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Which Input Method is more Efficient – A Comparison Between Mouse and Controller

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Abstract

Throughout the years, significant attention has been devoted to analyzing the advantages and limitations of huge numbers of already existing absolute (e.g. direct touch, stylus) and relative (e.g. computer mouse, tangibles) input devices. More often than not, comparing these in several environments is also rewarding, as the data could help improve human-computer interaction, future development of more efficient and precise input means, or even simply develop better ergonomics. Besides quantitative aspects, like speed, accuracy, and task completion times, the research has also focused on qualitative aspects, like user preferences, comfort, subjective feedback, and sometimes even perceived workload.

The mouse is indeed the center of attention of an enormous number of papers analyzing it or comparing it to other interaction devices. Meanwhile, the gaming controller sometimes seems to not be of such high interest. We have therefore decided to test and compare the mouse and the controller through 5 diverse interaction tasks in a 2D environment.

This thesis proposes a novel implementation aimed at gathering data for a comprehensive analysis of the differences in performance and usability between tackling various tasks with a mouse or with a gaming controller. It will compare the dissimilarities in quantitative performance and subjective preference by focusing on the variations in precision, efficiency, user preference, and perceived workload associated with the two aforementioned input devices. By conducting this research, interesting insights can be gained, shedding light on the strengths and weaknesses of each approach, ultimately contributing to a better understanding of their respective applications and potential improvements.

Überblick

Im Laufe der Jahre wurde der Analyse der Vorteile und Grenzen zahlreicher bereits existierender absoluter (z. B. direkte Berührung, Eingabestift) und relativer (z. B. Computermaus, Tangibles) Eingabegeräte große Aufmerksamkeit gewidmet. In den meisten Fällen ist ein Vergleich dieser Geräte in verschiedenen Umgebungen ebenfalls aussagekräftig, da die Daten dazu beitragen könnten, die Mensch-Computer Interaktion zu verbessern, effizientere und präzisere Eingabemittel zu entwickeln oder einfach eine bessere Ergonomie zu entwickeln. Neben quantitativen Aspekten wie Geschwindigkeit, Genauigkeit und Dauer der Aufgabenerledigung konzentrierte sich die Forschung auch auf qualitative Aspekte wie Benutzerpräferenzen, Komfort, subjektive Rückmeldung und manchmal sogar die empfundene Arbeitsbelastung.

Die Maus steht in der Tat im Mittelpunkt einer enormen Anzahl von Arbeiten, in denen sie analysiert oder mit anderen Interaktionsgeräten verglichen wird. Demgegenüber scheint der Gaming-Controller manchmal nicht von so großem Interesse zu sein. Wir haben uns daher entschlossen, die Maus und den Controller anhand von 5 verschiedenen Interaktionsaufgaben in einer 2D-Umgebung zu testen und zu vergleichen.

In dieser Arbeit wird eine neuartige Implementierung vorgeschlagen, die darauf abzielt, Daten für eine umfassende Analyse der Unterschiede in der Leistung und Benutzerfreundlichkeit bei der Bewältigung verschiedener Aufgaben mit einer Maus oder einem Gaming-Controller zu sammeln. Sie vergleicht die Unterschiede in der quantitativen Leistung und der subjektiven Präferenz, indem sie sich auf die Unterschiede in der Präzision, der Effizienz, der Benutzerpräferenz und der wahrgenommenen Arbeitsbelastung im Zusammenhang mit den beiden oben genannten Eingabegeräten konzentriert. Durch die Durchführung dieser Untersuchung können interessante Erkenntnisse gewonnen werden, die die Stärken und Schwächen der beiden Ansätze beleuchten und letztendlich zu einem besseren Verständnis ihrer jeweiligen Anwendungen und potenziellen Verbesserungen beitragen.

Acknowledgements

First and foremost, I would like to extend my gratitude towards Prof. Dr. Borchers and Prof. Dr. Schroeder for their valuable time in examining this thesis and for all their insightful feedback I feel so privileged to receive.

I would also like to take a moment to express my appreciation towards my supervisor, Anke Brocker, for providing me with an engaging research topic, for consistently showing genuine interest in my ideas, for the thorough assessments and for her remarkable patience.

Furthermore, the finalization of this research endeavour would have not been possible without all the people that volunteered their valuable time to participate in our examination.

Also, I would want to thank my lovely girlfriend for her endless love, help and motivation and for always being there for me.

Last but not least, I would like to seize this opportunity to thank my parents for all their effort, dedication, love and selflessness in ensuring that my two younger siblings and I receive the best possible education. I am deeply thankful for their sacrifices and for always putting our needs before their own.

Conventions

Throughout this thesis we use the following conventions.

Text conventions

Definitions of technical terms or short excursus are set off in coloured boxes.

EXCURSUS:
Excursus are detailed discussions of a particular point in a book, usually in an appendix, or digressions in a written text.

Definition: *Excursus*

The whole thesis is written in American English.

Throughout this thesis, we refer to unidentified third persons (e.g. participants to our user study) with the gender-neutral pronouns ”they” / ”them”.

For simplicity, we will refer to participants as ’Px’ with $x \in \{1, ..., 14\}$.

Chapter 1

Introduction

In the context of advancing scientific research, many researchers have focused their attention on comparing diverse input methods to one another through various 2D and 3D tasks (see Zaman et al. [2010], Besançon et al. [2017], Tuddenham et al. [2010], Melcer and Isbister [2017], Sambrooks and Wilkinson [2013], Forlines et al. [2007], Meyer et al. [1994]). They combined them in an attempt to enrich desktop interactions (see Villar et al. [2009]), analyzed the influence factors like device size or the number of pointers have (see Hourcade et al. [2007], Block and Gellersen [2010]) and even observed their potential uses in other unexplored fields, e.g. medicine (see Teistler et al. [2016]). The research into comparisons between input devices has proven immensely helpful to their continuous development. As pointed out by Klochek and MacKenzie [2006], finding out the exact differences would help researchers appropriately guide design changes to existing or future devices.

There is a substantial amount of research papers focusing on input devices.

Regardless of type, absolute input methods, like touch-based or stylus-based input, and relative input methods, like mouse-based or controller-based input, both come with their own benefits and limitations.

The differences between mouse and controller were looked at in works like Young et al. [2016], Klochek and MacKenzie [2006], or intel [2023], but they are either too informal or

We have tested the two devices on more than one task.

only focus on a very limited task. Moreover, as previously signaled by Meyer et al. [1994] and Epps [1987], when researchers compare input devices through one single task, the results are difficult to generalize. We have therefore decided to overcome this problem by testing and comparing both devices on a wider variety of tasks.

What is our contribution?

This thesis presents a purpose-built application aimed at gathering sufficient data for a preliminary analysis of the performance and usability of the mouse and gaming controller. We go beyond only looking at the differences in quantitative aspects - efficiency and precision -, by also analyzing differences in qualitative aspects - workload and subjective preference - of the two input methods through a series of basic 2D-interaction tasks. We hope to provide a deeper understanding of the benefits and limitations of these existing interaction techniques.

Participants in our user study came up with exciting insights after tackling the tasks.

Expectedly, throughout the study, the majority of participants continuously answered that the mouse would be faster, more efficient, easier to use, and generally better suited for the presented tasks before actually tackling them. But, surprisingly, they provided a lot of interesting insights and drew surprising conclusions after effectively finishing the tasks.

Even with the mouse continuously being faster and more accurate, participant opinions would sometimes differ.

The results show that the mouse was indeed continuously faster and more accurate throughout the proposed tasks, but participant opinions were sometimes ambivalent. When asked which input device is better suited for a task and why, participants came up with interesting insights. Their answers show that not only quantitative performance influences such a decision, but also ease of use, how "fun" one feels, subjectively perceived speed and accuracy, and more.

Chapter 2

Related work

2.1 Comparing Input Devices

As previously pointed out by Besançon et al. [2017], a lot of previous work has focused on the comparison of interaction devices. The never-ending development in this domain provides researchers with continuous opportunities to analyze novel interaction devices and compare them to already established ones. As is probably expected, there is an enormous amount of research papers featuring one of the world's oldest input devices there is: the computer mouse.

A lot of attention was directed towards analyzing input devices.

Sambrooks and Wilkinson [2013] present an experiment that tasked 15 participants with selecting 100 targets in order to compare gestural, touch, and mouse interaction. Their selections were grouped into smaller rounds separated by short breaks in order to measure participant fatigue and potential fluctuations in performance.

Comparison between gestural, mouse, and touch interaction.

Forlines et al. [2007] compare task performance and user preference between direct-touch and mouse input. They analyze this through an unimanual and bimanual object selection and docking task (shown in Figure 2.1) on a tabletop display.

Comparison between direct-touch and mouse input.

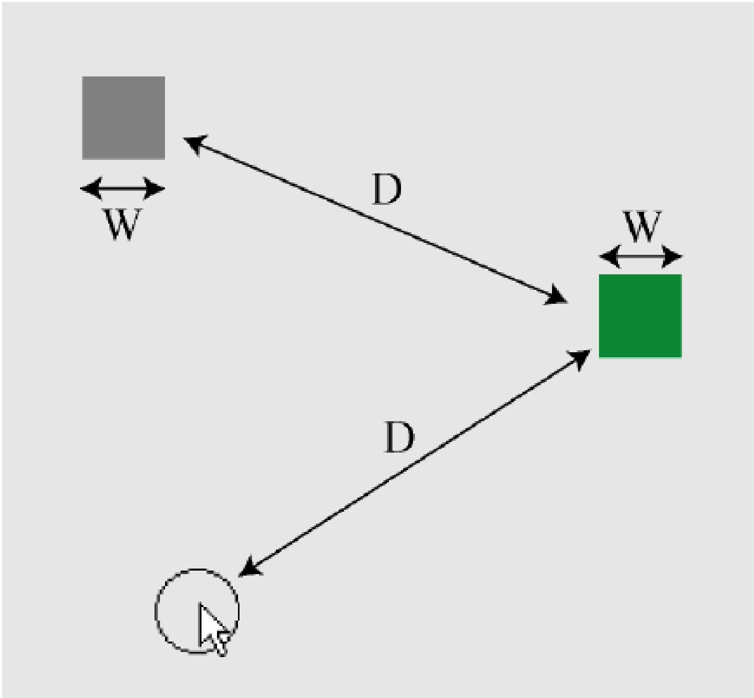

Figure 2.1: Example of an object selection and docking task. Participants move the cursor from the home location (circle) to the green square and drag it into the grey one. Image from Forlines et al. [2007]

Comparison between mouse, tactile, and tangible interaction.

Besançon et al. [2017] analyze participant performance and usability of mouse, tactile, and tangible interaction through a 3D object docking task. They measure task trial times and accuracy, as well as user fatigue, workload, and preference. The ultimate goal is to facilitate transitioning between 3D data exploration environments.

At the same time, although more limited, researchers also concentrated on the gaming controller.

The mouse is more precise and efficient, the controller is more portable and immersive.

Even though it is not a veritable scientific research paper, the article 'Mouse and Keyboard Vs. Controller: Which Is Better for PC Gaming' by intel[1] provides us with an interesting comparison in gaming terms. The authors argue one

[1] intel.com/content/www/us/en/gaming/resources/keyboard-controller.html

of the notable advantages of the mouse is in games where accuracy is crucial, such as first-person shooters. This is because a mouse allows for easier aiming and execution of fast reaction-based shots, like the so-called 'flickshots'. In fact, some controller-based FPS games have aim-assist features to help balance out this disadvantage. At the same time, regardless of its precision and efficiency, the mouse might not be as portable or comfortable to use as a controller. The latter also benefits from the added touch pads, lighting effects, rumble effects, or pressure-sensitive triggers, making gaming more immersive.

The mouse performs better in a 3D object tracking task.

In the experiments described in Klochek and MacKenzie [2006], participants were presented with a 3D object tracking task (see Figure 2.2). The authors have chosen this approach as they argue that target acquisition has already been studied extensively, and they wanted their experiment to reflect what usually happens in games after acquiring a target. Their task challenges 10 participants to accurately track an object around the screen. In one scenario, the objects have a constant velocity, but in another, the speed and direction of the objects will vary. Their results show a visible difference in performance between mouse and controller. The mouse also provided a greater degree of precision when changing direction and tracking objects that were moving at constant speeds.

There is previous research comparing mouse and controller in a selection task.

Lastly, the thorough analysis of Young et al. [2016] presents the differences in precision and time efficiency, among other aspects, between mouse and keyboard, touchpad and keyboard, Steam Controller, and Sony DualShock 4 gaming controller. Their experiment consisted of two tasks. One challenges participants with a well-known 2D object-selection task (similar to the work of Sambrooks and Wilkinson [2013], Forlines et al. [2007]). In the other task, participants use the aforementioned input devices to play "Half Life 2". Their performance and in-game experience were recorded throughout.

Noticeably, previous work indicates that the mouse is more precise, more efficient, and altogether better suited for many tasks. We therefore also expect it to outperform the gamepad. But, besides accuracy and efficiency, we are also

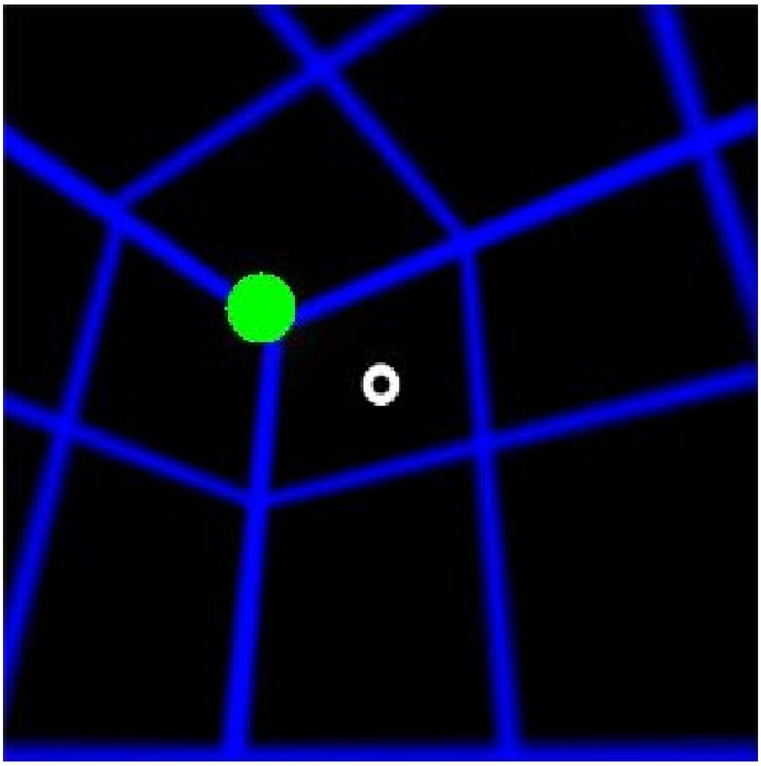

Figure 2.2: Visualization of the 3D object tracking environment showing the crosshair (the white circle) and the target (the green circle). Image from Klochek and MacKenzie [2006]

interested in finding out how performance evolves over time, how high a workload users perceive, and what their subjective preference is. All this data is important for understanding what users like, what they dislike, and how they interact with the mouse and the controller. At the same time, analyzing this data is essential for improving current and future input devices.

2.2 Workload Analysis using NASA TLX

Analyzing the workload users perceive during a specific task is extremely helpful for exploring the task's potential stress-inducing factors, their source, and their possible ef-

Mental Demand	How mentally demanding was the task?
Physical Demand	How physically demanding was the task?
Temporal Demand	How hurried or rushed was the pace of the task?
Performance	How successful were you in accomplishing what you were asked to do?
Effort	How hard did you have to work to accomplish your level of performance?
Frustration	How insecure, discouraged, irritated, stressed, and annoyed were you?

Table 2.1: Descriptions of each individual subscale. Taken from the official NASA website[2] (September 2023)

fects. It is also essential in figuring out what specific aspects could be improved. In our search for an answer to the question 'Which input method is more efficient?', we are going to record user workload after completing each task with the mouse and the controller. The results will show in which scenario either device is less demanding.

Hart and Staveland [1988] came up with a six-scaled assessment test for rating the perceived workload of a subject. It was created to measure the effectiveness and other aspects relating to performance of a task, a system, or a team. The assessment consists of two parts. In the first one, the subject would give a rating between 1 and 20 on each of the six aforementioned subscales (mental demand, physical demand, temporal demand, performance, effort, and frustration). In order for the subjects to provide accurate ratings, each subscale comes with a description, presented in Table 2.1. The second part presents pairwise combinations of the six subscales. The user has to choose which measurement was more important in terms of perceived workload. This creates an individual weighting of the subscales.

To compute a user's workload, they would have to rate each of the six subscales from 1 to 20.

We have selected two most relevant works to our research from the literature.

Besançon et al. [2017] make use of NASA's Task Load Index to measure participant workload after they had completed a series of 3D dockings with a mouse, a tactile interface, and a tangible device. In order to perform measurements that are as accurate as possible, the researchers

The mouse appears to have the best performance rating in a comparison with tactile and tangible input.

[2] https://humansystems.arc.nasa.gov/groups/tlx/tlxpaperpencil.php

asked the participants to fill out a TLX questionnaire after completing the dockings with each input device. Their results show that the overall workload for the mouse condition was situated between the overall workloads of the other two devices. Looking at the individual subaspects revealed that the mouse was the most mentally demanding, but the least physically demanding. The average performance rating was also lowest for the mouse condition, indicating that participants were most successful in completing the task with it.

Aslan et al. [2013] use the questionnaire to measure the correlation between workload and specific finger movements.

Secondly, Aslan et al. [2013] use an established psychological stressor, a Stroop task, to analyze the correlation between the perceived workload of a user and measurements relating to finger movements during the task. The researchers opted to ask every participant to fill out a NASA TLX questionnaire after each of the eight trial blocks.

2.3 Performance Analysis Using Fitts's Law

Definition: *Fitts's Law*

FITTS'S LAW:
Formulated by Paul Morris Fitts, 1954.
States that the time needed to rapidly move to a target area is directly related to the distance to the target and the width of the target (Fitts [1954]).

Since its creation, Fitts' Law has been extremely important for analyzing data resulting from target acquisition tasks. The first part of our paper will be focusing on exactly that. It is therefore crucial to understand how to compute a task's difficulty, quantify its performance, and analyze movement time before proceeding with the presentation of our work.

Paul Fitts' research resulted in a series of formulas for quantifying performance, difficulty, and throughput in a pointing task. Figure 2.3 shows just such a task. It shows 'A', the target amplitude (or distance to the target's center), and the target's width, 'W'.

The index of difficulty of such a task was formulated as

INDEX OF DIFFICULTY (AFTER FITTS):

$$ID_{Fitts} = log_2(\frac{2A}{W}).$$

Definition:
Index of Difficulty (after Fitts)

The Shannon formulation of the Index of Difficulty proposed by Scott MacKenzie[1] is argued to be preferred in research, as MacKenzie and Buxton [1992] claim that it will always result in a positive value, better mimic the theory Fitts' Law is formulated on and would better fit the observations.

