Developing a Human-Centric Strategy for the Future Design of Agricultural Tractor Cabs: Optimizing User Interaction and Ergonomics

by

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“We spend a lot of time designing the bridge, but not enough time thinking about the people who are crossing it.”

– Dr. Prabhjot Singh, Director of Systems Design at the Earth Institute

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Abstract

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(Under the direction of Dr. Danny Mann)

The evolution of tractor cab design has transitioned from a focus solely on functionality to a more holistic approach that prioritizes human-centered design principles. This research delves into the ergonomic considerations necessary for the design of semi-autonomous tractor cabs, aiming to enhance operator comfort, safety, and efficiency. The study begins by exploring ergonomic shortcomings in current tractor cab designs, highlighting issues such as awkward seating postures, frequent neck and back twisting. Observational techniques, usability assessments, and interviews with design engineers were employed to gain insights into these ergonomic challenges. The study also incorporates anthropometric modeling to understand the active range of motion for key joints, classifying these movements into comfortable, acceptable, and unsatisfactory zones. The RAMSIS software was employed for evaluating comfort and discomfort as well as determining the optimal visual field. This information is vital for guiding the placement of controls and features within the cab, ensuring that human comfort is prioritized.

The research further ranks tasks performed by operators in both on-road and field modes, evaluating them based on frequency of use, task priority, and safety concerns. This prioritization guides the strategic placement of controls, ensuring that high-priority tasks are easily accessible. Recommendations are provided for the optimal placement of features, such as speed control, steering, and emergency systems, within the operator's comfort zones. The study also emphasizes the need for adjustable features to accommodate different operator sizes and preferences.

This research provides a comprehensive framework for the human-centered design of semi-autonomous tractor cabs. By integrating ergonomic principles and prioritizing operator needs, the proposed design aims to enhance the overall user experience, ensuring that future tractor cabs are not only functional but also comfortable and safe for operators.

Keywords: *Human-centered design, Semi-autonomous tractors, Tractor cab ergonomics, Comfort and discomfort assessment, Control placement.*

1. INTRODUCTION

The rapid technological advancements during World War II, along with the introduction of complex and sophisticated machines and weaponry, imposed new demands on operators' cognition and response times. This prompted researchers to develop modern ergonomics and investigate the cognitive and physical demands of tasks (Maddox et al., 1995; Waterson, 2011).For instance, interest in the design of controls and displays grew, leading to the realization that logically placed and differentiated controls significantly reduced the frequency of pilot error (U.S. Fire Administration, 2021). In this era, farm mechanization aimed to develop machinery and systems that could perform tasks more efficiently than human labor. These advancements were designed to increase productivity, reduce manual labor, and drive economic growth (Benos et al., 2020). The goal was to maximize productivity, resulting in more output, more products, and increased revenue.

While the goal of reducing labor necessary for farm work was successfully achieved, it also resulted in prolonged exposure to vibration, noise, and poor working conditions in the tractor cab. This prolonged exposure can lead to numerous health issues for tractor operators, such as musculoskeletal disorders (Merryweather et al., 2011), hearing loss (Dewangan et al., 2023), and chronic fatigue (Vidhu & Tewari, 2015). The rapid mechanization of agriculture highlighted the urgent need for ergonomic improvements in tractor design. Initially, efforts were concentrated on enhancing basic operator safety and comfort to reduce fatigue and boost productivity.

With technological advancements, such as the introduction of air conditioning systems in cabs, noise reduction through insulation, and vibration-insulated seats, early problems were better managed. However, these improvements also brought numerous new controls and features that needed to be managed properly to avoid confusing the operator. Consequently, the aim was to organize these features effectively, making the controls as comprehensive as possible while minimizing physical and mental fatigue for the operator (Barbieri et al., 2018; Mehta et al., 2008a; Yadav et al., 2017).

