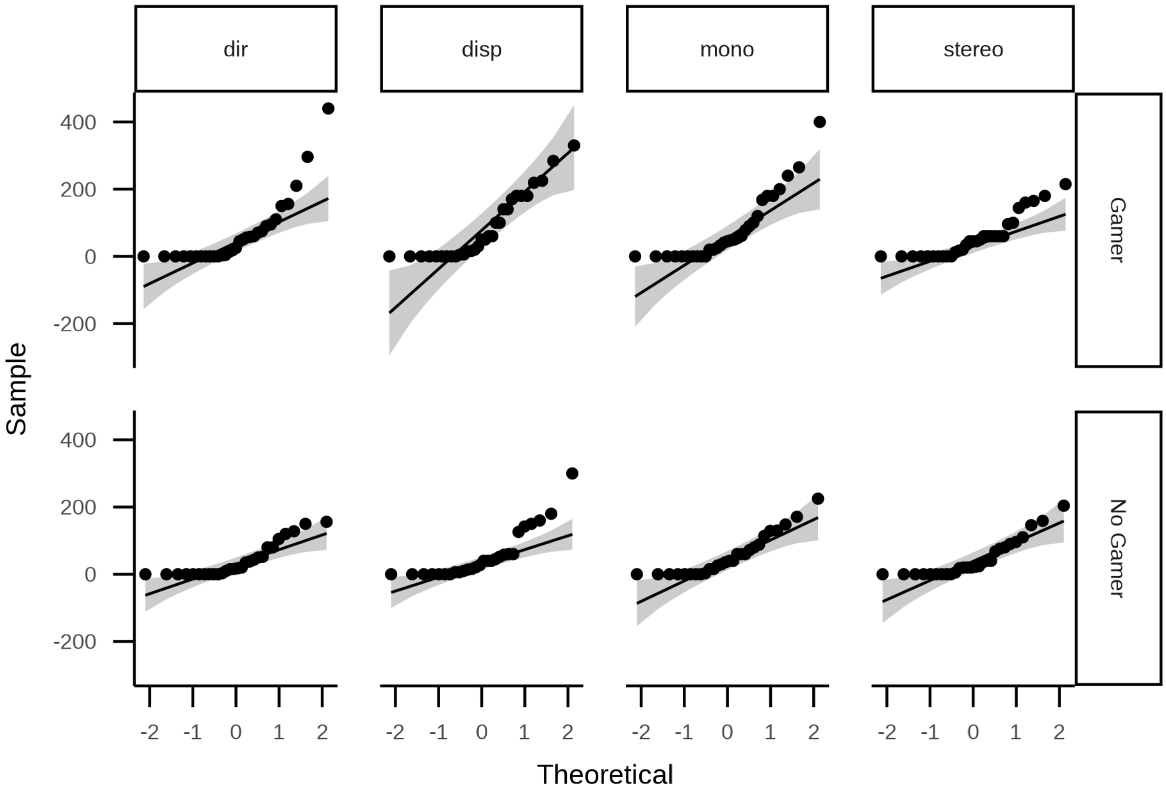

Figure Appendix J.3 Q-Q plot of NASA-TLX score of temporal dimension

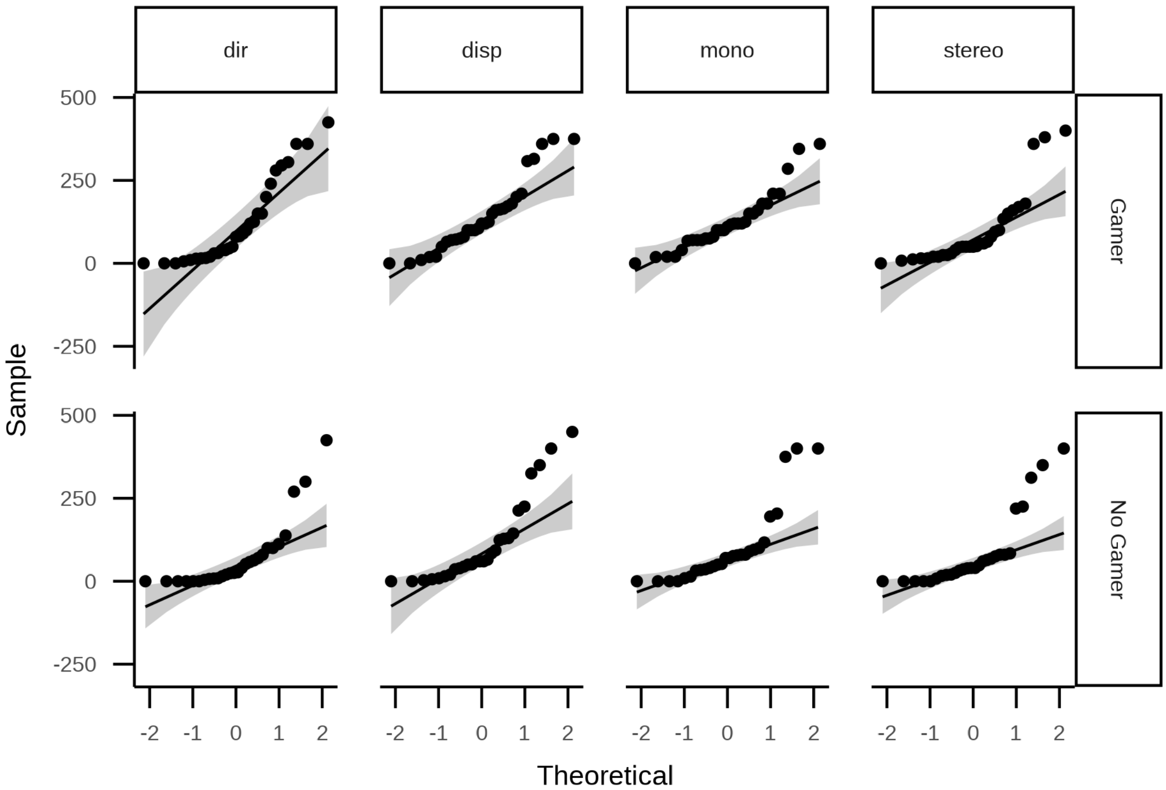