INDEX OF DIFFICULTY (SHANNON'S FORMULATION):

$$ID_{Shannon} = log_2(\frac{A}{W} + 1)$$

Definition:
Index of Difficulty (Shannon's formulation)

At the same time, Fitts also provided a metric for user performance, which depends on the index of difficulty of the target and movement time (the time needed to point at the target).

INDEX OF PERFORMANCE:

$$IP = \frac{ID}{MT}$$

Definition:
Index of Performance

Also, Fitts [1954] states that the movement time for each target can be expressed depending on the index of difficulty of that specific target.

MOVEMENT TIME (MT):

$$MT_{Fitts} = a + b * ID = a + b * log_2(\frac{2A}{W})\ and\ MT_{Shannon} = a + b * log_2(\frac{A}{W} + 1)$$

MacKenzie and Buxton [1992] argue that even if Fitts' Law was formulated for one-dimensional tasks only, some previous research (e.g. Card et al. [1987], Epps [1986],

Fitts' Law was initially formulated for 1D tasks, but was later extended to 2D target acquisition tasks.

[1] http://www.yorku.ca/mack/

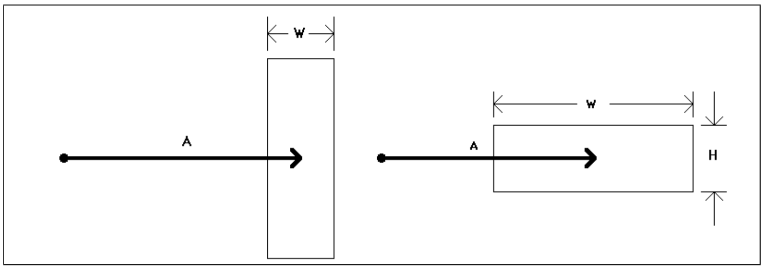

Figure 2.3: Visualization of pointing tasks. Images from MacKenzie and Buxton [1992]

MacKenzie et al. [1991]) had analyzed the results of two-dimensional experiments combining the initial formulation of the law with other confounding variables such as object shape or approach angle. Their paper provides an extension of the initial formulation of Fitts' Law to 2D target acquisition tasks. Their experiment sees participants selecting targets at various distances and angles of intercept.

Fitts' Law is widely used to analyze performance and precision in target acquisition tasks.

Fitts' Law and its subsequent formulations and extensions have been widely used since its apparition to analyze various target acquisition tasks. Sambrooks and Wilkinson [2013] compare performance and precision between mouse, touch, and gestural interaction in a 2D target selection task on a computer screen. Also, Hourcade et al. [2007] challenge 50 children to complete a target selection task in order to observe if mouse size will influence their performance and precision. We have inspired our first two experiments from Forlines et al. [2007]. This research paper presents an already-established target acquisition and manipulation task used to observe differences between direct-touch and mouse input using Fitts' Law.

Chapter 3

Implementation

This chapter presents the workflow of the application we have developed for the user study, together with our underlying considerations. It is worth mentioning that our application also logs valuable data in the background, facilitating the upcoming analysis.

The entire application[1] presented in this section has been developed using the Unity Real-Time Development Platform[2]. The associated codebase has been written using the C#[3] programming language. Established libraries and namespaces such as the Microsoft 'System' Namespace[4] and Unity 'Input System'[5] for controller support have also been integrated.

Our purpose-built application was developed using Unity.

3.1 Object Selection, Object Docking

The initial phase of this challenge involves players being tasked with quickly and accurately selecting an object - either a red circle or square - that appears on the screen at a random position. In the latter phase, players are required

The first challenge involves a traditional 2D task of selecting and docking objects.

[1]https://gitfront.io/r/JohnnyB/TDqCrEEpbA1p/bachelorarbeit/
[2]unity.com
[3]learn.microsoft.com/en-us/dotnet/csharp
[4]learn.microsoft.com/en-us/dotnet/api/system?view=net-7.0
[5]docs.unity3d.com/Packages/com.unity.inputsystem@1.6/manual/index.html

to drag a similar object - again, a red circle or square - and place it into its corresponding blue placeholder.

The presented task also has applicability in real life.

This task simulates selecting objects in various environments (e.g. clicking links in an internet browser, writing using a floating keyboard, precision aiming in various First Person Shooter games like CS:GO[6] and PUBG[7], and dragging and dropping an object (e.g. file-upload systems, 3D data analysis, 3D design, gaming).

3.1.1 Settings

The player is, at first, presented with a 'Settings' screen.

In the beginning, the player has to select an optimal movement speed for the cursor for both controller and mouse scenarios. This is achieved by adjusting the slider visible in Figure 3.1 for the controller and customizing the operating system's cursor settings for the mouse. The hereby configured sensitivities would be used in both upcoming phases of this first task.

The settings screen also provides means of testing precision.

Additionally, moving the cursor below the midpoint of the 'Submit' button instantly attaches the red square to it. This allows players to test their selected cursor sensitivity and precision. Clicking on the 'Submit' button initiates the first phase of the task.

3.1.2 Selections

Placing the cursor inside the black circle starts a trial,

but,

we also wanted to avoid the anticipation.

After having configured suitable sensitivities for the mouse and controller, the player is presented with the initial phase of the task, which focuses on object selection. Figure 3.2 visualizes the beginning of a trial. The player would have to fully place the pointer inside the black circle , guiding themselves by its central red marker. Then, the warning (the red square above it), would turn green, signalizing that the trial has started. In alignment with Forlines et al. [2007], we prevented the player from anticipating the start

[6] https://store.steampowered.com/app/730/CounterStrike$_{Global_{O}ffensive}$/
[7] https://pubg.com/en-na

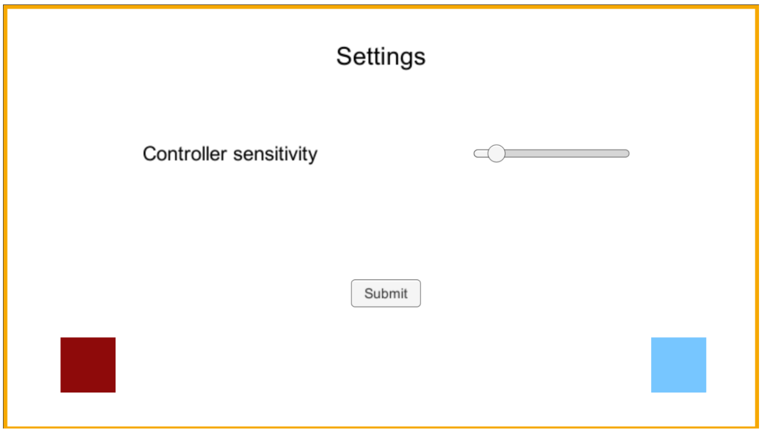

Figure 3.1: Settings - selections & dockings

of a trial by incorporating a temporal delay into this task's design. After the warning turns green, the player has to wait a random amount of time (between 0 and 2 seconds) until the black circle and now green square disappear from view, and a red figure appears somewhere in the frame. After a successful selection, the red object disappears, and the black circle and the red warning appear near the cursor's position. It has to be mentioned that moving the cursor outside the black circle after the warning has already turned green would simply cancel the start of the trial run, and the player would have to proceed as they normally would for a new trial start.

Solution: adding a delay.

Moving the pointer outside the black circle cancels the start of the trial.

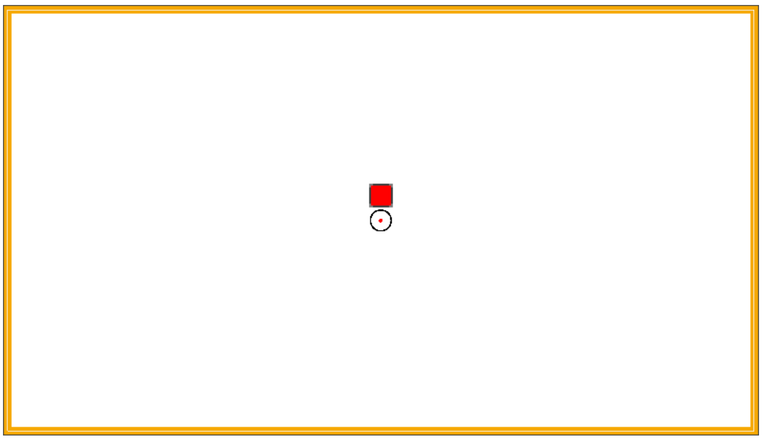

Figure 3.2: Beginning of a trial - selections & dockings

Every player would have to select a total of 48 objects: 24 with the mouse, and 24 with the controller.

The target selection phase is partitioned into 3 rounds of 8 trials each (separated by a brief 10-second break). This rationale, as inspired by Sambrooks and Wilkinson [2013], could show potential improvement or decline in performance over time. Within each round, players are tasked with selecting 4 squares and 4 circles with varying dimensions: 140x140 pixels, 100x100 pixels, 60x60 pixels, and 40x40 pixels (presented in Figure 3.3). Each trial round is initiated with the largest objects and concludes with the smallest ones.

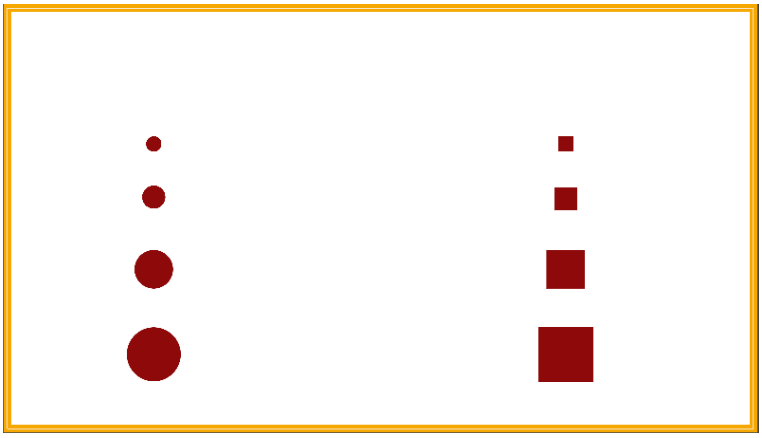

Figure 3.3: Presentation of the objects in the selection phase

3.1.3 Dockings

The start of a docking trial works just like the start of a selection trial.

Upon the successful completion of all three rounds of target selection, the player would be automatically transitioned to the subsequent phase of the task, focusing on the process of object docking. The player is presented with the familiar screen layout depicted in Figure 3.2. The trial start follows the previously described protocol: (1) the cursor is placed inside the black circle, (2) the red warning turns green, (3) the player has to wait between 0 and 2 seconds, (4) the black circle and now green warning disappear and (5) a red figure emerges beneath the cursor's location while, simultaneously, a corresponding blue placeholder appears at a randomized position on the screen, as illustrated in Figure 3.4. Then, the player has to move the cursor (and, simultaneously, the red object, as its center is bound to the position of the cursor) to the location of the blue shape. Docking occurs automatically once the distance between the centers of the red and blue objects, continuously measured using Euclidean distance, is less than 3 pixels and does not require clicking or any other action. Forlines et al. [2007] argue that this approach effectively removes between-player disparities in the perceived alignment accuracy of the red and blue targets.

Docking occurred once the centers of the 2 objects would be within 3 pixels of one another.

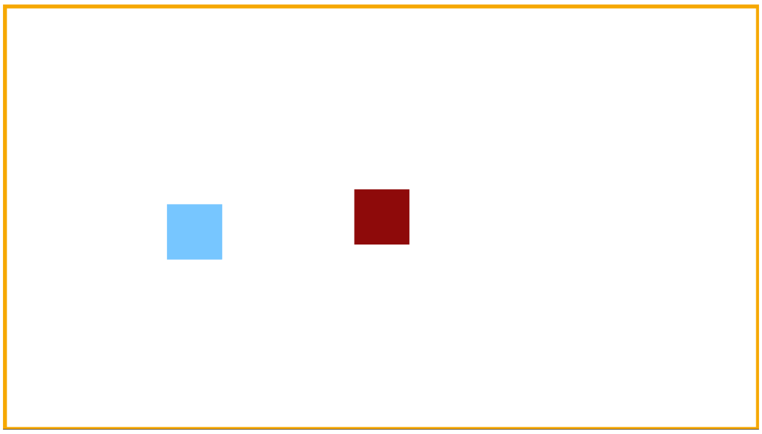

Figure 3.4: Red object to be docked and its corresponding blue holder

Just like the former half of this task, the target docking phase is also partitioned into 3 rounds of 8 trial runs each separated by a brief 10-second break, motivated by the same rationale as before. Within each round, players are again asked to dock 4 squares and 4 circles with varying dimensions (140x140 pixels, 100x100 pixels, 60x60 pixels, 40x40 pixels; see Figure 3.5), and each trial round also starts with the largest objects and ends with the smallest ones.

Every player would have to dock a total of 48 objects: 24 with the mouse, and 24 with the controller.

3.2 Object Tracking

In this part, the player is tasked with tracking a red circle that moves around the screen and changes its speed, direction, and size.

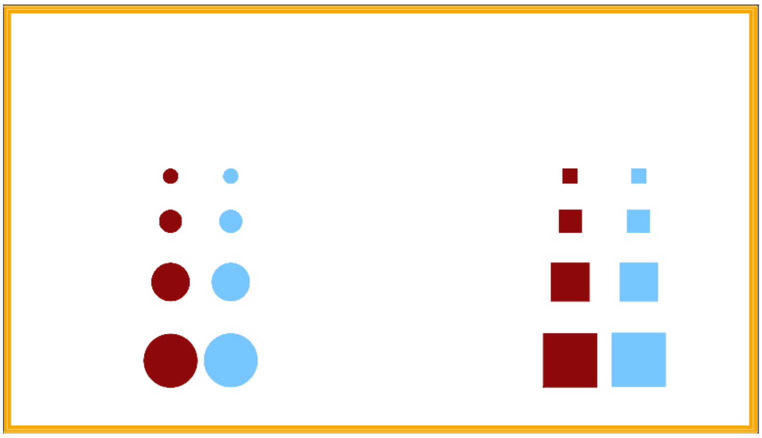

Figure 3.5: Presentation of the objects for the docking phase

This task is inspired from first-person shooters.

This task is based on the work of Tuddenham et al. [2010] and Klochek and MacKenzie [2006]. The authors of the latter wanted to analyze user performance in what usually comes after acquiring an object: tracking it. Accurately following an object is usually an important part of first-person shooters. These games include a lot of dynamic fire-fights in which it is imperative for the player to accurately follow the enemy in order to score a kill and survive.

3.2.1 Settings

The player is initially presented with a settings screen and a means of testing the configured sensitivities.

As before, the player is initially presented with a settings screen where they have to select an optimal movement speed for the cursor for both controller and mouse scenarios. Just like before, that is achieved by moving the slider in Figure 3.6 for the controller and customizing the operating system's cursor settings for the mouse. A red, 100-pixel wide circle is moving along the black dotted line (not present in the actual settings screen) with varying speeds, allowing the player the opportunity to observe their selected cursor speed and object tracking precision. Clicking on the 'Submit' button initiates the task.

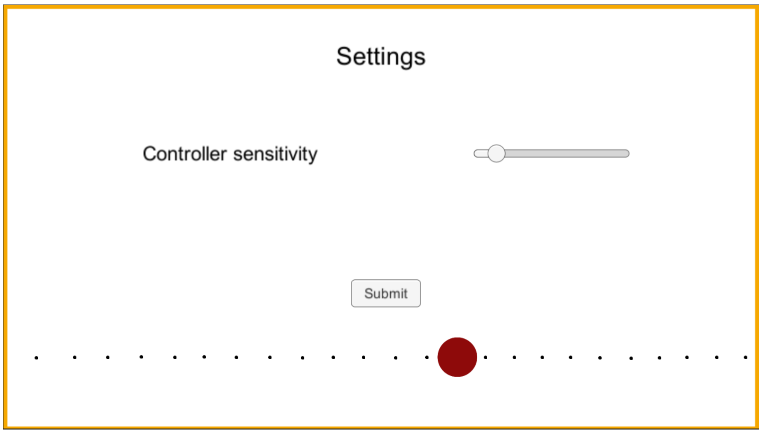

Figure 3.6: Settings - object tracking

3.2.2 Task

After having configured suitable sensitivities for the mouse and controller, the player is presented with the task at hand. They have to press a green 'Start' button (Figure 3.7), after which the red circle emerges just behind the cursor. The player then has to follow the moving circle around the screen. Every 2.5 seconds, the object chooses a new random movement direction and a random movement speed (between 100 and 150 pixels per second). This would also happen prematurely in the case of a collision with one of the 4 sides of the frame. Every 10 seconds, the circle also becomes smaller.

The circle changes its speed, direction, and size.

When a player's tracking becomes inaccurate (cursor leaves the circle's area), the application would provide feedback. This mechanism is meant to alert the player of the mistake and make them try and remediate it. In the mouse scenario, the background briefly turns red upon cursor exit and white upon re-entry. In the controller scenario, tactile feedback is given through vibration using the DualShock controller's internal vibration motors.

Our application would alert the player of any imprecisions.

The object tracking task is partitioned into 3 rounds of 4 trial runs each, separated by a 10-second break, to observe potential improvement or decline in player performance. Within each round, a player has to follow 4 circles with

Every player would track a total of 24 circles: 12 with the mouse, and 12 with the controller.

Figure 3.7: Task 'Start' button

varying widths - 140, 100, 60, and 40 pixels. A round starts with the widest circle and ends with the narrowest one.

3.3 Path Tracking

We propose a novel approach to input device comparison: path tracking.

In the context of the third task, we propose a novel approach for comparing input devices: path tracking. This evaluative exercise will put the player's aptitude in cursor control to the test, demanding precision during the traversal of not only straight lines but also tough curves. The main objective remains to keep the cursor within the designated path.

3.3.1 Settings

This page allowed checking cursor sensitivity and line following precision.

Tackling this challenge with the controller sensitivity configured in the previous task proved to sometimes be very difficult during our test studies. We have therefore decided to once again allow players to configure both cursor speeds for the mouse and the controller by using a slider (see Figure 3.8) or by altering the system's settings. The bottom half of this page shows a method for checking tracking precision and cursor sensitivity by presenting the players with one of the paths they would have to accurately follow in the upcoming task. Clicking on the 'Submit' button initiates the task.