As the agricultural industry becomes increasingly competitive, functionality alone is no longer sufficient to sell products. Farmers and agricultural businesses now prioritize comfort and ease of use when purchasing machinery, pushing manufacturers to be innovative. As a result, more research is being dedicated to humans and human-centered design. Human-centered design focuses on considering the user's needs and experiences at every stage of product development to ensure a positive user experience, as neglecting this can lead to the failure of the product (Garrett, 2011). Marcel Wanders, co-founder of a design label Moooi, argues that *"Human-centered design is about understanding that we are not as rational as we like to think. It's about how we engage with objects and each other in our world, both as individuals and together*" (Wanders, 2021). This design thinking process elevates design to the next level, ensuring that products not only function well but also enhance user experience and satisfaction.

In recent years, the rapid progress towards autonomous systems such as cars, airplanes, and tractors are making the vision of fully autonomous operations a reality (Zilberstein, 2015). However, several factors, including technological limitations, safety and reliability concerns, regulatory and legal challenges, and public acceptance, still hinder full autonomous tractor implementation. In the meantime, there are tractors that still require some level of human intervention to complete tasks, which are referred to as Semi-autonomous (SA) tractors. In these systems, human operators might no longer have the same responsibilities as before; instead, their roles have evolved. For example, they may no longer be responsible for driving tasks in the field but are now tasked with supervising and managing a fleet from within the cab.

This potential change in the role of human operators raises questions about whether the current cab configuration is ergonomically suitable for these new tasks. Is it possible to redesign the cab to avoid past ergonomic mistakes and better accommodate human needs? Can human comfort be prioritized in this new design?

Considering these questions, I decided to employ a human-centered design thinking process, inspired by Harvard Business School, to advance the design to the next level (Han, 2022). The initial phase, Clarify, involves observing the situation without bias. This stage emphasizes the user-centric aspect of design thinking, requiring empathy with those affected by the problem. It involves interacting with the vast group of users, observing their interactions with the system and understanding their challenges. Once the pain points of previous designs and common user complaints are understood, the next step is to develop potential solutions based on the generated ideas. The wider the application of this solution to a broader group of users, the greater its effectiveness will become. Finally, the last phase involves putting the developed solutions into action. This step is crucial for translating theoretical ideas into practical applications.

In this project, the initial step involves analyzing the interactions between humans and tractors to identify and clarify existing ergonomic issues without bias. Following this, the focus shifts to understanding the comfort levels of human operators in various scenarios. The aim is to understand the human comfort zones better. Insights from these two phases will inform the development of tasks for future tractor cab designs, ensuring they are placed within operator comfort zones. This knowledge acquired from three distinct segments serves as a design guideline for engineers on implementing a human-centered approach to tractor design.

2. OBJECTIVES

This thesis aims to explore and enhance the ergonomic design of tractor cabs, focusing on human-centered design principles for semi-autonomous tractor operations. The primary objectives of this research are as follows:

1. Identify Ergonomic Shortcomings: Conduct an in-depth analysis of current tractor cab designs to identify ergonomic flaws that impact operator comfort, safety, and efficiency.

2. Understand Human-Machine Interaction: Examine how operators interact with semi-autonomous tractor systems, focusing on the transition from manual to automated operations and the resulting changes in operator roles and tasks.

3. Integrate Advanced Anthropometric Modeling: Utilize advanced anthropometric tools to model the comfort and discomfort zones for various joints and body parts of tractor operators, guiding the ergonomic design process.

4. Develop Task Prioritization Framework: Create a comprehensive framework to prioritize tasks based on their frequency of use, urgency, and safety concerns in both on-road and in-field operations.

5. Optimize Control Placement: Provide recommendations for the optimal placement of controls and features within the tractor cab to enhance operator efficiency and comfort, ensuring that critical tasks are easily accessible.

To achieve these objectives, the thesis is structured into three main sections:

- Understanding Ergonomics of Current Tractor Cab Design: Addresses objectives 1 and 2.
- Anthropometric Modeling of the Tractor Cab: Focuses on achieving objective 3.
- Human-Centered Design of a Cab for a semi-autonomous Tractor: Aims to achieve objectives 4 and 5.

By achieving these objectives, this research aims to contribute to the development of tractor cabs that are ergonomically optimized for operator comfort and safety, facilitating a seamless transition to semi-autonomous operations while maintaining a focus on human factors.