Figure Appendix J.4 Q-Q plot of NASA-TLX score of performance dimension

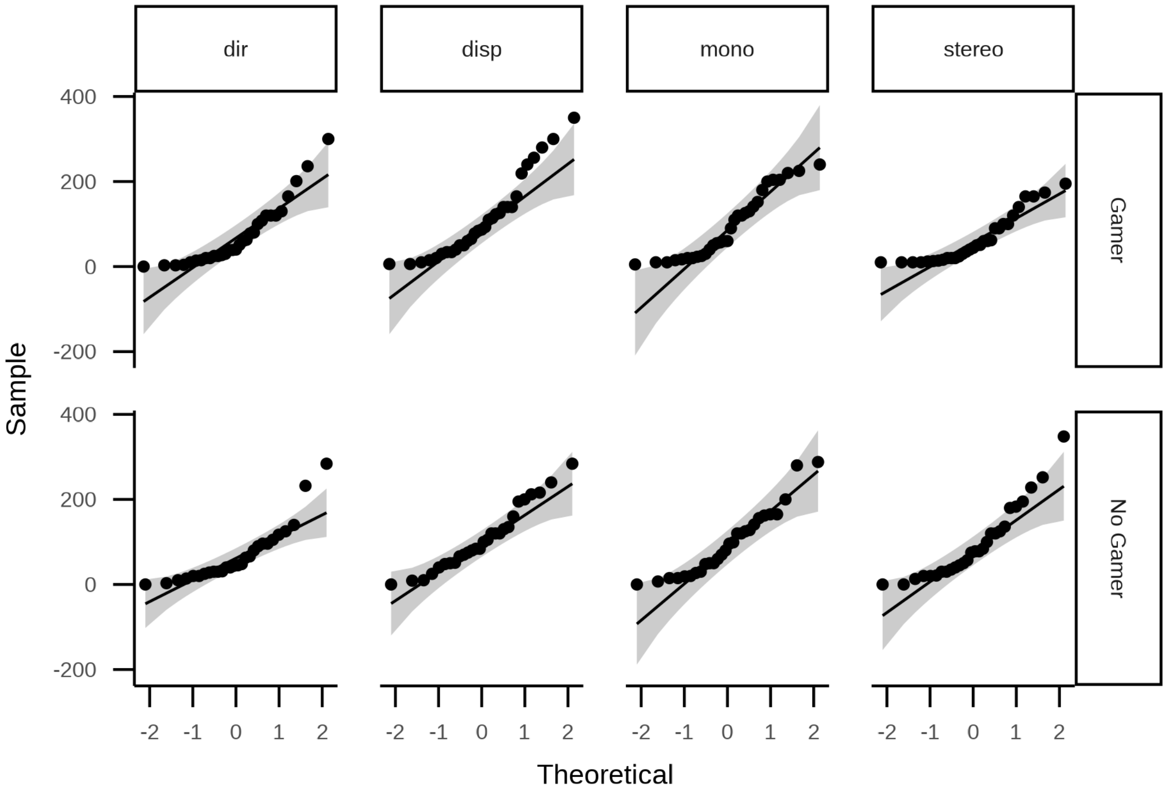

Figure Appendix J.5 Q-Q plot of