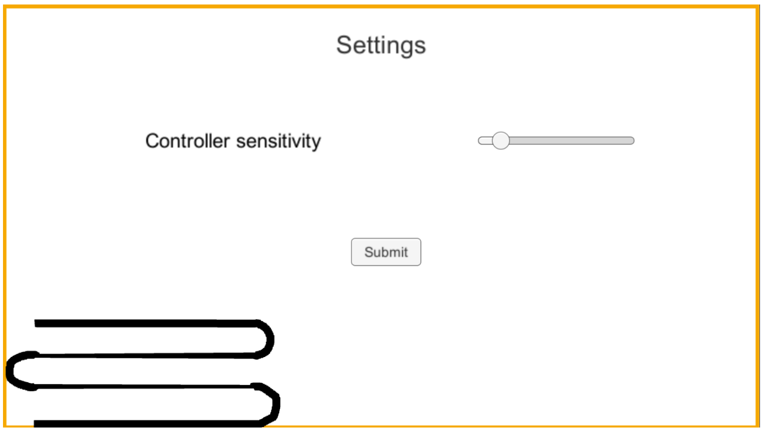

Figure 3.8: Settings - path tracking

3.3.2 Task

The beginning of this task presents the player with a green 'Start' button (as already depicted in Figure 3.7). Pressing it reveals the first path the player has to follow, along with two other supplementary controls labeled 'begin' and 'end'. The reasoning behind this is an accurate timing of task completion. We drew this conclusion from our preliminary study, where players occasionally needed to seek clarification or familiarize themselves with the task before starting. We have therefore deemed it essential to program our application to only initiate a background timer after the player would hover the 'begin' button. Similarly, the application would halt the timer upon the player placing the cursor above the 'end' button, which would also make the application seamlessly transition to a new path. Clicking on either button was not required. An illustration of a trial run is presented in Figure 3.9.

Our application would only count actual task completion times.

Hovering the 'end' button started the next trial run.

Similar to the object tracking task, players promptly receive feedback about tracking inaccuracies through the modalities they are already familiar with. In the case of the mouse,

Our application would alert the player of any imprecisions.

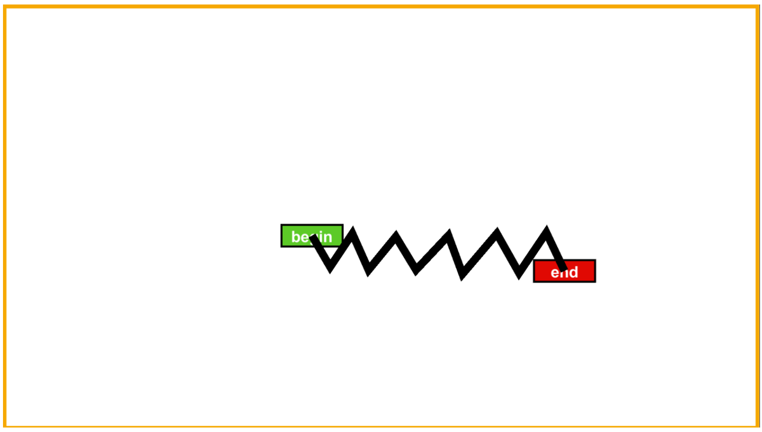

Figure 3.9: Example of a path tracking trial run

the background swiftly turns red when the cursor leaves the designated path and returns to white upon re-entry. In the controller scenario, tactile feedback in the form of vibration, generated by the DualShock controller's internal vibration motors, is employed once again.

In total, a player would have to accurately track 18 paths: 9 with the mouse, and 9 with the controller.

Like the preceding tasks, the path tracking challenge is also divided into three rounds of three paths each, separated by the already familiar 10-second break. However, the paths that have to be tracked become longer, thereby increasing tracking difficulty. We have provided a visualization of all paths in Figure 3.10. Note that the three paths on every column would be part of the same round (from left to right).

3.4 Configuring Finite-State Machines

We propose a task to record overall input device usage time.

The second new task we propose for observing differences in efficiency between input devices (and also the last task in our implementation) presents players with a series of buttons, a character, and a labyrinth. Their objective is to configure a finite-state machine that would control their character and guide it to a bounty chest. This task consists of 2 levels, presented in Figure 3.12 and Figure 3.13.

This level unifies actions usually done with a mouse or controller.

The sole purpose of this last approach is to bring actions

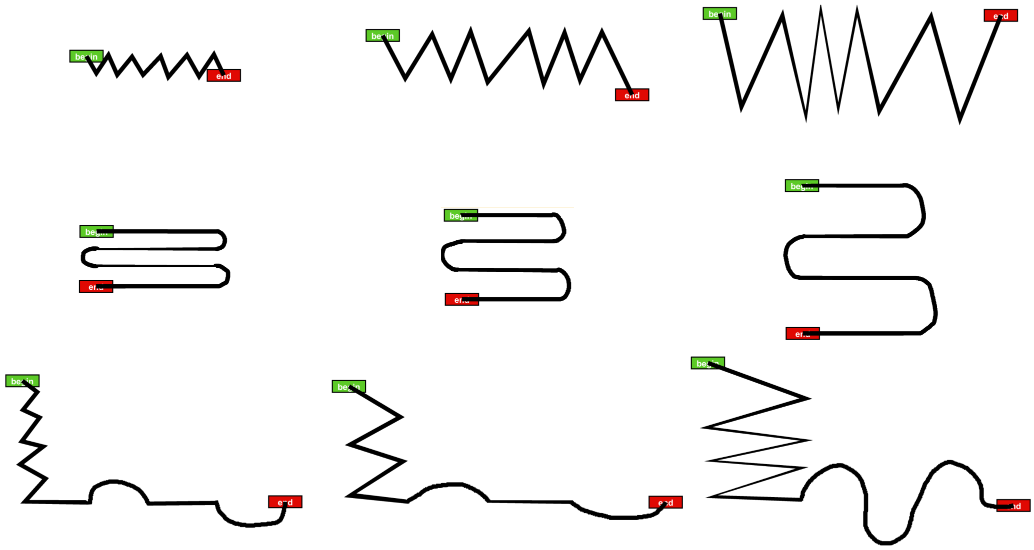

Figure 3.10: Paths available in the path tracking task

associated with a mouse or a controller - such as pointing, clicking, dragging, dropping - into a unified, timed exercise.

The 8-bit graphics used in the development of this part of our application (walls and paths of the labyrinth, swords, and the controllable character) are publicly available[8].

3.4.1 General Functionality

The gray circles outlined in white depict the character's states and dictate its actions. For instance, when the current state would be "going up", the character would correspondingly move upwards. This principle is extended to all the other states within the system. It was also possible to move the circles around, giving the players the possibility to ease the cognitive load by placing the states in more suggestive positions (an example is presented in Figure 3.11).

The circles depict states, and control the character's behavior.

The rectangles situated on the left side of the screen outline conditions for the transitions. To illustrate, if a player were

The rectangles on the left depict conditions for the transitions.

[8] https://0x72.itch.io/16x16-dungeon-tileset

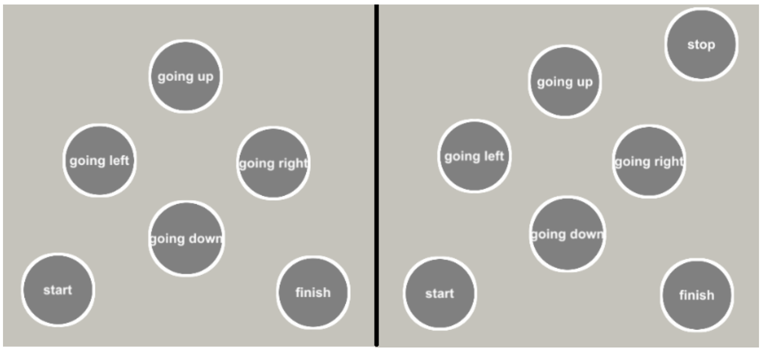

Figure 3.11: Example of states placement in level 1 (left) and level 2 (right)

to establish a transition between the states "going up" and "going left" with the designated condition "sword left", this signifies that, while the character is moving upwards, it would have to encounter a sword that is pointing left in order to subsequently change its movement direction, specifically to the left.

The buttons on the right would control the execution.

Once a transition between any two states was available, the 'Start' button (top right) would turn green. Pressing it would start the execution of the configured state machine. Pressing 'Pause' would halt its execution. The 'Reset' button would completely restart the level, deleting any configured transitions and replacing the character in its starting position.

3.4.2 First Level

Main objective: guide the character to the bounty chest.

In the initial level (illustrated in Figure 3.12), players are tasked with configuring a finite-state machine to maneuver the character from its starting point (lower right) to the final destination at the chest (indicated by the white circle). This involves employing the directional cues presented by the swords. The optimal solution for this level is presented in Table 3.1.

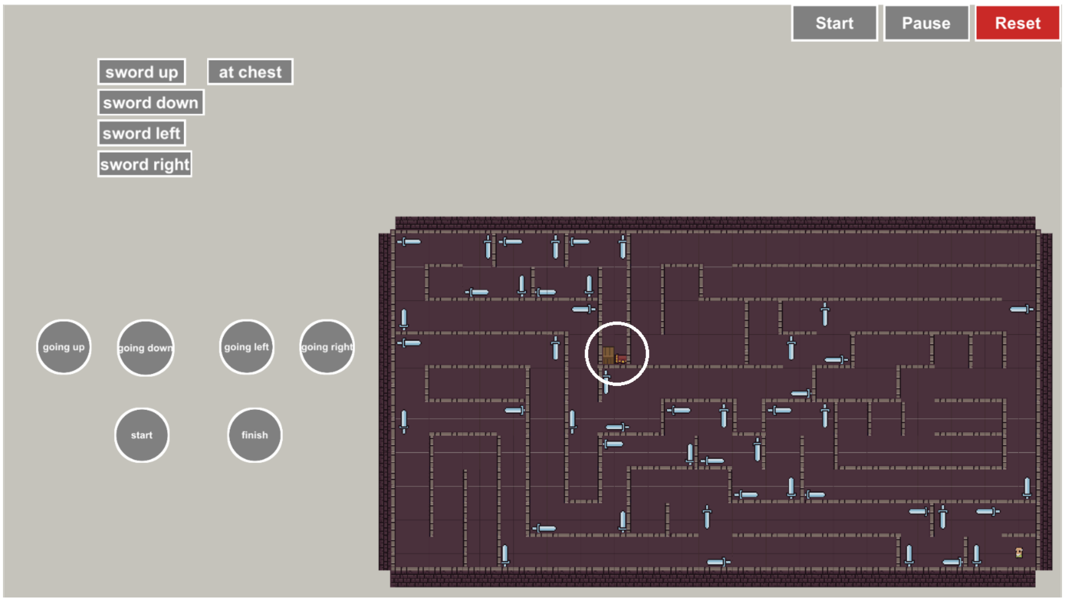

Figure 3.12: First level of the last task

3.4.3 Second Level

The final level of this task (Figure 3.13) offers a comparable challenge. Players are required to configure a finite-state machine to guide the character from its initial position in the upper right corner to the chest located in the lower right corner. Additionally, the controlling finite-state machine has to steer the character clear of the white ghosts by stopping it on the red warnings. The subsequent change of the warning's color to green means the resumption of safe movement for the character. The optimal solution for this level is presented in Table 3.2.

Main objective: guide the character to the bounty chest while avoiding the dangerous ghosts.

The rationale for developing two levels within this task aligns with the motivation for the preceding tasks. Drawing inspiration from Sambrooks and Wilkinson [2013], this approach seeks to observe potential performance fluctuations over time. It would have been futile to simply let players tackle the same level twice, as they would have simply used their previous solution once more. The second level slightly elevated the level of difficulty, albeit not considerably so. It added the need to bring the character to a halt and then re-put it in motion.

The division of the task into two levels serves the purpose of observing performance variations over time.

from	to	condition
"start"	"going left"	-
"going up"	"going left"	"sword left"
"going up"	"going right"	"sword right"
"going down"	"going left"	"sword left"
"going down"	"going right"	"sword right"
"going left"	"going up"	"sword up"
"going left"	"going down"	"sword down"
"going right"	"going up"	"sword up"
"going right"	"going down"	"sword down"
"going down"	"finish"	"at chest"

Table 3.1: Solution - Finite-State Machines, Level 1

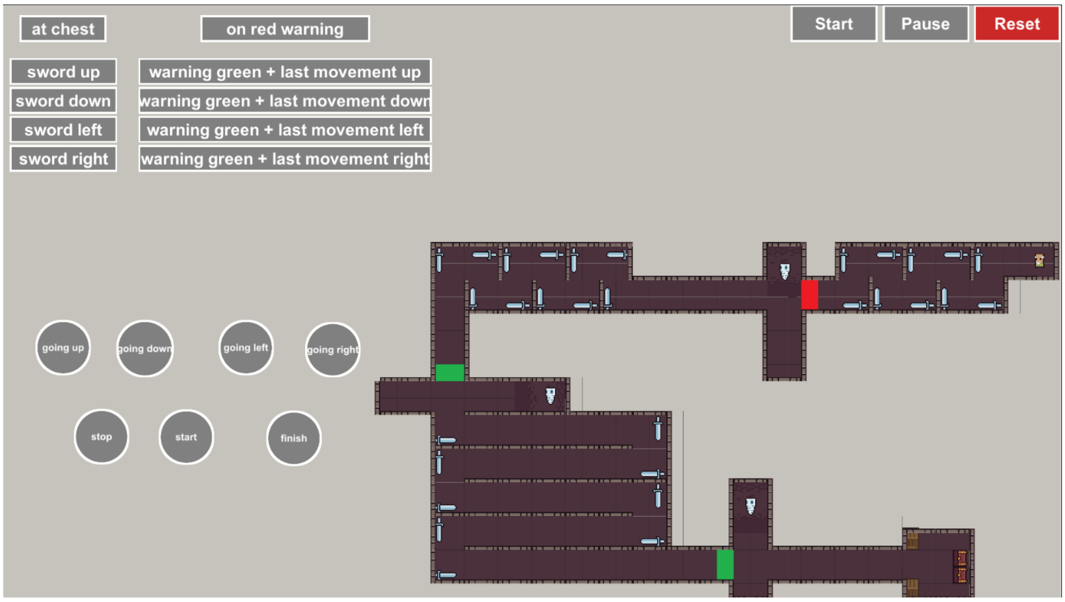

Figure 3.13: Second level of the last task

The application times the task in two ways: interaction time and total task time.

In order to time the completion of these levels more precisely, we have configured the application to separately register the interaction times (the time in which the player would actually interact with the input device by clicking on buttons or moving the mouse or the joysticks) and the total level completion time.

from	to	condition
″start″	″going left″	-
″going up″	″going left″	″sword left″
″going up″	″going right″	″sword right″
″going down″	″going left″	″sword left″
″going down″	″going right″	″sword right″
″going down″	″stop″	″on red warning″
″going left″	″going up″	″sword up″
″going left″	″going down″	″sword down″
″going left″	″stop″	″on red warning″
″going right″	″going up″	″sword up″
″going right″	″going down″	″sword down″
″going right″	″finish″	″at chest″
″going right″	″stop″	″on red warning″
″stop″	″going down″	″warning green + last movement down″
″stop″	″going left″	″warning green + last movement left″
″stop″	″going right″	″warning green + last movement right″

Table 3.2: Solution - Finite-State Machines, Level 2

3.5 Input Devices

As all the previously presented tasks have to be tackled with both input methods, we are hereby going to explain how each of them is configured.

3.5.1 Mouse

The mouse moves the cursor around the screen with the selected cursor speed set up during each of the settings phases of our tasks (see 3.1.1, 3.2.1, and 3.3.1). Object Selection also involves clicking with the left mouse button. The last task, described in section 3.4 (Configuring Finite-State Machines) is the most demanding. A player clicks the various buttons presented on the screen with the left mouse button. Holding the same button down over any of the states moves them around. Pressing the right mouse button deletes the last configured transition.

3.5.2 Controller

Figure 3.14: DualShock 4 Gaming Controller (taken from the official website[9])

Players configure the cursor speed for the controller scenarios by moving the sliders to the right (for increased sensitivity) or to the left (for decreased sensitivity), as outlined in sections 3.1.1, 3.2.1, and 3.3.1. To emulate the versatility of a mouse, encompassing both increased precision at slow cursor speeds and increased time efficiency at high cursor speeds, we configured the left joystick on the controller (see Figure 3.14) to move the cursor at the chosen speed and the right controller joystick to move the cursor at 50% of the selected speed. Combining them - i.e., aligning the directions of both joysticks - would make the cursor move at 150% of the selected speed. Functionally, button interactions, whether for object selection or finite-state machine configuration, were executed by pressing the 'X' button on the gamepad. Selecting the objects in the first task (see 3.1.2) would be done by placing the cursor above an object and pressing on either joystick.

The last task presented a somewhat greater challenge. For simplicity, the traditional cursor was disabled. Moving around the screen involved utilizing the left controller joy-

[9] https://www.playstation.com/de-at/accessories/dualshock-4-wireless-controller/

stick to designate direction. Then, the selector, represented by a yellow outline surrounding the chosen object (an example is visualized in Figure 3.15), promptly shifted to the nearest object in the designated direction - be it transition, or button. In case the selected object was a state, its core would turn black.

Figure 3.15: Examples of currently active transitions (1), buttons (2), and states (3)

Chapter 4

User Study and Results

4.1 Aim of the User Study

We analyze the data produced by our application relating to participant performance, workload, and subjective preference. Our goal is to answer the following research questions:

RQ1: Which input device is faster in each of the presented tasks?

RQ2: Which input device is more accurate in each of the presented tasks?

RQ3: Which input device is generally easier to use in each of the presented tasks?

RQ4: Which input device is better suited for each of the presented tasks?

RQ5: What influences participants in choosing which input device is better suited for each of the presented tasks?

RQ6: What does the individual and overall workload look like for each of the presented tasks?

4.2 Methodology

Upon arriving, participants were informed about the nature of the upcoming tasks and asked to fill out the Informed Consent Form (see Appendix A). Then, the user study would be carried out as follows:

1. Fill out the 'before' part of the User Study Questionnaire section corresponding to the task (see Appendix B).
2. Complete the task at hand with the first input device the application selected.
3. Fill out the NASA TLX questionnaire regarding the workload they had just perceived.
4. Complete the task at hand with the remaining input device.
5. Fill out the NASA TLX questionnaire regarding the workload they had just perceived.
6. Fill out the 'after' part of the User Study Questionnaire section corresponding to the task.
7. Answer the question 'What influenced your decision?' verbally. The experimenter would record the response with their phone.
8. Go to point 1 for the next task until the participant is done with the User Study.

As was done by Tuddenham et al. [2010], the order in which the input technologies were presented to the participant was balanced using a Latin square over the course of the 14 studies in order to avoid order effects.

4.3 Apparatus

Our apparatus for the presented experiments consisted of the Consent Form and User Study Questionnaire, the

NASA TLX Questionnaire (TLX), and our purpose-built application. The presented hardware was positioned on a commercially available desk. The participants would sit on office chairs while solving the tasks.

4.3.1 Software

During the user study, the participant would solve the tasks using our purpose-built application and answer the workload-related questions using a NASA TLX questionnaire available online[1]. For the cooperation scenario of the finite-state machine configuration task (which will be presented shortly), we used MouseMux[2] to make it possible to present the two cooperating participants with two different, independent cursors.