3. UNDERSTANDING ERGONOMICS OF CURRENT TRACTOR CAB DESIGN

3.1 BACKGROUND AND OBJECTIVES

The transition from level 0 to level 5 of autonomy (SAE International, 2021) in the tractor industry has accelerated recently. In the realm of SA tractors, where the operator is still present in the cab but no longer responsible for steering, the operator's role is evolving. This might present an opportunity to reconsider the cab layout to ensure the farmer's comfort, safety, and optimal use of operational time, aligning the design with the operator's new role. To achieve this goal, it is crucial to first identify the ergonomic flaws in the current design to avoid them in the future. Additionally, we need to understand how humans and machines interact when the operator is not fully responsible for the operation of the machine (i.e., semi-autonomous operation). Therefore, the objectives of this section are:

1. Understanding the ergonomic shortcomings of a current cab design.
2. Gaining insights into Human-Machine Interaction (HMI) in the context of SA operation.

The knowledge gained from this section is expected to be the first step toward designing the cab of the future, improving the overall design and functionality of SATs.

3.2 OVERVIEW OF HUMAN FACTOR ENGINEERING

Human Factors (HF), also referred as ergonomics, is a multidisciplinary field that focuses on gathering and utilizing information about human capabilities and limitations (Elbert et al., 2018). The International Ergonomics Association (IEA) adopts this perspective and defines ergonomics as the scientific discipline concerned with understanding HMI and the profession that applies theories, principles, data, and methods to optimize human well-being and overall system performance (Kari & Steinert, 2021). Considering the diverse goals, rules, and preferences across different industries, human factors influencing system success are often categorized based on various aspects. For instance, Kirwan & Ainsworth (1992) identified six aspects of human factors: allocation of function, person specification, staffing and job organization, task and interface design, skills and knowledge acquisition, and performance assurance. Another example of classification comes from the IEA (International Ergonomics Association, 2019), which divides the domains of human factors into three distinct disciplines: physical ergonomics, cognitive ergonomics, and organizational ergonomics. Physical ergonomics focuses on human anatomical, physiological, and biomechanical characteristics in relation to physical activity, addressing topics such as working postures, movements, and workplace safety. Cognitive ergonomics focuses on mental processes and their impact on HMIs, covering areas such as decision making, human-computer interaction, and work stress. Organizational ergonomics optimizes sociotechnical systems, including organizational structures, communication, teamwork, and the design of work paradigms.

The central focus of this part of study is to conduct an extensive examination of physical ergonomics, with a specific emphasis on understanding the interaction between humans and machines within the tractor cab environment. The study will investigate the typical usage patterns of tasks performed in the cab and conduct assessments of potential ergonomic shortcomings in the design. This preliminary investigation is crucial in the design process, as it ensures that the needs and abilities of tractor operators are given primary consideration. By gaining insights into how farmers utilize their workspace and identifying the challenges they commonly face, engineers can better anticipate and avoid these issues in future iterations of tractor cab designs.

3.3 PHYSICAL HUMAN FACTORS PRINCIPLES RELEVANT TO OPERATING A TRACTOR

3.3.1 Awkward seating

Individuals operating tractors could frequently encounter discomfort because of extended periods of sitting, the vibrations produced by the tractor, and unfavorable bodily position, typically when overseeing rear-mounted equipment (Gruver et al., 1997; Calvo, 2008). Engaging in upper body twisting while observing objects behind, rotating the neck to look back, and sudden movements of the vehicle – all these actions have the capacity to independently contribute to the development of back pain (Gruver et al., 1997; Cutini et al., 2017). Over an extended duration, these factors can also lead to the onset of musculoskeletal disorders (Calvo, 2008). For instance, literature argues that a significant portion of operational tasks like ploughing and seeding, which take place behind the tractor, require farmers to maintain an uncomfortable posture in standard tractor cab designs due to their desire to monitor these activities (Sjøflot, 1980).

Therefore, farmers allocate a substantial chunk of their operational time to being seated in an uncomfortable position for the sake of rear equipment monitoring. Consequently, it becomes imperative to comprehend the extent of time during which the operator occupies an uncomfortable posture. Additionally, it is important to assess how features like auto-steering and adjustable seats impact neck movement and seating posture. This information can assist in comprehending behavioral patterns and anticipating future trends or potential risks. Considering the significant exposure, and importance of the tasks that put the operator into these awkward positions, special emphasis should be allocated to observing the duration for which an individual maintains awkward seating positions and the degree of multitasking.