NASA-TLX score of effort dimension

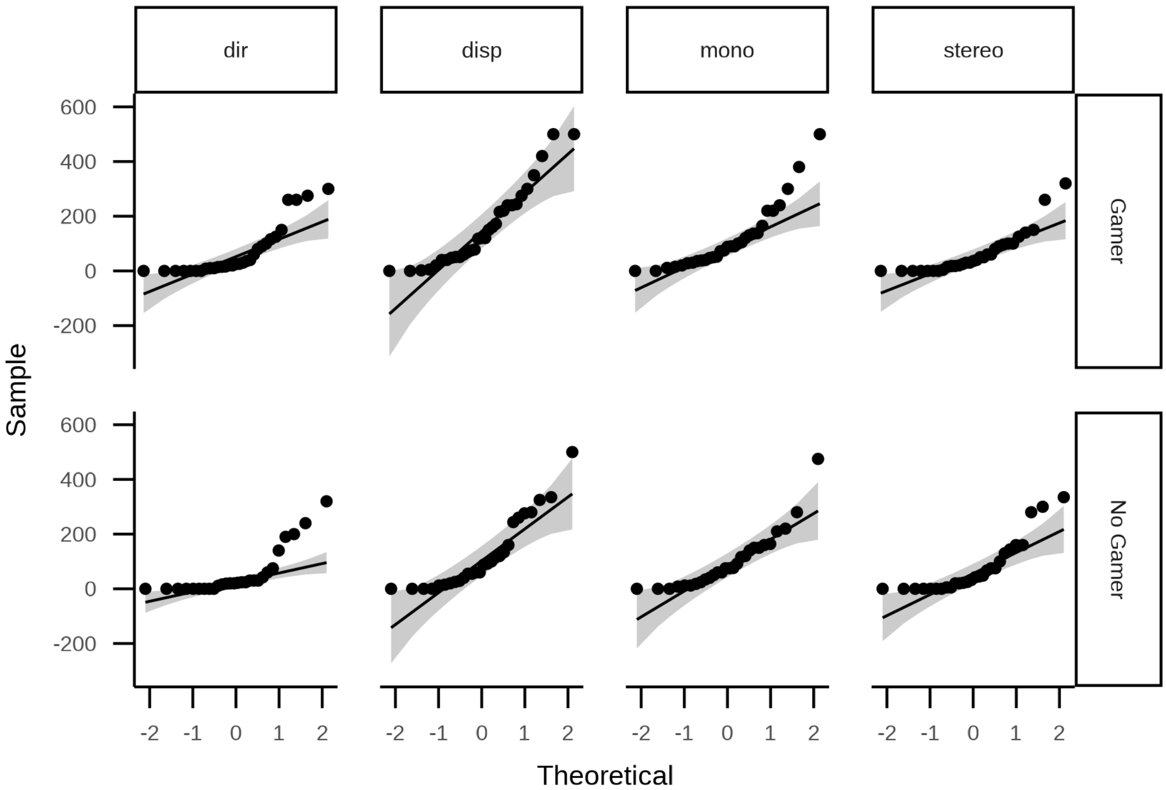

Figure Appendix J.6 Q-Q plot of NASA-TLX score of frustration dimension