4.3.2 Hardware

The desk setup consisted of an HP Pavilion 15-ec2013nq Gaming-Notebook, a PlayStation 4 DualShock 4 gaming controller, and a Logitech optical USB mouse, respectively 2 mice and 2 DualShock controllers for the cooperative setting of Experiment 4.

The user study configuration is shown in Figure 4.1.

4.4 Participants

A total of 14 students participated in our study.

N = 14 participants (8 males / 6 females) aged 20-25 (mean = 22.14, standard deviation = 1.36) were recruited from the RWTH Aachen University Campus between the 21st of July and the 8th of August 2023. Of these, one was ambidextrous, and the rest used the mouse with the right hand. All but one participant, who suffered from color blindness, had

[1]https://www.keithv.com/software/nasatlx/
[2]https://mousemux.com/

Figure 4.1: User Study Configuration

normal or corrected-to-normal vision. It was also imperative that no participant was suffering from photosensitive epilepsy, due to the occasional flickering of the screen when visual feedback was provided during experiments 2 and 3.

All participants had previously used a mouse and a controller.

All participants had previously played games on a computer using a mouse, as well as on a gaming console (e.g. PlayStation, Xbox) using a controller, and they were familiar with both input devices.

Participants use mice or touchpads often.

7 participants (50%) use a mouse daily, 3 (21.4%) use one at least once a week, 1 (7.1%) does so at least once a month, and the remaining 3 only use a mouse a few times a year. Notably, those who use a mouse less than daily simply explained that they use a touchpad instead.

Although familiar with one, participants rarely use a controller.

As for the controller, one participant (7.1%) uses it at least once a month, 11 participants (78.6%) engage one a few times a year, and the remaining 2 participants (14.3%) almost never use a controller.

4.5 Data Analysis

The various task completion times (selection and docking) and total trial times (object and path tracking) will be analyzed using basic descriptive statistics. The object selection task will also be analyzed using Fitts' Law (explained in 2.3.) We have chosen to use the Shannon formulation to compute the Index of Difficulty, and therefore also the Index of Performance and Movement Time, to keep in line with the latest research in this domain. As we are using squares and circles for our objects, the width equals the height, and we will therefore calculate the aforementioned values accordingly (Lin and Cheng [2022]).

Task trial and completion times are analyzed using descriptive statistics.

The provided Likert Scales are composed of five possible answers - Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, and Strongly Agree - and we will attribute each of these possible options a numerical value from 1 to 5. As this variant will provide us with ordinal data (as presented by Kostoulas [2014]), we will compute the central tendency and spread of the answers for each question (available in Appendix B) by calculating their median value and IQR (Inter Quartile Range; the difference between the third and first quartile of a distribution).

We compute the central tendency and spread for the answers of each item in the user study questionnaire.

For measuring workload, we have employed the use of the NASA TLX questionnaire. We will only analyze its first part, where participants had to select a rating for each of the six indicators, therefore not considering the weights. We are thus left with what is known as a Raw TLX (RTLX), about which Hart [2006] argues that it may be equally suited as the regular TLX. Just like Besançon et al. [2017], we will compute the workload for each task as an average of the RTLX ratings provided by the participants.

We compute the average workload for each task using only Raw TLX ratings.

We will also present 95% confidence intervals in our analysis of participant workload. As argued by Lisa Sullivan, the Central Limit Theorem does not apply for sample sizes smaller than 30, and the t-distribution should be used for the computation of confidence intervals instead of the z-value.

We compute 95% CIs for the workloads using the t-distribution.

We will combine performance, workload, and preference in the 'Combining Results' sections.

In the 'Combining Results' subsection of every experiment, we will simultaneously look at the performance analysis, the answers to the dichotomous questions, and participant workload, hoping to draw some interesting insights from the data. Dichotomous questions that refer to speed (contain the keyword 'faster') will be integrated with the average trial times and the performance sub-aspect of the workload. Those that refer to difficulty (keywords 'generally easier') will be paired with the average between physical demand, mental demand, and effort for the task. For simplicity, we will call this value 'stress factor'. Questions that refer to precision (keywords 'more accurate') will be joined with selection errors or overall trial accuracy (for object and path tracking), and TLX frustration. Lastly, answers that indicate which input method is more suited for a specific task are combined with the overall participant workload. Please note that, in these sections, IQR values for the dichotomous questions were computed assigning the mouse the value 1 and the controller the value 2.

4.6 Experiment 1: Object Selection, Object Docking

We have decided to follow the existing research precedent (Forlines et al. [2007]) and treat the Object Selections and Object Dockings as two halves of the same task.

4.6.1 Independent Variables

- *input device* (mouse and controller)
- *target shape* (square and circle)
- *target width* (140, 100, 60, 40 pixels)

4.6.2 Dependent Variables

- *movement time*, the duration between the spawn of the red object on the screen and the cursor entering its perimeter (only in the selection task)

- *selection errors*, so-called 'misclicks' (only in the object selection task)
- *selection time*, the duration between the spawn of a red target and its successful selection (only in the object selection task)
- *docking-time* (only in the object docking task)
- *position of blue placeholder* (only in the object docking task)
- *distance between red and blue target* (only in the object docking task)

4.6.3 Results - Object Selection

Performance Analysis

A Wilcoxon Signed-Rank Test shows a statistically significant difference between the selection times performed with the mouse and those performed with the controller (z = -3.3, $p < 0.001$). The average selection time using the mouse was 955.73ms (± 394.63ms), while with the controller, it increased to 1846.97ms (± 730.44ms, mean difference = 891.24ms). The discrepancy in performance is also clearly visible in Figure 4.2 (mean IP for the mouse is 3.53 and for the controller 1.91). A Friedman Analysis proves that the shape size influenced selection time with both mouse and controller (X_r^2 = 55.33, $p < 0.00001$ for the mouse and X_r^2 = 33.74, $p < 0.05$ for the controller), with smaller objects always taking more time to select.

There was a significant difference in performance between mouse and controller.

As previously mentioned in section 3.1.2, our experiment also sought to determine if performance improved or declined over the course of the three rounds. Table 4.2 shows a definitive increase in performance for both input devices over the three rounds, although admittedly somewhat more limited over the last two. Expectedly, selection times increased with the decrease in object size. The only

The data shows an increase in performance over the three rounds.

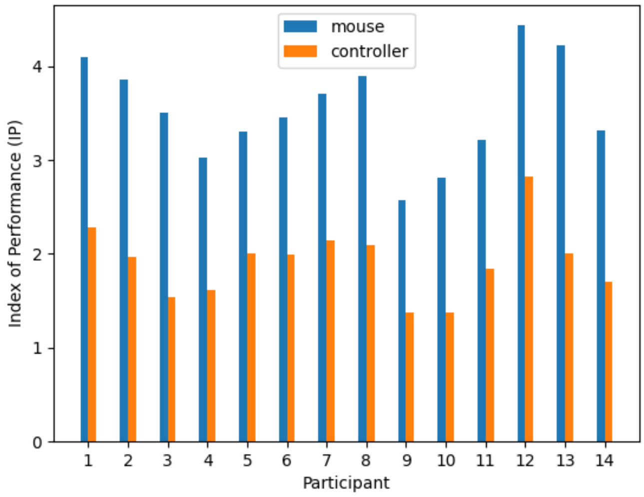

Figure 4.2: Participant IP by input method

Input device	MT	IP
mouse	477.85 + 147.94 * ID	3.53
controller	754.03 + 335.38 * ID	1.91

Table 4.1: Fitts Model and Index of Performance for each input device

exception is between the two largest sizes, where we observe a slight decline (see Figure 4.3).

After talking about mean selection time and index of performance, it would only be wise to also take a look at the predicted movement times for the mouse and the controller, as calculated using linear regression according to Fitts [1954] (shown in Table 4.1).

Clicking took less with the mouse.

Taking a closer look at the data shows that the mean movement time is 751.88ms for the mouse and 1286.33ms for the controller. We can therefore conclude that the average time it took to actually click on the target with the mouse was 203.85ms and 560.14ms with the controller. This proves that a click with the controller took more than twice as long as with its counterpart.

	1	2	3
IP - mouse	3.32	3.56 (up 7,2%)	3.7 (up 4%)
IP - controller	1.74	1.96 (up 12,6%)	2.02 (up 3%)

Table 4.2: Mean selection IP per round

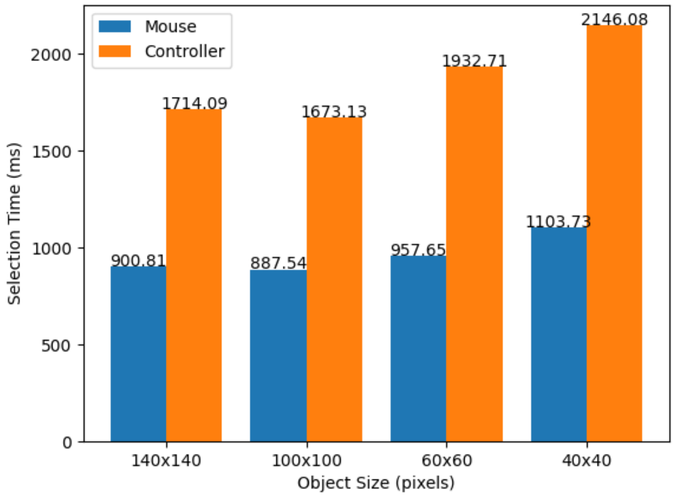

Figure 4.3: Mean selection time per shape size

If a participant initially missed a target, a selection error would be registered, and the participant would have to continue trying to select the target in order to move on with the rest of the task. In total, participants 'misclicked' 50 times with the mouse and 62 times with the controller. A Wilcoxon Signed-Rank Test shows no noticeable influence of input device on selection errors (z = -0.38, p = 0.7). Nonetheless, a Friedman Analysis shows that object size influenced the number of selection errors committed with the mouse (X_r^2 = 7.86, p = 0.0489), but not those committed in the controller condition (X_r^2 = 7.86, p = 0.36). We also observe a steep decline in the number of selection errors over the course of the three rounds (see Figure 4.4).

The number of misses declined over the course of the three rounds.

Object size influenced the number of selection errors committed with the mouse, but not with the controller.

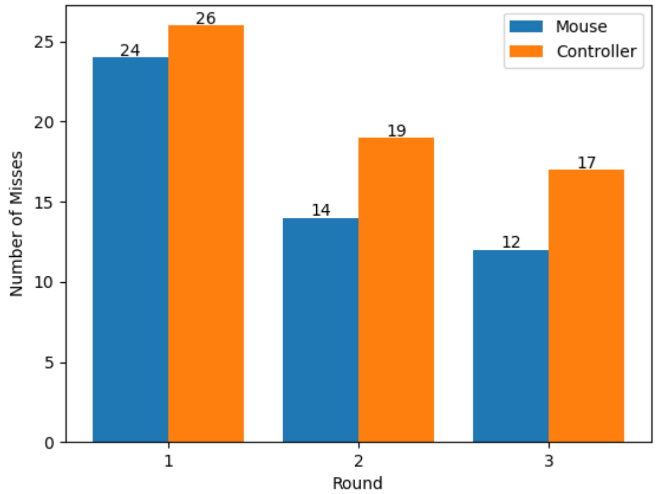

Figure 4.4: Total number of misses per round

Questionnaire Answers

Table 4.3 presents the total number of answers in each category before participants started and after they finished the object selection task, together with the respective median values and the Inter Quartile Range (IQR). The numeric column names represent possible answers (1 - Strongly Disagree, 2 - Disagree, 3 - Neither agree nor disagree, 4 - Agree, 5 - Strongly Agree).

Participants agree with the fact that selecting objects with the mouse was easy.

Almost all participants indicated agreement or strong agreement with the idea that selection with the mouse was easy (21,4% agree and 78,6% strongly agree), and even the more reserved person who was unconvinced at first agreed to the aforementioned after actually tackling the task (mdn = 5, IQR = 0; before & after).

Selecting the targets with the controller was enjoyed more than with the mouse.

Most notably, there was a high consensus that participants enjoyed the object selection task with the controller, with 36% and 64% of participants expressing agreement and strong agreement (mdn = 5, IQR = 1), as opposed to 50% and 42.9% of participants in the mouse scenario (mdn = 4, IQR = 1). P4 even mentioned that doing this task with the

	1	2	3	4	5	Median	IQR	1	2	3	4	5	Median	IQR
Q1	0	1	0	4	9	5	1	0	0	1	4	9	5	1
Q2	0	2	6	6	0	3	1	0	0	3	8	3	4	0
Q3	0	0	1	2	11	5	0	0	0	0	3	11	5	0
Q4	0	3	3	8	0	4	1	0	2	3	6	3	4	1
Q5	0	0	0	7	7	4.5	1	0	0	1	7	6	4	1
Q6	0	1	3	5	5	4	1.75	0	0	0	5	9	5	1
Q7	0	0	1	5	8	5	1	0	0	1	6	7	4.5	1
Q8	0	3	7	4	0	3	0.75	0	3	3	5	3	4	1

Table 4.3: Questionnaire answers (questions 1 through 8) before (left) and after (right) selections with median values and IQRs

controller was 'more fun' than with the mouse.

After looking more closely at Table 4.3, we can conclude that participants were more convinced that selecting the targets will be, and also was, fast, generally easy and precise with the mouse.

Workload Analysis

Figure 4.5 shows the average overall workload for each input device, together with the specific sub-aspects as indicated by the participants. The error bars represent 95% confidence intervals around the overall workload for each condition.

A detailed analysis of the differences in the sub-aspects of the workloads of the two input devices is visualized in Figure 4.6. The more apparent differences between the two conditions are in mental demand and effort, as well as somewhat more limited in physical demand and performance.

There are some visible differences in workload sub-aspects.

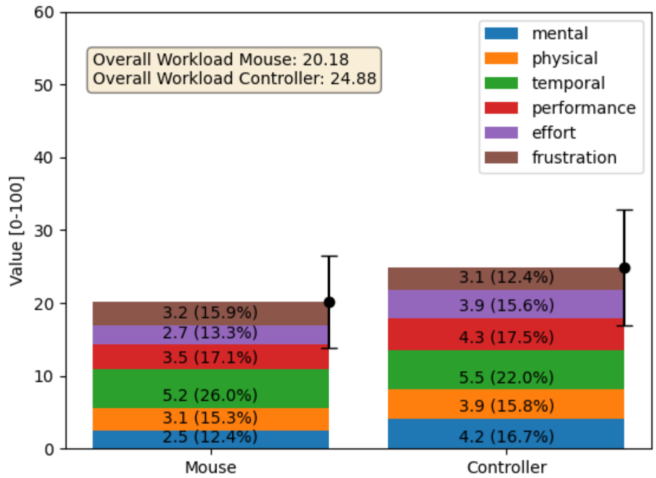

Figure 4.5: Total workload (in overall NASA TLX units). Error bars represent 95% confidence intervals for the total workloads

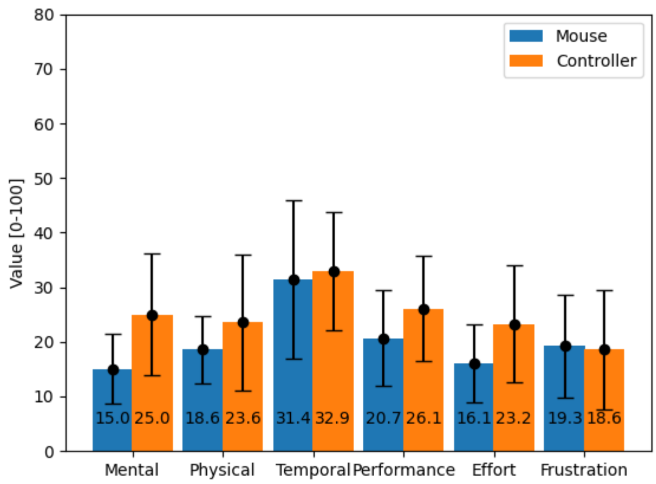

Figure 4.6: Workload sub-aspects (in individual NASA TLX units). Error bars represent 95% CIs

Interestingly, although the mean difference in selection time was very high (891.24ms), the temporal demand does not reflect that, as opposed to the performance indicator that was lower for the mouse, thus indicating better performance. More baffling is the fact that temporal demand fluctuated more for the mouse condition. We can also observe that the only workload sub-aspect that is higher in the mouse scenario if frustration.

The difference in mean selection time is not visible in the difference in temporal demand.

Running a Paired t-test on the individual overall workloads for the two input devices shows the difference to be not quite statistically significant (t = -2.01, p = 0.065).

There is no proof of an influence of input device on overall workload

According to Prabaswari et al. [2019], solving this task with both the mouse and the controller resulted in 'medium' workloads.

The selection task produced a medium workload.

Combining Results

	mouse	controller	Median	IQR	mouse	controller	Median	IQR
Q9	13	1	1	0	8	6	1	1
Q10	11	3	1	0	12	2	1	0
Q11	13	1	1	0	10	4	1	0.75
Q12a	13	1	1	0	12	2	1	0

Table 4.4: Questionnaire answers (questions 9 through 12) before (left) and after (right) selections

Table 4.4 shows the answers to the dichotomous questions. The column values represent the number of participant votes.

(Q9) All participants were faster with the mouse, which makes the disputed answer in Question 9 most peculiar (mdn = 1, IQR = 1). 50% of the participants who thought they were faster with a controller also had a better performance index with it in the TLX answer section. But, bizarrely, the other 50% had a better performance index with the mouse. Please note the fact that 5 participants

The fastest option for this task is disputed.

changed their minds: from thinking that the mouse would be faster to thinking that the controller was actually faster.

(Q10) The stress factor of two of the participants (P5 and P10) who thought the task was 'generally easier' with the mouse showed quite the opposite. On the other hand, one of the participants (P11) who considered the task easier with the controller actually favored the mouse, according to their stress factor.

(Q11) Furthermore, one participant (P3) who thought the controller was more accurate actually had fewer selection errors with the mouse. Only six of the participants who considered the mouse more precise were actually right. 75% of those who were wrong also considered using the controller less frustrating, so it is somewhat puzzling why they still chose the mouse.

(Q12a) Lastly, 4 out of the 12 participants that considered the mouse better suited for this task actually had lower overall workloads with the controller, and 50% of those that held the controller as better suited had lower overall workloads with the mouse.

4.6.4 Results - Object Docking

Performance Analysis

The average docking time with the mouse was almost one second lower than with the controller.

The mean docking time using the mouse stood at 1272.92ms ($\pm$444.18ms), whereas with the controller, it extended to 2272.5ms ($\pm$874.76ms), resulting in a substantial difference of nearly 1 second (999.58ms). The prominent discrepancy in performance is clearly visible in Figure 4.7. We have also run a Wilcoxon Signed-Rank Test on the docking times. The result further proves the profound influence of input device on docking time ($z = -3.06$, $p = 0.002$). Given that Fitts's Law was originally oriented at pointing tasks, we scrutinize the mean participant docking time rather than the mean participant Index of Performance. Notably, several participants displayed mean docking times with the mouse that were less than half as high as with the controller (P1, P3, P8).