3.3.2 Frequency and sequence of use

As we transition from the current design to the future design, it is essential to prioritize efficient communication between humans and machines. A key strategy to achieve this effective communication is to position frequently used controls in easily accessible locations and arrange controls to align with the natural sequence of actions required to complete a task (Mann, 2021). In a study involving experienced air seeder operators, ride-along observations unveiled the use of eight control types during seeding operations (Mastorakos, 2013). These controls were divided into four related to tractor motion (e.g., throttle, transmission) and four tied to the implement attached behind the tractor (e.g., air seeder lift, monitor). Notably, the controls associated with the air seeder's operation were activated approximately 74.2 times on average during the 1-hour ride-along, while those linked to tractor motion were only activated 21 times.

In a separate study involving ten experienced tractor operators in Greece, it was found that the steering wheel was the most frequently used control on the tractor, followed by controls for managing the implement attached to the tractor (Drakopoulos & Mann, 2020). Additionally, Mann (2021) argues that the specific sequence and timing of control usage may be more critical during headland turns than during the primary seeding process, suggesting distinct operational challenges during these turns that require careful consideration of control sequencing.

In contemporary tractor designs, particularly with the integration of SA capabilities like auto-steering, the centrality of the steering wheel to the operator's attention may be reduced. Consequently, a careful analysis of control employment, including considerations of frequency and sequence while steering and not steering, is crucial for the optimization of operational interactions with heightened efficiency.

3.3.3 Ergonomic triggers

When transitioning from the existing tractor design to semi-autonomous tractors, it is imperative to ensure that the new design minimizes avoidable actions by operators that could result in operator discomfort or, in the worst scenario, harm to the operator. The factors to consider can be summarized as the accessibility of controls, levels of vibration and noise, the comfort of the operator's legs, arms, back and neck as well as the ease of egress from the equipment (Drakopoulos, 2007). In a study by Kim et al. (2018), it is asserted that working on uneven terrains can subject the operator to the risk of overusing and potentially damaging the soft tissues in the lower back and neck areas, primarily due to exposure to multi-axial vibrations. Therefore, it is essential to understand the factors that could impact the human body’s well-being during farm operation.

Additionally, it is essential to consider the anthropometric characteristics of the individuals being addressed in the design process of future cabs. This ensures a well-accommodated cab-enclosure (Hsiao et al., 2005), controls being situated within easy reach (Eltawil & Hegazy, 2011) and ensuring that control placement does not restrict the natural body movements of operators (Drakopoulos & Mann, 2007). In an investigation, a team of scholars (Hsiao et al., 2005) conducted a research study involving a sample of 100 farm workers to measure their body dimensions, with the aim of evaluating the suitability of cab accommodations. The research findings indicated that the vertical clearance specified in the existing studies for agricultural tractor enclosures, set at 90 cm, appeared to be insufficient when compared to the 99% of male farm workers' sitting heights observed in this study, which averaged 100.6 cm.

Given the information provided, it is necessary to identify the parameters that might contribute to operator discomfort, also known as ergonomic triggers, which can lead to both physical and mental fatigue. Therefore, within the context of this study while conducting research, particular attention should be given to identifying actions that can be prevented or HMIs that lead to operator discomfort, with the intention of addressing these issues in future cab design improvements.

3.4 TASK ANALYSIS AS A TOOL FOR THE DESIGN ENGINEER

Engineers undertake the analysis of HF to ensure that the design achieves optimal efficiency, effectiveness, and user satisfaction. Although there are multiple approaches available for evaluating designs, task analysis (TA) has emerged as a highly effective method. TA encompasses a diverse range of techniques utilized by ergonomists, designers, operators, and assessors, with the aim of comprehensively describing and assessing the HMI within complex systems (Kirwan & Ainsworth, 1992). Its primary objective is to gain insights into both existing and hypothetical work methods and documenting them to identify potential gaps or opportunities for enhancement (Kieras, 1999). The initial phase of TA focuses on identifying areas in the current design that may require improvement or refinement. By employing this systematic approach, engineers can uncover valuable information to bridge design gaps and optimize overall system performance.