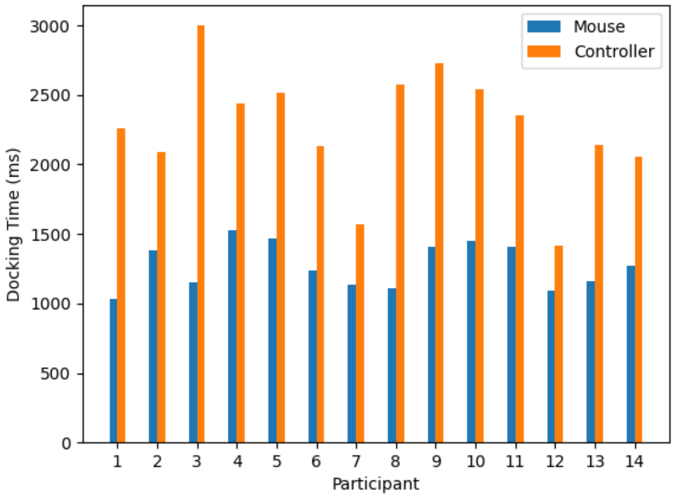

Figure 4.7: Mean docking time per participant

We are also keen to investigate possible fluctuations in performance throughout the rounds. As Figure 4.8 showcases, the performance did indeed improve (the mean docking time decreased), but the differences are much more limited in comparison to those in the selection task. In total, the docking times decreased by 7.8% for the mouse and 7.7% for the controller, as opposed to 10.2% and 16.45% in the former half of this task.

Performance only slightly improved.

Interestingly, as average selection times increased with the reduction in object size, the mean docking times were somewhat more constant. Figure 4.10 shows a slight decrease in average docking time with the mouse but an almost constant average docking time with the controller over the four object sizes. The aforementioned is also proven by the result of a Friedman Analysis: the shape size only influenced mouse dockings (X_r^2 = 10.02, p = 0.02), but had no notable effect on the dockings performed with the controller (X_r^2 = 0.23, p = 0.97).

Mean docking times did not differ very much over the four different object sizes.

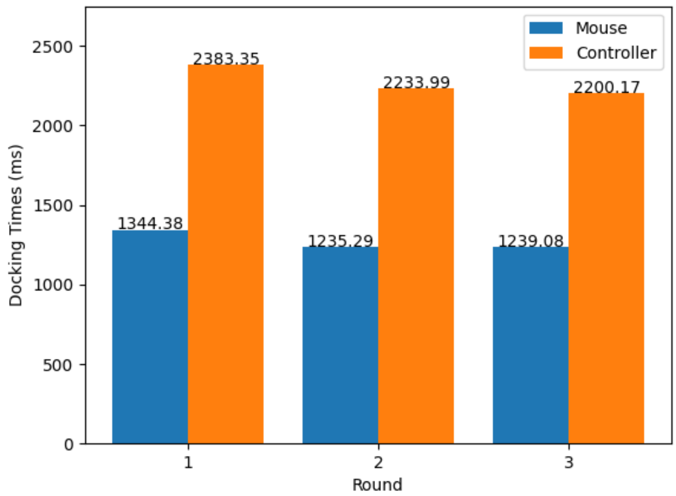

Figure 4.8: Mean docking time per round

Average docking time with the controller increased with the distance between the red and blue targets.

At the same time, looking at Figure 4.9 reveals that, while average docking time with the mouse remained constant with the increase in distance between the red and blue targets, the mean docking time with the controller kept on increasing before leveling out around the highest possible distances.

Questionnaire Answers

Table 4.5 presents the total number of answers in each category before participants started and after they finished the object docking task, together with the respective median values and the Inter Quartile Range (IQR). The numeric column names represent possible answers (1 - Strongly Disagree, 2 - Disagree, 3 - Neither agree nor disagree, 4 - Agree, 5 - Strongly Agree).

Participants agree with the fact that docking with the mouse was fast.

8 participants (57.1%) strongly agreed with the fact that docking the objects with the mouse was fast, as opposed to 6 (42.9%) with the controller. The median value and spread (med = 5, IQR = 1 to mdn = 4, IQR = 1) also show a higher degree of consensus towards the former.

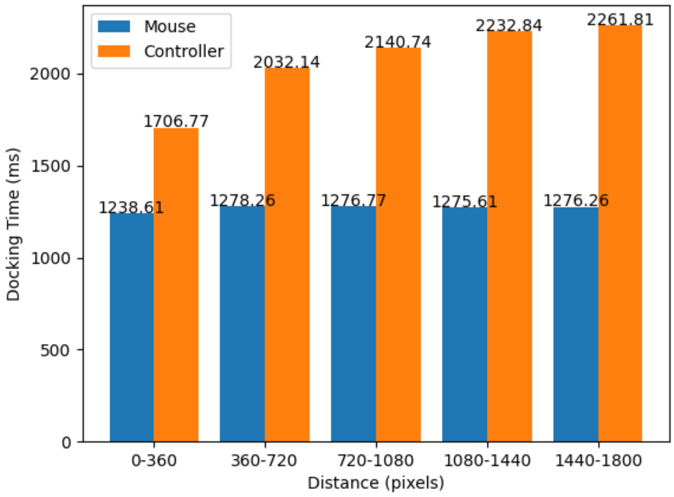

Figure 4.9: Mean docking time per distance range

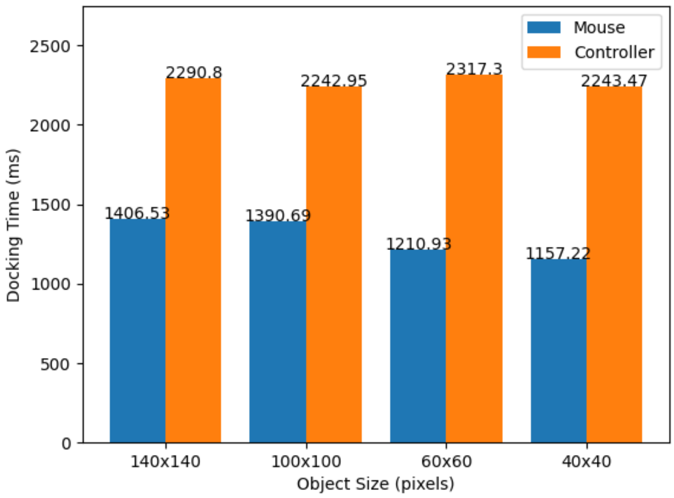

Figure 4.10: Mean docking time per shape size

	1	2	3	4	5	Median	IQR	1	2	3	4	5	Median	IQR
Q1	0	0	1	4	9	5	1	0	0	0	6	8	5	1
Q2	0	2	3	7	2	4	1	0	1	1	6	6	4	1
Q3	0	0	0	6	8	5	1	0	1	0	5	8	5	1
Q4	0	2	4	8	0	4	1	0	3	3	3	5	4	2
Q5	0	1	1	4	8	5	1	0	0	1	6	7	4.5	1
Q6	0	0	1	7	6	4	1	0	0	0	3	11	5	0

Table 4.5: Questionnaire answers (questions 1 through 6) before (left) and after (right) dockings with median values and IQRs

Like for the first half of the task, more participants enjoyed playing with the controller.

Like in the selection task, participants expressed a higher number of agreements and strong agreements with the statement 'I have enjoyed solving this task with the controller'. 3 participants (21.4%) agreed and the remaining 11 (78.6%) strongly agreed (mdn = 5, IQR = 0), compared to the mouse scenario, where 6 (42.9%) agreed and 7 (50%) strongly agreed (mdn = 4.5, IQR = 1). Please note that the median value for the mouse scenario decreased from before to after the task (IQR remained the same), while that of the controller increased and its IQR disappeared completely.

Workload Analysis

Figure 4.11 shows the total workload for each input device, together with the specific sub-aspects as indicated by the participants. The error bars represent 95% confidence intervals around the overall workload for each condition.

There are visible differences between some of the sub-aspects.

A detailed analysis of the differences in the sub-aspects of the workloads of the two input devices is visualized in Figure 4.12. The more apparent differences between the two conditions are in physical demand, temporal demand, and performance.

Every workload sub-aspect was higher for the mouse.

Surprisingly, every workload sub-aspect was higher in the case of the mouse, although admittedly not so much so in

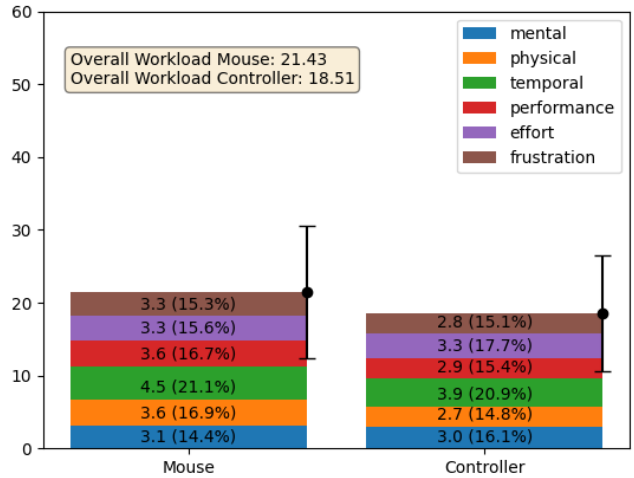

Figure 4.11: Total workload (in overall NASA TLX units). Error bars represent 95% confidence intervals for the total workloads

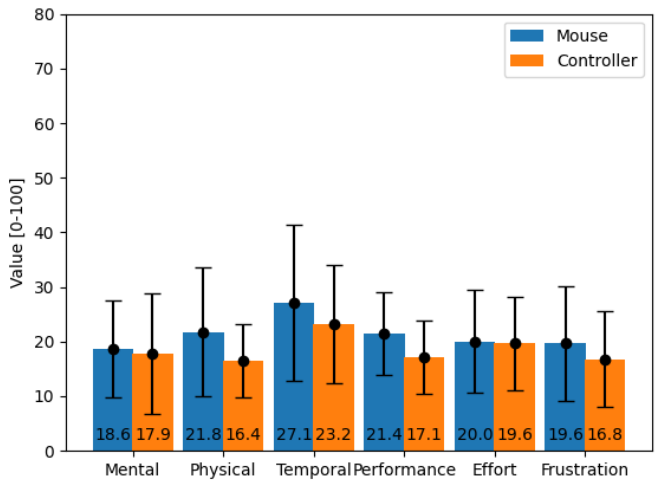

Figure 4.12: Workload sub-aspects (in individual NASA TLX units). Error bars represent 95% CIs

some cases. As mentioned before, the average docking time in the mouse scenario was 44% lower than in the controller scenario. Despite that, we observe the same issue as presented in 4.6.3: the temporal demand in the case of the mouse was higher. The top end of the confidence interval in the mouse condition also reached higher than that of the controller. On the same note, the performance index of the mouse is higher, showing that participants considered to have been more successful in completing the task with the controller, although this is clearly not true. Participants were also more frustrated while completing this task with the mouse.

There was no proven influence of input device on overall workload.

We observe a similar situation as discussed in 4.6.3 for the overall workloads of the selection task. There is no statistically significant influence of the input device on the individual overall workload for the docking task, as shown by the result of a Wilcoxon Signed-Rank Test ($z = -1.51$, $p = 0.13$).

The docking task produces a medium workload.

This task produced a 'medium' workload for both conditions, as presented by Prabaswari et al. [2019].

Combining Results

Table 4.6 shows the answers to the dichotomous questions. The column values represent the number of participant votes.

	mouse	controller	Median	IQR	mouse	controller	Median	IQR
Q7	12	2	1	0	12	2	1	0
Q8	14	0	1	0	12	2	1	0
Q9a	13	1	1	0	13	1	1	0

Table 4.6: Questionnaire answers (questions 7 through 9) before (left) and after (right) dockings

Completing this task was faster with the mouse.

(Q7) As was the case in the selection part of this experiment, all participants completed the task faster with the mouse. Although the consensus is clear (mdn = 1, IQR =

0), there were still two participants (P10 and P12) who believed the opposite. One of them (P10) did show better performance with the controller, but the other one's TLX performance rating shows they were more successful in this task with the mouse.

(Q8) 5 out of the 12 participants who thought solving this task was easier with the mouse actually had lower stress factors with the controller. One of the participants (P7) who considered that completing this task was generally easier with the controller actually exhibited a lower stress factor with the mouse.

Completing this task was generally easier with the mouse.

(Q9a) The mouse was better suited for this task in the opinion of 13 out of the 14 participants (92.9%; mdn = 1, IQR = 0). This is also proven by the lower overall workload in the mouse condition in 10 out of the 13 cases.

The mouse is better suited for this task.

4.7 Experiment 2: Object Tracking

4.7.1 Independent Variables

- *input device* (mouse and controller)
- *target shape* (square and circle)
- *target width* (140, 100, 60, 40 pixels)
- *total trial time* (4 sizes x 10 seconds x 3 rounds x 2 input devices = 240 seconds)

4.7.2 Dependent Variables

- *accuracy* (time spent inside the circles)

4.7.3 Results

Performance Analysis

We will not analyze trial time.

There is no possibility to analyze individual round times or overall trial times, as these aspects are independent variables (40s per round, 120s total trial time; therefore 14 * 120 = 1680s in total per input device). We will therefore only concentrate on participant accuracy.

There was a 7.2% difference in accuracy.

The cursor stayed inside the perimeter of the circles for 93% $\pm$ 5.1% of the total time (1562.4s $\pm$ 85.8s) in the mouse condition and for 82% $\pm$ 3.8% of the total time (1377.6s $\pm$ 63.4s) in the controller condition, leading to a somewhat high difference of 184.8s. The difference in performance between the two input means was also shown through a Paired t-test: the used input device strongly influenced overall accuracy ($t = 7.79$, $p < 0.0001$).

Performance did not improve nor decline over the course of the three rounds.

Figure 4.13 shows the total accuracy over the course of the three rounds. Although we were used to seeing at least some level of improvement in performance, this was not the case. We can even clearly observe that it decreased in the mouse condition by half a percent (Round 1 $\rightarrow$ 2) and six-tenths of a percent (Round 2 $\rightarrow$ 3), respectively.

Figure 4.14 shows that all participants performed better with the mouse than with the controller.

Lastly, Figure 4.15 shows that accuracy declined as object size decreased. The results of a Wilcoxon Signed-Rank Test show the difference to be extremely statistically significant. Object size strongly influenced tracking accuracy in both conditions ($X_r^2 = 39.94$, $p < 0.00001$).

Questionnaire Answers

Table 4.7 presents the total number of answers in each category before participants started and after they finished the object tracking task, together with the respective median

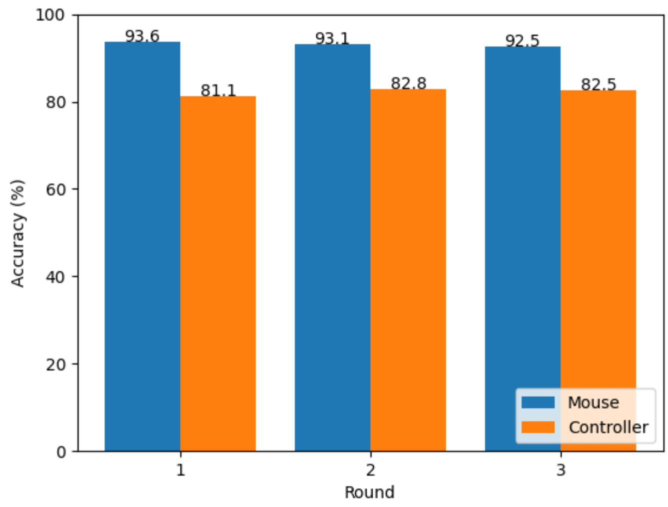

Figure 4.13: Object tracking accuracy per round

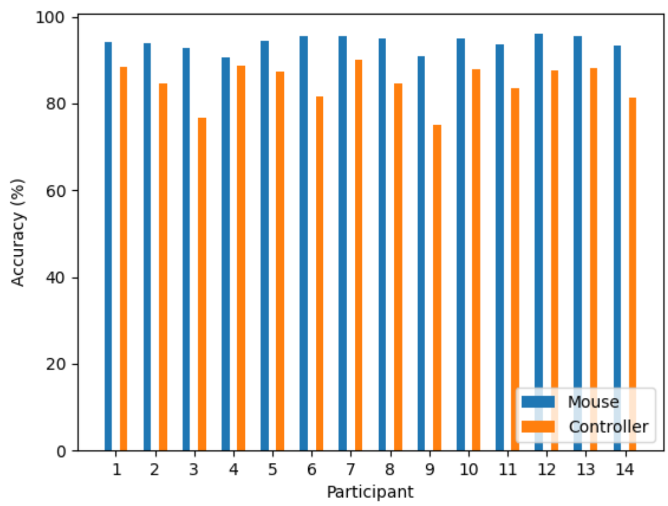

Figure 4.14: Object tracking accuracy per participant

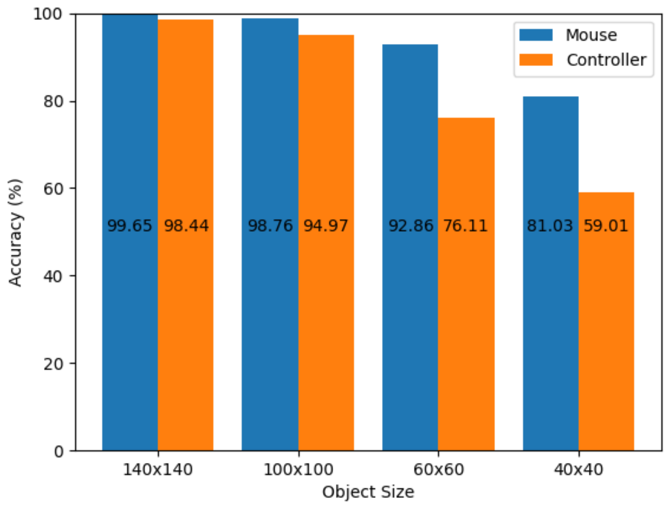

Figure 4.15: Object tracking accuracy per object size

values and the Inter Quartile Range (IQR). The numeric column names represent possible answers (1 - Strongly Disagree, 2 - Disagree, 3 - Neither agree nor disagree, 4 - Agree, 5 - Strongly Agree).

There is strong agreement with the fact that completing the task was accurate and easy with the mouse.

It is visible that, for the mouse condition, the answers of participants were more concentrated around agreement and strong agreement in the case of accuracy and easiness as opposed to in the controller scenario, where no participant expressed strong agreement (mdn_{mouse} = 4, IQR_{mouse} = 0 for both cases, compared to $\text{mdn}_{controllerQ2}$ = 3, $\text{IQR}_{controllerQ2}$ = 1.5 and $\text{mdn}_{controllerQ4}$ = 3.5, $\text{IQR}_{controllerQ4}$ = 2).