The selection of an appropriate TA method is influenced by factors such as the availability of resources, previous research findings that have demonstrated success, and the specific HF issues that need to be addressed in the subsequent design. It is crucial to consider these factors to ensure a consistent and robust approach to TA, taking into account the unique requirements of the design context. Based on the HFs mentioned above (awkward seating, ergonomic triggers, and frequency and sequence of use) the following methods have been identified as the most suitable TA techniques to align with the objectives of this study.

3.4.1 Observational techniques

One of the valuable means for TA is observational techniques, enabling researchers to directly grasp and witness the activity being performed in an unaltered setting (Kirwan & Ainsworth, 1992). By observing people's behaviors, actions, and interactions one can gain valuable insights on the steps they take to perform tasks, the challenges they encounter, and how they engage with their workspace. Moreover, through observational techniques, one can obtain valid understanding by contrasting an individual's self-perceived task performance with their actual execution. As an illustration, in the study conducted by Dey & Mann (2010), the comparison between the outcomes obtained from a written questionnaire and subsequent observation of sprayer operations revealed intriguing findings. According to the questionnaire, operators indicated that lightbars were the primary source of guidance. However, the observational data on operators' eye-glance behavior demonstrated that they predominantly focused on external field cues during the task. Hence, this technique offers an opportunity to observe the task without being influenced by biased perceptions of operators. In this study, observational techniques offer the researcher a valuable opportunity to intimately understand the practical dynamics of the work environment in action.

A diverse array of observational techniques is commonly employed including direct observation, remote observation through live recordings or video recording, and activity sampling (Kirwan & Ainsworth, 1992). During observation, it is crucial to give significant attention to HF considerations including: appropriate task allocation, interface and task design, ensuring performance, assessing Mental Workload (MWL), and taking into account physical factors. Specifically, when employing observational techniques, it is important to closely monitor the duration individuals spend in uncomfortable seating positions, identify ergonomic triggers, and note the frequency and sequence of control usage.

3.4.2 Usability assessment as a tool for the design engineer

Usability, as defined by the Cambridge dictionary, refers to how easy something is to use or the extent to which it is user-friendly. When evaluating a current system, it is essential to ensure that tasks can be performed easily, quickly, and with minimal errors. The primary goal of usability assessment is to enhance the product by reducing user errors, increasing user efficiency, ensuring user safety for both the system and the user, and enhancing their satisfaction (Kortum, 2016).

Even though designers apply HFs' considerations and evaluate designs using CAD software before developing a prototype, it is common for certain aspects of the design to not work as intended (Rakhra et al., 2020). As quoted by Kortum (2016) "while good usability may go unnoticed, poor usability can have significant consequences".

Assessing the design's usability is crucial for ensuring an effective HMI and identifying potential ergonomic flaws. Due to the importance of usability, a distinctive part of the TA is dedicated to the usability assessment of the current design. There are various types of usability assessment methods, each with its strengths and focus. For the evaluation of a partially automated cab, the following methods have been selected: heuristic evaluation, cognitive walkthrough, and user satisfaction evaluation.

3.4.2.1 Heuristic evaluation

Heuristic evaluation (HE) is an analytical technique within UX design, wherein experts (professional engineers in this case) assess an interface against established usability principles (heuristics) to pinpoint usability problems and propose enhancements (Nielsen & Molich, 1990; Silva et al., 2023). Derived from the research of Nielsen & Molich (1990), nine fundamental principles have been condensed to serve as guidelines for HE. These include concepts such as maintaining a simple and intuitive dialogue, utilizing language familiar to the user, minimizing memory demands, ensuring consistency, delivering feedback effectively, offering clearly identifiable exit points, providing shortcuts, crafting meaningful error messages, and proactively averting errors. These principles are essential considerations to be implemented in practical design.

Over time, these principles have undergone adaptations and refinements to align with specific project objectives. For instance, when evaluating the Tesla Model 3, issues were discovered that resonated with the core nine principles, encompassing factors like the clarity of system status display, user autonomy, alignment with real-world expectations, adherence to consistency and standards, error mitigation, prioritization of recognition over recall, efficiency in usability, aiding users in recognizing, diagnosing, and overcoming errors, as well as the provision of effective help and documentation (Parkhurst et al., 2019).