Object tracking was enjoyable.

Interestingly, there was a high degree of consensus toward acknowledging that completing the task with the controller was enjoyed more with the controller (6 agree, 5 strongly agree; mdn = 4, IQR = 1) than with the mouse (where 3 agree and 5 strongly agree; mdn = 4, IQR = 2).

	1	2	3	4	5	Median	IQR	1	2	3	4	5	Median	IQR
Q1	0	0	0	10	4	4	0.75	0	2	1	9	2	4	0
Q2	0	2	6	6	0	3	1	0	4	6	4	0	3	1.5
Q3	0	0	1	9	4	4	0.75	0	1	2	9	2	4	0
Q4	0	2	3	9	0	4	1	0	5	2	7	0	3.5	2
Q5	0	0	2	8	4	4	0.75	0	3	3	3	5	4	2
Q6	0	0	1	8	5	4	1	0	3	0	6	5	4	1

Table 4.7: Questionnaire answers (questions 1 through 6) before (left) and after (right) object tracking with median values and IQRs

Workload Analysis

Figure 4.16 shows the total workload for each input device, together with the specific sub-aspects as indicated by the participants.

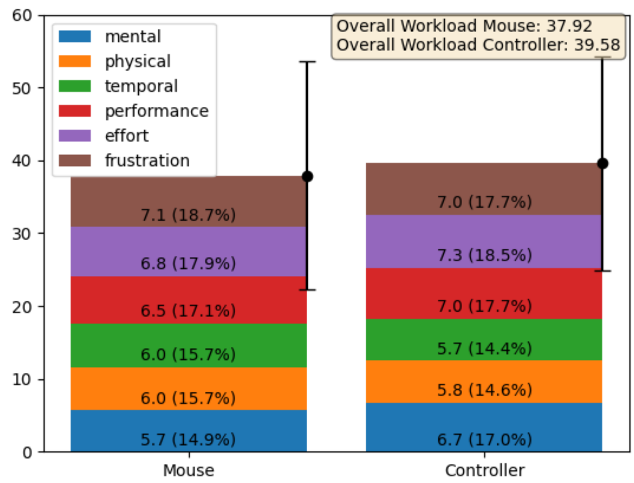

Figure 4.16: Total workload (in overall NASA TLX units). Error bars represent 95% confidence intervals around the overall workload

The workload sub-aspects are more mixed.

A detailed analysis of the differences in the sub-aspects of the workloads of the two input devices is shown in Figure 4.17. For the object tracking task, the workload aspects are somewhat more mixed. The physical demand, temporal demand, and frustration sub-aspects were higher in the mouse condition. In comparison, the mental demand, performance index, and effort were higher in the controller scenario.

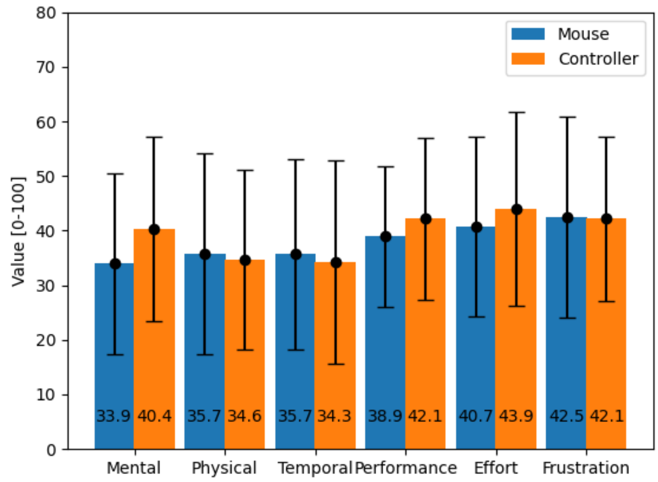

Figure 4.17: Workload sub-aspects (in individual NASA TLX units). Error bars represent 95% CIs

The temporal demand is higher in the mouse scenario, even if the task took the same for every participant.

As mentioned before, the individual round time and overall trial time cannot be analyzed, as the task took the same fixed amount of time for every participant. We mentioned in 4.6.3 and 4.6.4 that the temporal demands were higher for the mouse condition even if the average overall task completion time was way lower than for the controller. The current situation goes one further: even if the task took exactly the same for every participant, they still perceived a higher temporal demand with the mouse.

The performance sub-aspect indicates more success with the mouse.

The performance sub-aspect, on the other hand, is aligned with the overall accuracy: it is higher for the controller condition, suggesting that participants were more successful in tracking the objects with the mouse. Even so, the figure indicated higher frustration for the more precise variant of the two input means.

Just like for the two previous tasks, we could not establish whether the input device influenced the overall workload. A Paired t-test shows no proof of the aforementioned, as the t-value equals -0.73, and the p-value is higher than 0.05 (p = 0.48).

There is no proof that the input device influenced the overall workload.

As argued by Prabaswari et al. [2019], the object tracking task produces a 'somewhat high' workload for both conditions.

Combining Results

As we cannot look at trial times, we will combine the sub-aspect of performance with the individual participant accuracy.

	mouse	controller	Median	IQR	mouse	controller	Median	IQR
Q8	13	1	1	0	10	4	1	0.75
Q9	13	1	1	0	12	2	1	0
Q10a	14	0	1	0	10	4	1	0.75

Table 4.8: Questionnaire answers (questions 8 through 10) before (left) and after (right) object tracking

(Q8) Four of the participants who considered this task easier to tackle with the mouse (P5, P6, P7, P12) actually displayed lower stress factors with the controller. Of the four participants who considered it easier to complete the task with the controller, three (P1, P2, P11) also displayed lower stress factors with it, while one (P4) was actually put under more stress with the controller than with the mouse.

(Q9) As mentioned before, every participant tracked the objects more accurately with the mouse. Staggeringly, 10 of the 12 participants who correctly assessed their accuracy were actually less frustrated by the controller. At the same time, 5 of the 10 (50%) believed to have been more successful with the controller, while the remaining 5 did indeed display a better performance value in the questionnaire with the mouse.

(Q10a) Finally, 2 of the 10 participants who considered that the mouse was better suited for this task (P6 and P7) did in fact achieve a lower overall workload with the controller.

As the answers to Q8 and Q10a are more spread out, it is hard to confidently pinpoint which input device this task is more accurate with or if a mouse or controller is better suited for this kind of task (mdn = 1, IQR = 0.75 for both). We can certainly still consider that, according to the participants, accurately following the objects was easier with the mouse (mdn = 1, IQR = 0).

4.8 Experiment 3: Path Tracking

4.8.1 Independent Variables

- *input device* (mouse and controller)
- *path shape*
- *path length*
- *path width*

4.8.2 Dependent Variables

- *accuracy* (time spent inside the paths)
- *error* (time spent outside the paths)
- *total trial time per round and path*

4.8.3 Results

Performance Analysis

The path tracking task took an average of 214.5s ± 94.7s with the mouse and 281.4s ± 102.8s with the controller. At the same time, the overall accuracy of the mouse lies at 84.7% ± 8.6% and that of the controller at 68.5% ± 19.5%. The result of a Wilcoxon Signed-Rank Test of the individual total trial durations and individual total accuracies revealed that the input device influenced task duration (X_r^2 = -3.3, p < 0.001), and also accuracy (X_r^2 = -2.51, p = 0.01).

The mouse was more efficient and accurate than the controller.

Figure 4.18 shows that, while the average accuracy of the mouse has increased only slightly (a total of 1.2%), that of the controller has improved by a staggering 17.4% over the course of the three rounds. This is made even more interesting by the fact that the paths to be followed became longer over the course of the three rounds, providing a more and more difficult challenge.

The performance of the controller has visibly improved.

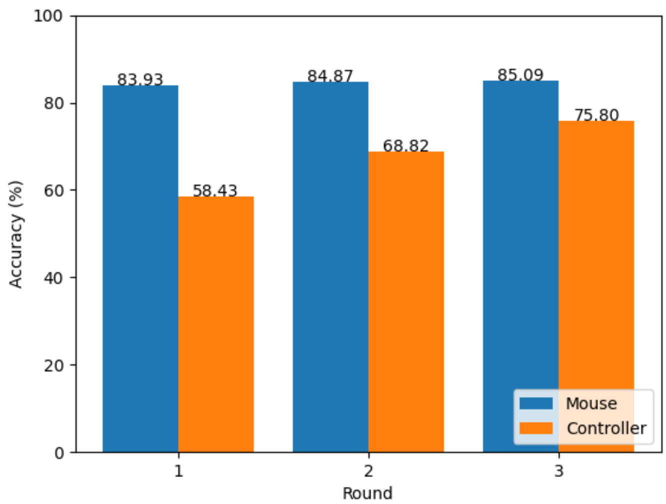

Figure 4.18: Path tracking accuracy per round

Questionnaire Answers

The task was 'accurate', 'generally easy', and enjoyable with the mouse.

Table 4.9 shows that the participants became somewhat unconvinced by the mouse between before and after the task. For all three statements ('Following the paths with the mouse was accurate', 'Following the paths with the mouse was generally easy', 'I have enjoyed solving this task with the mouse'), the answers became more spread out as opposed to before the task, when they were more concentrated around agreement (see 'Median' and 'IQR' columns for Q1, Q3, and Q5 before and after the task). Anyway, the participants were more convinced that it was 'accurate', 'generally easy', and that they enjoyed tackling this task with the mouse than with the controller.

	1	2	3	4	5	Median	IQR	1	2	3	4	5	Median	IQR
Q1	0	1	2	8	3	4	0	0	2	3	7	2	4	1
Q2	0	3	6	3	2	3	1	1	2	5	6	0	3	1
Q3	0	1	1	9	3	4	0	0	4	2	6	2	4	1.75
Q4	0	5	3	4	2	3	2	1	5	2	6	0	3	2
Q5	0	0	1	9	4	4	0.75	0	4	2	6	2	4	1.75
Q6	1	2	3	5	3	4	1	0	2	4	3	5	4	2

Table 4.9: Questionnaire answers (questions 1 through 6) before (left) and after (right) path tracking with median values and IQRs

Workload Analysis

Figure 4.19 shows the total workload for each input device, together with the specific sub-aspects as indicated by the participants. The error bars represent 95% confidence intervals around the overall workload for each condition.

There are visible differences in workload sub-aspects.

A detailed analysis of the differences in the sub-aspects of the workloads of the two input devices is visualized in Figure 4.20. There are apparent differences between all workload sub-aspects.

Figure 4.19 and Figure 4.20 both show that, similarly to the object selection and the object tracking tasks, every workload sub-aspect for the path tracking task was higher in the controller scenario.

Every workload sub-aspect is higher in the controller scenario.

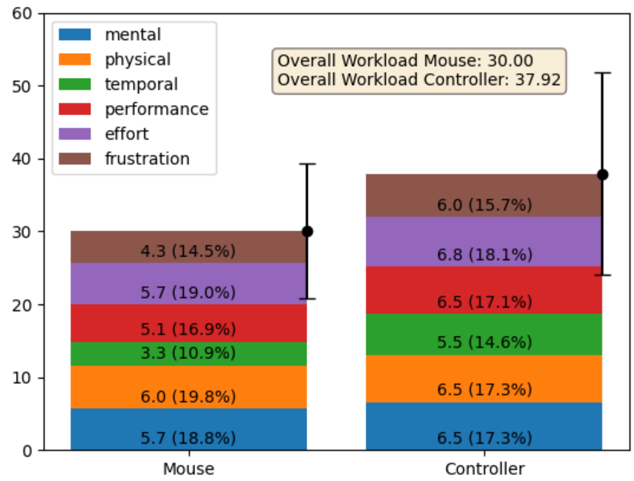

Figure 4.19: Total workload (in overall NASA TLX units). Error bars represent 95% confidence intervals for the total workloads

Finally, for the first time in 3 experiments, the temporal demand is aligned with the actual result of the performance analysis. The temporal demand was clearly higher in the controller condition, and the confidence interval of the mouse was also comparatively shorter, signaling that participants chose similar (lower) temporal demands for the mouse condition. As mentioned above, the task took, on average, 66.9s longer to complete with the controller. The height of the 'performance' bars also show that participants believed to have been more successful in completing the task with the mouse.

The temporal demand was aligned with the average task time.

Lastly, a Paired t-test of the individual overall workloads shows no statistically significant influence of input device on the workload ($t = 1.73$, $p = 0.11$).

As argued by Prabaswari et al. [2019], the path tracking

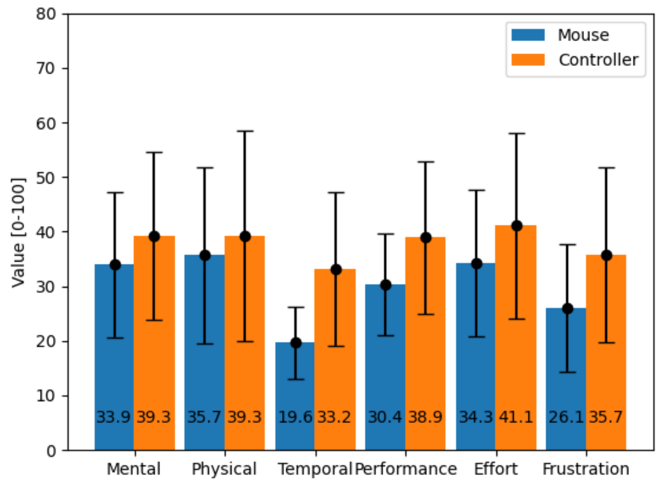

Figure 4.20: Workload sub-aspects (in individual NASA TLX units). Error bars represent 95% CIs

task resulted in 'somewhat high' overall workloads for both conditions.

Combining Results

	mouse	controller	Median	IQR	mouse	controller	Median	IQR
Q7	13	1	1	0	12	2	1	0
Q8	13	1	1	0	10	4	1	0.75
Q9	12	2	1	0	11	3	1	0
Q10a	12	2	1	0	10	4	1	0.75

Table 4.10: Questionnaire answers (questions 7 through 10) before (left) and after (right) path tracking

This task was easier with the mouse (mdn = 1, IQR = 0).)

(Q7) Every participant was faster with the mouse. Both participants (P2 and P13) who thought completing this task was faster with the controller were therefore wrong. At the same time, both displayed better performance evaluations with the controller.

(Q8) Even if there is no clear consensus regarding which input device completing this task is generally easier with, two of the 4 (50%) participants that preferred the controller (P2 and P3) actually had lower stress factors with the mouse. Simultaneously, 50% of those who preferred the mouse displayed lower stress factors with the controller.

The definitive answer to Q8 is disputed.

(Q9) Every participant was more accurate with the mouse. It is thus confusing why there are still three participants (P1, P6, and P7) who believed to have been more accurate with the controller. 6 participants who correctly evaluated their accuracy displayed higher frustration while tackling this challenge with the mouse.

This task was more accurate with the mouse (mdn = 1, IQR = 0).

(Q10a) Lastly, 10 participants consider the mouse better suited for this task. Between them, 4 effectively exhibited lower overall workloads with the controller.

4.9 Experiment 4: Building Finite-State Machines

The 4^{th} experiment was implemented in such a way to be played in a single-player scenario, as well as in a multiplayer one. 4 of the 14 participants completed this experiment on their own, and the remaining 10 were split into 5 groups of 2 participants each. The mouse and controller functionality matched that described in section 3.5. The sole difference was that the two cooperating participants were presented with two independently controlled cursors in the mouse scenario. In the controller condition, the participants would be presented with a supplementary selector, represented through a red outline. The participants would know which outline they controlled based on the color their DualShock controller would be displaying (see Figure 4.21).

Participants could complete the last experiment in a single-player, but also a multiplayer scenario.

Figure 4.21: DualShock controllers lighting yellow and red

4.9.1 Independent Variables

- *level of difficulty* (as all players would be presented with the same labyrinths)
- *input device* (mouse and controller)

4.9.2 Dependent Variables

- *interaction time* (time in which mouse or controller joysticks are moved or any button on the mouse or controller is pressed)
- *total trial time*

4.9.3 Results

Performance Analysis

Completing the task non-cooperatively took longer with the controller, but the average movement time was higher in the mouse condition.

Figure 4.22 shows the average total trial times and movement times for the two input devices in the non-cooperative scenario. The average total trial time in the controller condition was almost twice as high as that in the mouse condition. Nonetheless, it is interesting to observe that the average movement time with the controller was around 23.1% lower than with the mouse. Weirdly, the result of a Paired t-test shows no significant influence of input device on movement time (t = 0.64, p = 0.57) or total trial time (t = 1.15, p = 0.33).

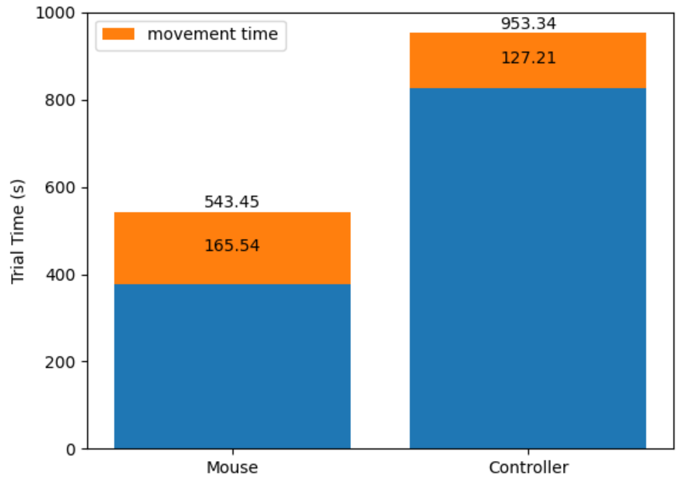

Figure 4.22: Average movement time and total trial time - single player

Completing the task cooperatively took longer with the mouse.

At the same time, the average movement and total trial times in the cooperative scenario (shown in Figure 4.23) offer us another perspective. The average total trial time in the controller condition was around 3.4% lower than in the mouse condition. Also, only looking at the average movement time shows that the actual device usage time with the controller is less than half as high as its counterpart. The result of a Paired t-test showed the influence of the input device on movement time to be statistically significant (t = 4.14, p = 0.014).

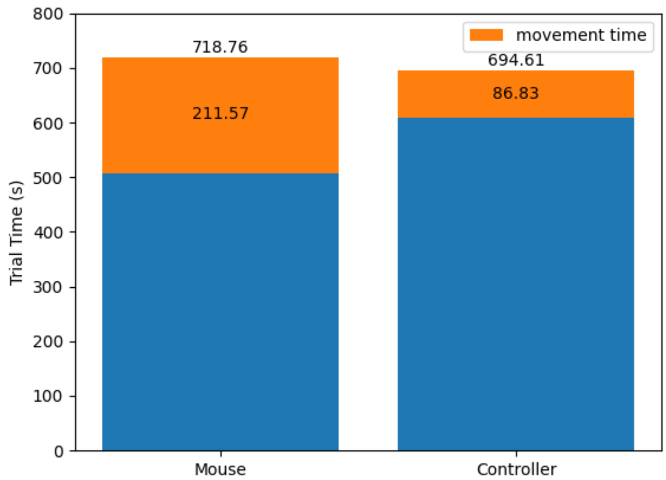

Figure 4.23: Average movement time and total trial time - multiplayer

Questionnaire Answers

Participants reached consensus around the answers regarding Q1, Q3, and Q5.