Given the significant benefits of HE, including its cost-effectiveness, user-friendly nature, ease of motivation, and lack of extensive planning prerequisites (Silva et al., 2023; Kortum, 2016) it is well-suited for implementation at this phase of the project, with some modifications. Since this study primarily emphasizes the evaluation of physical ergonomics, the selected heuristics will primarily address this aspect.

3.4.2.2 Cognitive walkthrough

Cognitive Walkthrough (CW) stands as a method to evaluate usability, stemming from the psychological principle denoted as CE+, a theory including the elements shaping the ease of grasping novel interfaces or their proficiency in supporting the process of explorative learning (Rieman et al., 1995; Jacobsen & John, 200). Similar to HE, it avoids the use of end users for evaluation, preferring experts (engineers) instead. Yet, the distinction in CW lies in its focus on being task oriented and the undertake tasks step by step (Kortum, 2016).

An illustration of the implementation of CW can be found in research by that evaluated a user interface designed for supervising autonomous agricultural sprayers. In the initial phase, evaluators streamlined their attention to machine status, spraying functions, and navigation features. Certain outcomes of the CW analysis highlighted the potential hindrance caused by small font size in accurately reading analog readings and comprehending label captions. Furthermore, the necessity for users to click a weather button to access weather information (like temperature, wind speed, and direction) was noted, contrasting with the immediate availability of other elements.

The CW emerged as an extra tool in the realm of engineering. It is a straightforward technique aiding designers to embrace the viewpoint of a potential user. This, in turn, aids in uncovering potential challenges that could emerge during interactions with the system. Given these rationales, it shows the potential to be a beneficial approach for assessing HMI and in this project's phase.

3.4.2.3 User satisfaction evaluation

User satisfaction evaluation (USE) involves the process of measuring the satisfaction level of users with a design. This includes gathering feedback from potential users to understand their perspectives and general feelings about the design. Various methods are employed to assess design, including surveys and questionnaires (Brooke, 2013), interviews and focus groups (Edley & Litosseliti, 2010), online analytics and behavioral data (Motiwalla et al., 2019), and social media and online reviews (Snelson, 2016). Social media and online platforms offer insights from a broad customer base, revealing their genuine opinions on different brands and products. By monitoring social media platforms for mentions and discussions about a product or service, public sentiment can be gauged effectively. This approach is created as a simple and useful tool, allows for the swift evaluation of user perceptions and product usability. Hence, this method is highly appropriate for this project phase and serves to complement the two preceding usability assessment techniques (HE and CW).

3.5 METHODS

Throughout the research, various methods for TA have been applied. The reasoning for choosing specific methods was discussed in the previous section. In this part, the methods applied will be discussed based on the project's goal, which is to understand HMI and the tractor cab and to identify potential ergonomic shortcomings. The focus of this analysis was during tillage and fertilizing season in Manitoba, Canada.

3.5.1 Direct Observations

3.5.1.1 Ride-alongs

During the initial phase of the study, our partner organization facilitated 3 ride-along sessions to observe and record farmers' behaviors inside the cab of Versatile tractors. These activities were conducted with approval from the University of Manitoba's Research Ethics Board (HE2023-0338). The recordings were made using two 3CH 1080P Dash Cameras, each with a 60 GB memory card. These cameras were positioned at opposite corners of the tractor cab to optimize the capture of posture, hand movements, neck movements, and armrest interactions. The recorded videos depict the interior of Versatile 580 FWD and 365 MFWD series tractors from different viewpoints (front and back) while farmers carried out their daily tasks. During the first hour of operation, I analyzed the behaviors of operator 1 with a passenger seated beside them for 48 min, followed by operator 2 with a passenger for the initial 62 min and then alone for the subsequent 45 min. Operator 3 was observed solo in the cab for the first 35 min of operation. All these tractors were equipped with auto-steering features, and the participants were male farmers spanning ages 18 to 70 all with more than 5 years of operation. The recruitment process was based on selecting farmers who have contracts with Buhler Versatile.