Table 4.11 shows that median values were higher and IQRs were lower for the questions regarding the mouse in the 'after' section (Q1, Q3, Q5). This means that participants showed a higher degree of unanimity when asked if the task was 'fast', 'generally easy', and that participants enjoyed completing it with the mouse.

Also, 50% of the solo playing participants agreed and 50% strongly agreed with the fact that cooperating with another participant would be helpful. When asked if cooperating would be more time efficient, one participant neither agreed nor disagreed, two agreed and one strongly agreed. On the other side, 20% of those who cooperated disagreed, 40% agreed and 40% strongly agreed when asked if the cooperation was helpful. Also, 90% of the cooperating participants think they could also solve the task alone.

	1	2	3	4	5	Median	IQR	1	2	3	4	5	Median	IQR
Q1	0	0	2	8	4	4	1	0	0	0	7	7	4.5	1
Q2	0	3	5	6	0	3	1	2	2	2	6	2	4	2
Q3	0	0	0	11	3	4	0	0	0	2	6	6	4	1
Q4	1	3	5	5	0	3	2	2	3	3	4	2	3	2
Q5	0	0	2	9	3	4	0	0	2	1	7	4	4	1
Q6	0	0	5	8	1	4	1	2	2	1	6	3	4	2

Table 4.11: Questionnaire answers (questions 1 through 6) before (left) and after (right) state machine configuration with median values and IQRs

Workload Analysis

We will look at overall and independent workloads for both the cooperation and no-cooperation scenarios. Unfortunately, due to the small sample sizes, we will not show the 95% confidence intervals, as the values are not trustworthy (e.g. some lower ends of the CIs even became negative, but NASA TLX does not afford choosing a negative value for any sub-aspect).

Figure 4.24 shows the average overall workload for each input device, together with the specific sub-aspects as indicated by the participants. The error bars represent 95% confidence intervals around the overall workload for each condition. It is clearly visible that the overall workload in the cooperative scenario was lower for both input methods than the overall workload resulting from the single player scenario. The overall workload in the controller condition of the multiplayer scenario was even lower than that of the mouse during the single player scenario. Most notably, completing the task was more frustrating and mentally demanding when participants were on their own compared to when they had a partner.

The task produces a higher overall workload when participants were on their own.

Figure 4.25 shows a more detailed analysis of the differences in the sub-aspects of the workloads of the two input devices. The left presents the resulting individual workloads for the single player scenario, while the right shows

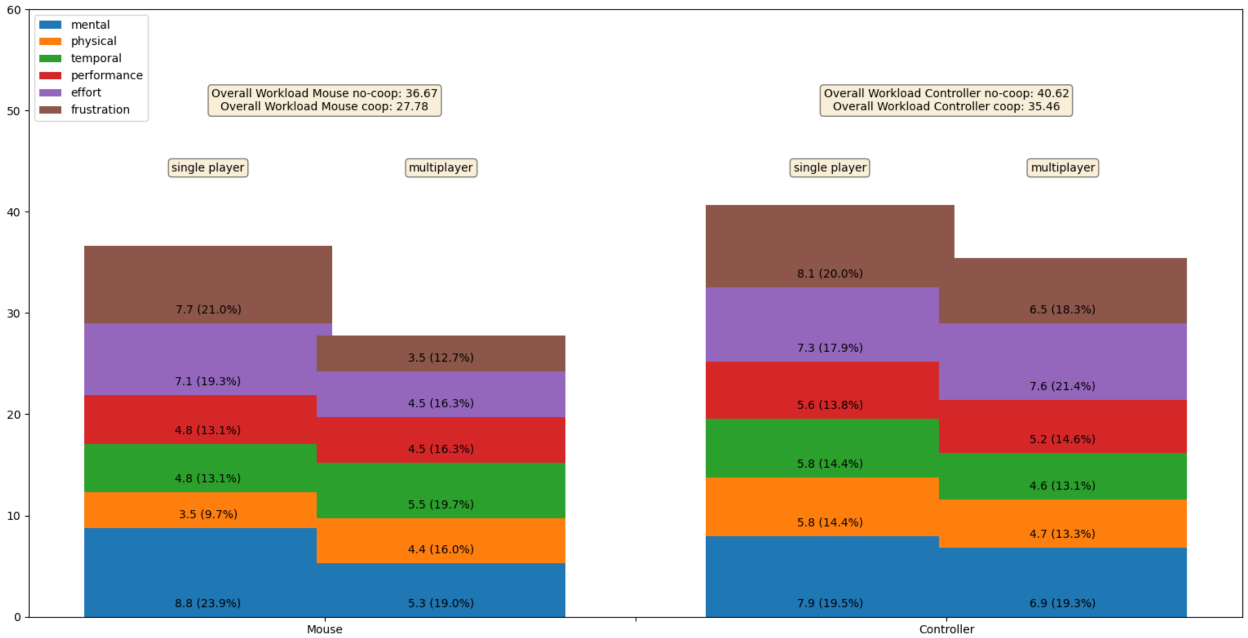

Figure 4.24: Total workload (in overall NASA TLX units). Error bars represent 95% confidence intervals for the total workloads. Columns on the left of the label represent the single player scenario, those on the right, the multiplayer one

the multiplayer scenario.

Single player
Apparently, completing the task with the mouse was less mentally demanding than with the controller. At the same time, every other workload sub-aspect was lower in the mouse condition. Also, participants clearly felt a much greater physical demand for the controller than for the mouse.

Almost all workload sub-aspects were higher in the controller condition.

Multiplayer
In this scenario, every sub-aspect of the workload (except for the temporal demand) was higher in the controller condition. Participants believed they had to work more (higher effort) to achieve the same result with the controller than with the mouse. They were also more frustrated by the controller.

Effort and frustration were higher in the controller condition.

A Paired t-test showed no statistically significant influence of input device on individual overall workload (t = 2.06, p = 0.07 for both single-player and multiplayer conditions).

It is interesting to observe that the temporal aspect of the workload was aligned in both scenarios with the actual average trial time. The mouse was more time efficient in the single player scenario, but less time efficient when participants collaborated.

The temporal demand was aligned with the average total trial time.

According to Prabaswari et al. [2019], the single-player scenario of this task produced a 'somewhat high' overall workload. As did the controller condition of the multiplayer scenario. But, rather surprisingly, the overall workload for the mouse condition when participants cooperated is the lowest of the 4, and can even be categorized as only 'medium'.

Combining Results

As accuracy is not relevant for this task, we will look at frustration when analyzing which input device was easiest to use.

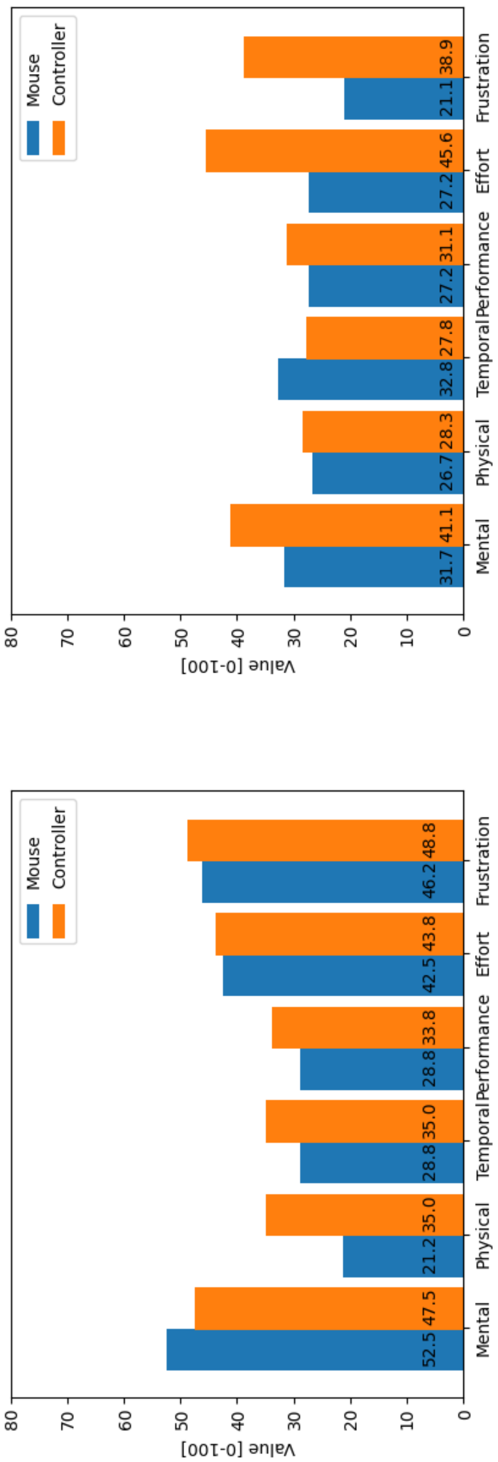

Figure 4.25: Workload sub-aspects (in individual NASA TLX units). Error bars represent 95% CIs. Workload sub-aspects for the single player scenario are on the left, and those for the multiplayer scenario are on the right

	mouse	controller	Median	IQR	mouse	controller	Median	IQR
Q9	14	0	1	0	13	1	1	0
Q10	14	0	1	0	13	1	1	0
Q11a	14	0	1	0	13	1	1	0

Table 4.12: Questionnaire answers (questions 9 through 11) before (left) and after (right) state machine configuration

It is clear from Table 4.12 that participants believed that completing this task was faster, generally easier and that they enjoyed it more with the mouse. Nevertheless, P10 was adamant that they perceived the controller as superior in every one of the enumerated criteria.

According to the participants, completing this task was faster, generally easier, and enjoyed more with the mouse.

(Q9) 3 individually playing participants (P5, P9, P13) and one cooperating group (P11 + P12) completed the task faster with the controller, but, as is visible in the first line of the table above, they believed to have been faster with the mouse. P5 and P13 also had lower performance values (indicating a higher success rate) with the controller. Of the participants that cooperated, P11 believed to have been more successful with the mouse, while P12 indicated the opposite.

(Q10) Even if P5 and P12 voted that completing the task was generally easier with the mouse, their stress factors indicated otherwise. They were also less frustrated when playing with the controller.

(Q11a) Lastly, P5 and P12 also indicated the mouse as the better-suited input device for this task. Both actually displayed lower overall workloads after playing with the controller.

4.10 Qualitative Observations

In addition to the quantitative analysis presented in the previous section, we will also take a short look at the qualitative data captured during the study by the experimenter.

General Observations

Some participants concentrated better by talking.

P3, P4, P5, and P7 were able to concentrate better on the task at hand by either engaging the experimenter in a simple discussion or by simply describing what they were doing.

Some participants concentrated better by listening to music.

P1 and P7 associated our experiments with playing computer games. They also explained that they are used to listening to music when gaming, thus needing to be allowed to listen to their favorite music when engaging in the tasks.

Mouse and Controller Senitivity

Over the course of the user study, only P1 opted to modify the mouse sensitivity by changing the system settings. They also added that

"I got used to the sensitivity of the controller and it felt weird going back to the mouse".

Some participants set the controller sensitivity too high or too low.

On the same note, although being presented with an example of what was to come during the settings screen of experiments 1, 2, and 3, some participants set their controller sensitivity too high or too low. This sometimes resulted in a mild degree of frustration, as our application did not allow changing the sensitivity mid-experiment.

Experiment 1

Some participants tried starting a trial run by clicking on the black circle.

Participants were instructed that, except for placing the cursor inside the home location and then waiting, no other interaction was necessary for a trial run to start. Regardless, P2, P5, and P13 erratically clicked on the circle during their first 2 to 3 trial runs of the object selection task but seized doing this after being reminded that it was not necessary. Anyway, these misclicks were not recorded by our application, as we had programmed it to only register erroneous clicks on the white background.

It was extremely interesting to observe the different strategies participants had approached for completing the two tasks. When the objects appeared near a screen border, P1 chose to drive the cursor all the way into the closest wall and then become more accurate. P6 chose to follow the catheti of an imaginary right triangle from the initial cursor location to the objects to be selected or docked (see Figure 4.26 for a visual cue). The rest of the participants followed one of two approaches. One was to simply follow a straight line from the initial cursor or red object location to the object to be selected or docked. The other one was to reach the rough target location as fast as possible, and then use only the slower joystick (in the controller condition) to complete the trial run. Regarding the latter in the selection task, participants noted:

The participants made use of diverse strategies to complete the tasks.

[P3]: *"I don't know how much to move the mouse to not go over the shape".*

[P9]: *"I liked doing the whole task with the slower joystick".*

Lastly, P12 and P13 added:

[P12]: *"The selection task was about hand-eye coordination",*

[P13]: *"I easily had more fun with the controller in selection and docking as it 'gamifies' the task and makes it more rewarding. [...] Using the controller adds a whole new layer of challenge to the whole task.".*

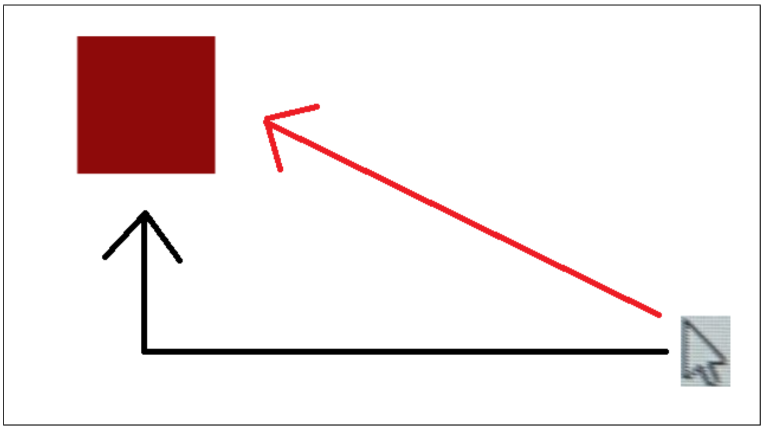

Figure 4.26: Exemplification of some of the employed strategies using the catheti or the hypothenuse of an imaginary right triangle

Experiment 2

Participants also made use of a few unique strategies to tackle the task during the second experiment.

The majority of participants kept as close as possible to the center of the object.

P1, P3, P5, P6, P7, P9, P10, P11, P12, P14 tried to keep the cursor as close as possible to the center of the object that had to be tracked. This was completely straightforward in the mouse condition. However, in the controller condition, participants achieved this either by pinching the low-sensitivity joystick very often or by finely pointing it in the desired direction of movement. The other participants tried keeping the cursor as close as possible to the border of the object in the direction it was moving.

Regarding this task, P3 and P4 added:

'The smallest size scares me.".

Also, P10 stated that

"The red screen flicker scared me and made me make mistakes".

Experiment 3

Again, completing the challenge with the mouse was pretty straightforward. Participants simply moved slowly and tried keeping the cursor as close as possible to the center of the path. Strangely enough, P1 added that

Completing the task with the mouse was pretty straightforward.

"It's easier if I keep the mouse clicked".

With the controller, some participants decided to tackle the task by finely adjusting the low-sensitivity joystick in the wanted direction. At the same time, others pointed it completely in the direction the path was going during the straight parts and pinched it slowly when in a curve.

Precise movement of the cursor with the controller implied pinching the low-sensitivity joystick.

Regarding the task's feedback, P5 commented:

"I was more aware that I was inaccurate while feeling the vibration of the controller than by seeing the red screen".

Experiment 4

For the last experiment, the cooperating participants decided that to solve the task more efficiently, one participant would only click on the conditions, while the other would only click on the states. The groups then interchanged roles for the second level in each condition.

Participants divided the screen up for more efficient cooperation.

To complete the task, some participants decided to follow the labyrinths with a finger and configure the state machines as they went along. Others decided to simply create a complete graph: add transitions between all states to follow any possible conditions, but do not add redundant behavior.

Configuring the state machines was done in two ways.

For better visibility and ease of use, all participants decided to move the states to custom positions on the screen. Regarding this aspect, P6 even stated that

"The placement of the states is really important. It's easier when they are well-placed".

Admittedly, not all participants were happy with how the controller scenario worked. P11 remarked that

"The cursor is sometimes all over the place and it makes it hard to see where you are".

Chapter 5

Discussion

This chapter will discuss the previously presented results of the user study. Firstly, we will take a deeper look into the performance, workload, and subjective preference. The latter part of this chapter concentrates on the observed limitations of our approach.

5.1 Performance

Our quantitative findings align with the literature.

Overall, the results show that the mouse was either the fastest, most accurate, or both, depending on which of the two applied to each task. Our average selection time and Index of Performance (also called Throughput) are very similar to those presented in Young et al. [2016] for the mouse, as well as for the controller. Furthermore, the average accuracy in the object tracking task (time spent inside the targets) is very close to the 'Time on Target' metric resulting from the first trial block in Klochek and MacKenzie [2006].

5.1.1 Performance / Workload Inconsistencies

Our most important contribution is combining performance with qualitative aspects.

Previous work has focused heavily on the quantitative aspects of the mouse or the gaming controller. As previously pointed out, we went further than that, balancing the objective, quantitative aspects with subjective ones like workload and preference. We have thus been able to acquire a very interesting and unexpected finding: even if the mouse was continuously proven fastest and most accurate, the subjective workload or participant opinion would sometimes point in the opposite direction.

We observed three patterns when analyzing participant feedback.

Examining the participants' justifications for choosing a particular input device as better suited for each task can provide valuable insights into the underlying psychology, as well as into factors of influence within each task. All in all, we have observed three different patterns throughout the audio recordings of the above answers: (a) participants only liking the mouse, (b) participants only liking the controller, and (c) participants praising the benefits of both input devices. Let us take a closer look at the three categories.

Sometimes, participants would only have good things to say about the mouse.

Participants who only liked the mouse stated that it was more precise, easier to control, easier to select the objects with, or more comfortable to move around. Also, one participant (P7) mentioned that their response time was overall lower with the mouse. Sometimes, the greater precision perceived with the mouse was motivated by the fact that the participant was 'simply more used to using it' (P3, P5, P9, P10, P14).

Other participants would only have good things to say about the controller.

When participants had to say good things only about the controller, the predominant expressions used were that completing the tasks with it was "more precise" (P10, dockings), "more fun" (P4, selections & dockings, P5, P10, P13, dockings; P5. object & path tracking), that it "felt like a game" (P5, object tracking), that it was "easier to physically engage" (P12, selections) or that it would "gamify" the tasks (P13, throughout). During the later stages, P1 also observed that the feedback provided by the application (object & path tracking) was less frustrating, adding less mental workload to the task.

There were also participants who liked playing with both.

Throughout our experiments, there would always be a few participants praising elements of both devices. P1 mentioned that, even if the mouse was faster and more accurate, they were surprised by the fact that they were able to complete the object selection task in such a good manner with it. After the object docking task, they added that it went very "smooth" with the controller. For P2, for example, the object docking task was less frustrating with the mouse but less physically demanding with the controller. Interestingly, P7 mentioned after the object docking task that it depends if speed or accuracy is more important, adding that "it was faster with the mouse, but more accurate with the controller". Also, after the path tracking task, P11 said that, while they were faster with the mouse, they had to concentrate less with the controller. Lastly, P5 stated that "it was easy with both devices once you get used to the mechanics" when answering 'Which input device is better suited?' for the object tracking task.

5.1.2 Performance-Gaps

Regardless if looking at time efficiency in the object selection, object docking, and path tracking task, or at precision in the object selection, object tracking, and path tracking task, the mouse always indicated better performance than the controller.

The mouse was almost always faster and/or more accurate.

The high performance gaps could partly be attributed to the fact that, although participants considered themselves familiar with using a gaming controller, they engaged with one more seldom (as opposed to the mouse). Our results therefore align with those of Sambrooks and Wilkinson [2013], who previously signaled that this potentially suggests that an individual's ability to use an interaction technique effectively is influenced by their familiarity with it.

The performance gap is partly attributed to participant familiarity with either input method.

We have observed that the mean selection times increased with the decrease in object size. With the larger objects, participants would sometimes select them without having to stop moving the cursor. As objects became smaller, the participants needed longer to (1) successfully place the cursor inside them, and (2) make sure that the cursor's hitpoint, which lies near its tip, was fully inside the target before pressing the left mouse button or one of the joysticks. This was especially hard with the smallest targets, as the cur-

Why did mean selection time increase while object size decreased?

sor would occlude almost half the object, adding additional stress to the task.

Why did mean docking time decrease with the object size?

At the same time, as the mean selection time increased with the decrease in shape size, the mean docking time was reduced. Docking wider objects took longer, as the participants had to watch a larger area, and it was harder to try and find the center of the blue placeholder. Conversely, docking smaller objects sometimes happened without even stopping the movement of the cursor. The participant would simply follow an almost perfect imaginary trajectory to the center of the placeholder.

The performance gap is influenced by more than one aspect.

Concerning the object and path tracking tasks, we can also attribute the performance gaps to the fact that participants sometimes chose controller sensitivities that were too high. Also, some mentioned that it was easier to account for abrupt movements of the object with the mouse and move in a straight line with the controller. With the latter, participants would sometimes pinch the joysticks a little too much. It would thus take them somewhat longer to recalibrate their movements to account for the circle's change in speed or direction or accurately follow curves.

Lastly, we have observed a very high difference in average trial time in the single-player condition of the last task. We partly attribute it to the difference in UI. With the mouse, participants would simply point and click their target of interest. With the controller, however, controlling the selector proved more demanding. This was made more so by the fact that pointing the left joystick in an inaccurate direction (in which there were no selectable objects) would sometimes make the selector jump to a random location. On the other hand, the multiplayer condition only showed a modest difference in average trial time. This is because, as presented before, participants divided the roles and each of them only had a limited area of movement (in both scenarios).

5.1.3 Improvements in Performance

The results showed that performance improved throughout the rounds in the object selection, object docking, and path tracking tasks, showing that learning effects and exercise played a significant role in our experiments.

In the object selection task, the increase in performance might also be explained by a steep decrease in the number of selection errors throughout the three rounds. This means that time was saved because the trial time of a selection was increased by having to reacquire the target and select it.

Improvements in the object selection task.

As for the path tracking task, only the controller accuracy improved throughout the three rounds. Besides the learning effects and exercise, this could also be explained by the fact that participants learned to tackle straight lines by pointing the joystick in a single direction and focusing more on the curves (based on the observations by P1, P3, P13, and P14). This shows that finding a good interaction strategy will also improve performance.

Improvements in the path tracking task.

Noticeably, the difference in average trial time / average precision between the first two rounds is always bigger than that between the last two rounds. We hypothesize that participants needed some time to become accustomed to the controls in each task, create interaction strategies, and accommodate to each of the device's behavior.

The performance in the first round was always worst.

5.2 Limitations

5.2.1 General Aspects

Firstly, in contrast to other works in the literature that either (a) did not mention it or (b) did not allow it altogether, we have made it possible to change the sensitivity of the mouse and controller to suit each participant's personal preference. They had the option to alter this before starting each task where this could have been important. Thus, we might have unintentionally increased the number of unseen variables that could influence the performance or perceived workload.

5.2.2 Object Selection

Selecting the targets with the controller sometimes proved difficult.

Because clicking with the controller required pressing either joystick, participants would sometimes place the cursor on the target to be selected, press the joystick and, at the same time, tilt it slightly in a random direction, thus moving the cursor away from the target. This was problematic, as the application would only validate a click when one of the joysticks would be pressed and then released, but by this time, the cursor would not be inside the target area anymore. The trial run would hence be somewhat skewed, as the participant would not only need more time to reacquire the target and subsequently select it but also a misclick would be registered. We have only encountered this problem during the first object selection round of some of the participants. Notably, this was never the case in the mouse condition. The presented problem is very similar to the *exit error* described in Tuddenham et al. [2010], where lifting the finger from the screen after a multi-touch object docking resulted in a slight movement of the object. We therefore have to acknowledge the role of the aforementioned issue in the higher number of selection errors and higher average selection times of some of the first rounds in the object selection task.

5.2.3 Object Docking

Some differences to other works make our object docking task not directly comparable to other similar experiments.

Our object docking task was somewhat different from the examples seen in the literature. In contrast to Forlines et al. [2007], we did not combine the object selection and object docking tasks into one single task. Moreover, we did not require the object to be docked to first be clicked in order to start the manipulation. Also, we did not require the participants to release the mouse button in order to finish up a trial run. These aspects could have influenced the average docking time somewhat and therefore make the object docking task not directly comparable to other similar experiments.

Chapter 6

Summary and future work

This 6^{th} and last chapter of our thesis summarizes our contributions and our findings. The latter part will present a series of ideas for future work.

6.1 Summary and contributions

In this thesis, we have aimed to investigate the differences between the mouse and the gaming controller. We went beyond the usual approach presented in the literature of only looking at quantitative aspects by combining such findings with qualitative ones like subjective workload and user preference.

Our goal was to analyze quantitative and qualitative differences between mouse and gaming controller.

For our user study, we have developed a specialized application using the Unity Real-Time Development Platform. We then challenged 14 participants with a series of 5 tasks: object selection, object docking, object tracking, path tracking, and a newly designed approach, purposefully built to combine actions usually done with a mouse and a controller into a unified, timed exercise: state machine configuration.

We contributed a purpose-built application capable of gathering quantitative data.

Workload was recorded using the NASA TLX questionnaire.

We also needed to gather qualitative data. To measure the perceived workload, we have decided to ask the participants to fill out a NASA TLX questionnaire after completing every task with each input device.

Subjective preferences were recorded using a User Study Questionnaire.

To explore their prejudices and subjective preferences regarding the two input means, the participants had to answer a series of questions before and after actually completing the tasks. Among other things, they were questioned about which input device they thought would be/was faster, more accurate, generally easier to use, and better suited for each of the 5 previously presented tasks.

The data shows the mouse was almost always fastest and most accurate.

After analyzing the data provided by the application, we came to the conclusion that the mouse was (with only one exception) always the most accurate and the most time-efficient. At the same time, the perceived workload (averaged over all 14 participants) was lower in the mouse condition in all tasks except for the object docking one. Even if participant opinion would sometimes be more divided, the majority support these findings and have also favored the mouse as the generally easiest to use and best suited for every task. Regardless of these aspects, we have shown that the participant's subjective perceptions did not always match the objective findings. The answers to the questions "Which input device was better suited?" for each task were more often than not influenced by personal preference and subjectively perceived performance. This last statement is further proven by looking at the gathered feedback.

What is our conclusion?

We conclude that, while the mouse was the most accurate and the most time-efficient input device of the two throughout our experiments, answers to the question "Which input device is better suited?" are not only influenced by quantitative aspects, but also by subjective factors like how each participant perceived performance, subjective workload, how entertaining playing with each interaction device was, and overall comfort.

6.2 Future work

Firstly, conducting the same user study with a broader range of participants (wider age interval and different degrees of experience with either device) would surely provide further very interesting findings.

At the same time, it would make sense to conduct a user study using our developed object tracking and path tracking tasks, but configuring the application to not provide feedback when the cursor leaves the circle or paths. This would provide invaluable data for comparing not only perceived workloads and subjective preferences with and without feedback but also quantitative performance.

Another interesting research idea would be to only compare different types of gaming controllers, like DualShock 4, DualSense, and Xbox controllers, to one another, as they offer different specifications, feedback, triggers, joystick precision, and more.

Appendix A

Informed Consent Form

This Appendix shows the Informed Consent Form the participants had to read, fill out, and sign in order to participate in our user study.

Informed Consent Form

Which Input Method is more Efficient - A Comparison Between Mouse and Controller

Purpose: The goal of this observational study is to understand the differences in precision, time efficiency and user preference between using a mouse or a gaming controller in various scenarios. Participants will be asked to walkthrough three parts of a data-collecting environment in which they will have to solve diverse tasks with the two input methods. Be advised that the last of the three parts will include cooperating with another participant. The experimenter will use the data collected during this study to understand the key differences between the two input methods when it comes to quantitative performance and user preference.

Procedure: Participation in this study involves a discussion to understand user's experience and background information, followed by a walkthrough of the upcoming tasks. The experimenter will guide the participant through the session.

The experimenter will not capture the screen but will record audio of some parts of the discussion. All information will be confidential. (See 'Confidentiality' below for details.)

Principal investigator: Cristian-Ioan Bratu
ioan.bratu@rwth-aachen.de

Risks/Discomfort: Even though the study is expected to last no longer than one hour, you may become fatigued during the course of your participation in the study. Feel free to take as many breaks as necessary during the study. There are no risks associated with participation in the study. Should completion of the task becomes distressing to you, it will be terminated immediately.

Confidentiality: All information collected during the study period will be kept strictly confidential. You will be identified only through identification numbers and background information you divulge in publications or reports. If you agree to join this study, please sign your name below.

Addendums: Participation in this study is voluntary. You are free to withdraw or discontinue the participation. Participation in this study will involve no cost to you.

☐ I have read and understood the information on this form.

☐ I have had the information on this form explained to me.

Participant's Name	Participant's Signature	Date
	Principal Investigator	Date

Figure A.1: Informed Consent Form users had to sign in order to participate

Appendix B

User Study Questionnaire

This Appendix contains the user questionnaire presented to the participants during our user study. They had to fill it out as described in the Methodology.

Demographics

Age:
Gender:
Occupation:
If you're a student, what are you studying?:

General questions

Q1: I am familiar with using a mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q2: I am familiar with using a controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q3: I usually enjoy using a mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q4: I usually enjoy using a controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q5: How often do you use a mouse?
☐never ☐a few times a year ☐at least once a month ☐at least once a week ☐daily

Q6: How often do you use a controller?
☐never ☐a few times a year ☐at least once a month ☐at least once a week ☐daily

Q7: I have played games on a computer before. ☐yes ☐no
Q8: I have played games on a PlayStation / an XboX / another gaming console before. ☐yes ☐no

Figure B.1: User Study Questionnaire - Page 1

PART I.1: Selections – before

Q1: Selecting the objects with the mouse will be fast.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q2: Selecting the objects with the controller will be fast.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q3: Selecting the objects will generally be easy with the mouse.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q4: Selecting the objects will generally be easy with the controller.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q5: I will enjoy solving this task with the mouse.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q6: I will enjoy solving this task with the controller.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q7: The mouse will be precise (few missclicks).

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q8: The controller will be precise (few missclicks).

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q9: Selecting the objects will be faster with the ☐mouse ☐controller.

Q10: Selecting the objects will generally be easier with the ☐mouse ☐controller.

Q11: Selecting the objects will be more accurate (fewer missclicks) with the ☐mouse ☐controller.

Q12: The ☐mouse ☐controller is better suited for this kind of task.

Figure B.2: User Study Questionnaire - Page 2

PART I.1: Selections – after

Q1: Selecting the objects with the mouse was fast.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q2: Selecting the objects with the controller was fast.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q3: Selecting the objects was generally easy with the mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q4: Selecting the objects was generally easy with the controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q5: I have enjoyed solving this task with the mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q6: I have enjoyed solving this task with the controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q7: The mouse was precise (few missclicks).
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q8: The controller was precise (few missclicks).
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q9: Selecting the objects was faster with the ☐mouse ☐controller.
Q10: Selecting the objects was generally easier with the ☐mouse ☐controller.
Q11: Selecting the objects was more accurate (fewer missclicks) with the ☐mouse ☐controller.
Q12 a: The ☐mouse ☐controller is better suited for this kind of task.
Q12 b: This outcome was expected.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q12 c: What influenced your decision? **(VOICE RECORDING)**

Figure B.3: User Study Questionnaire - Page 3

PART I.2: Dockings – before

Q1: Docking the objects with the mouse will be fast.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q2: Docking the objects with the controller will be fast.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q3: Docking the objects will generally be easy with the mouse.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q4: Docking the objects will generally be easy with the controller.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q5: I will enjoy solving this task with the mouse.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q6: I will enjoy solving this task with the controller.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q7: Docking the objects will be faster with the ☐mouse ☐controller.

Q8: Docking the objects will generally be easier with the ☐mouse ☐controller.

Q9: The ☐mouse ☐controller is better suited for this kind of task.

Figure B.4: User Study Questionnaire - Page 4

PART I.2: Dockings – after

Q1: Docking the objects with the mouse was fast.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q2: Docking the objects with the controller was fast.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q3: Docking the objects was generally easy with the mouse.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q4: Docking the objects was generally easy with the controller.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q5: I have enjoyed solving this task with the mouse.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q6: I have enjoyed solving this task with the controller.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q7: Docking the objects was faster with the ☐mouse ☐controller.

Q8: Docking the objects was generally easier with the ☐mouse ☐controller.

Q9 a: The ☐mouse ☐controller is better suited for this kind of task.

Q9 b: This outcome was expected.

☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q9 c: What influenced your decision? **(VOICE RECORDING)**

Figure B.5: User Study Questionnaire - Page 5

PART II.1: Object following – before

Q1: Following the objects with the mouse will be accurate.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q2: Following the objects with the controller will be accurate.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q3: Following the objects will generally be easy with the mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q4: Following the objects will generally be easy with the controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q5: I will enjoy solving this task with the mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q6: I will enjoy solving this task with the controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q7: Following the objects will generally be easier with the ☐mouse ☐controller.
Q8: Following the objects will be more accurate with the ☐mouse ☐controller.
Q9: The ☐mouse ☐controller is better suited for this kind of task.

Figure B.6: User Study Questionnaire - Page 6

PART II.1: Object following – after

Q1: Following the objects with the mouse was accurate.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q2: Following the objects with the controller was accurate.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q3: Following the objects was generally easy with the mouse.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q4: Following the objects was generally easy with the controller.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q5: I have enjoyed solving this task with the mouse.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q6: I have enjoyed solving this task with the controller.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q7: Following the objects was generally easier with the ☐mouse ☐controller.

Q8: Following the objects was more accurate with the ☐mouse ☐controller.

Q9 a: The ☐mouse ☐controller is better suited for this kind of task.

Q9 b: This outcome was expected.

☐Strongly disagree	☐Disagree	☐Neither agree nor disagree	☐Agree	☐Strongly agree

Q9 c: What influenced your decision? **(VOICE RECORDING)**

Figure B.7: User Study Questionnaire - Page 7

PART II.2: Path following – before

Q1: Following the paths with the mouse will be accurate.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q2: Following the paths with the controller will be accurate.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q3: Following the paths will generally be easy with the mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q4: Following the paths will generally be easy with the controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q5: I will enjoy solving this task with the mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q6: I will enjoy solving this task with the controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q7: Following the paths will be faster with the ☐mouse ☐controller.
Q8: Following the paths will generally be easier with the ☐mouse ☐controller.
Q9: Following the paths will be more accurate with the ☐mouse ☐controller.
Q10: The ☐mouse ☐controller is better suited for this kind of task.

Figure B.8: User Study Questionnaire - Page 8

PART II.2: Path following – after

Q1: Following the paths with the mouse was accurate.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q2: Following the paths with the controller was accurate.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q3: Following the paths was generally easy with the mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q4: Following the paths was generally easy with the controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q5: I have enjoyed solving this task with the mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q6: I have enjoyed solving this task with the controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q7: Following the paths was faster with the ☐mouse ☐controller.
Q8: Following the paths was generally easier with the ☐mouse ☐controller.
Q9: Following the paths was more accurate with the ☐mouse ☐controller.
Q10 a: The ☐mouse ☐controller is better suited for this kind of task.
Q10 b: This outcome was expected.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree
Q10 c: What influenced your decision? **(VOICE RECORDING)**

Figure B.9: User Study Questionnaire - Page 9

PART III: State machines – before

Q1: Configuring the state machines with the mouse will be fast.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q2: Configuring the state machines with the controller will be fast.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q3: Configuring the state machines will generally be easy with the mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q4: Configuring the state machines will generally be easy with the controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q5: I will enjoy solving this task with the mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q6: I will enjoy solving this task with the controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q7: Configuring the state machines will be faster with the ☐mouse ☐controller.
Q8: Configuring the state machines will generally be easier with the ☐mouse ☐controller.
Q9: The ☐mouse ☐controller is better suited for this kind of task.

Figure B.10: User Study Questionnaire - Page 10

PART III: State machines – after

Q1: Configuring the state machines with the mouse was fast.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q2: Configuring the state machines with the controller was fast.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q3: Configuring the state machines was generally easy with the mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q4: Configuring the state machines was generally easy with the controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q5: I have enjoyed solving this task with the mouse.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q6: I have enjoyed solving this task with the controller.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q7: Cooperating with another person was helpful. (cooperative scenario) / Cooperating with another person would be helpful. (non-cooperative scenario)
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q8: I could have solved this task alone. (cooperative scenario) / Cooperating with another person would make solving this task faster. (non-cooperative scenario)
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q9: Configuring the state machines was faster with the ☐mouse ☐controller.
Q10: Configuring the state machines was generally easier with the ☐mouse ☐controller.
Q11 a: The ☐mouse ☐controller is better suited for this kind of task.
Q11 b: This outcome was expected.
☐Strongly disagree ☐Disagree ☐Neither agree nor disagree ☐Agree ☐Strongly agree

Q11 c: What influenced your decision? **(VOICE RECORDING)**

Figure B.11: User Study Questionnaire - Page 11

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