3.5.1.2 Site visits

One of the usability assessment methods suggested in the previous section was the CW where the researcher puts themselves in the user's perspective. Our partner organization also facilitated site and dealership visits, enabling the researcher to operate the tractor and examine tasks from the user's viewpoint, gaining a direct understanding of the HMI. Subsequently, the analyst explores the tasks, offering responses to four key inquiries (Kortum, 2016; Jacobsen & John, 2000):

1. Would the user endeavor to achieve the intended result?
2. Would the user recognize the availability of the correct action?
3. Would the user connect the accurate action with the intended outcome?
4. Upon executing the right action, would the user perceive advancements toward task resolution?

Some models of the tractors that were operated by the researcher include John Deere 542, 8RX, Versatile 365, Fendt 530, 5X 90, 516, and 1167, Case IH 340, Claas 5000, 4500, and 960 Xerion, and Massey Ferguson 7724.

3.5.1.3 Review of YouTube videos

To understand user satisfaction with the current cab configuration, 42 online videos featuring user walkthroughs of tractor cabs from various brands were reviewed on YouTube. These videos often include detailed commentary from customers expressing their preferences and critiques regarding the ergonomics of the tractor cabs. Complaints mentioned more than three times were documented as common ergonomic flaws in the design. Some models of the tractors that have been reviewed include John Deere 9RX 640, 8RX 370, Versatile 610 DT, New Holland T7.315 HD, Massey Ferguson 7719S, Fendt 700 Series, and Case IH 580.

3.5.2 Interviews with designers

The HE was extensively discussed in section 3.4.2.1. There are multiple ways to apply this method to research. In this case, the HE was implemented through interviews with design engineers. Based on the suggestion by Nielsen (1995) a group of five experienced design engineers, also referred to as "experts" throughout this research, specializing in agricultural equipment design were individually interviewed to investigate the ergonomic issues related to the existing 4WD, Nemesis, MFWD series of Versatile tractor cab. Participants were chosen from Buhler Versatile staff members who have over five years of experience in designing agricultural equipment. The interviews were structured around nine key subtasks within the cab, covering areas such as steering, foot pedal operation, engine and gearshift controls, use of multifunction and auxiliary joysticks, touch screen monitors, lighting, and safety features, as well as convenience controls (seat adjustment, radio, HVAC, etc.). The first section of the interview includes the following question about Usability and Ergonomics.

Are there any difficulties or discomforts encountered when interacting with the tractor components listed below?

1. Steering
2. Foot pedal
3. Engine and gearshift controls
4. Hydraulic controls
5. Multifunction joystick
6. Auxiliary joystick
7. Touchscreen monitors

8. Lights and safety
9. Convenience controls (seat adjustment, radio, HVAC, etc.)

In the next section, each engineer was asked to provide the comment on whether they will keep a specific task for a futuristic design, with a SA capability, and the reasoning why they will keep the task (the complete questionnaire can be found in Appendix A).

3.6 RESULTS AND DISCUSSION

3.6.1 Awkward seating posture and backward looking

Farmers frequently twist their backs and turn their necks often to monitor the implements behind them. In a study by Barber (1979),it was found that ploughing operations involved an average of 11 turns per minute, while forage harvesting operations saw an average of 17 turns per minute, and baling operations had an average of 15 turns per minute (Mehta & Tewari, 2000).

Combining multiple innovations, including the adoption of larger mirrors (Sjøflot, 1980), the implementation of GPS-guided auto-steering systems and rearview cameras (Karimi et al., 2012), and the integration of swiveling seats (Bottoms & Barber, 1978), have improved overall posture of operators. Through conducting ride-alongs and closely studying farmers in the cab environment (outlined in Methods section 3.5), it became clear from our analysis that despite notable technological advancements, farmers continue to spend a significant amount of their operational time monitoring rear equipment while seated in an uncomfortable posture.

Detailed observations included a comparison of three farmers regarding the duration (in minutes) they spent with their backs twisted while doing tillage and fertilizing (Figure 1). Operator 1, with a passenger on the side, demonstrated a tendency to spend 8.3% of their operational time seated in a twisted back posture. For Operator 2, this percentage increased to 53.3% during operations and remained similar at 56.5% when a passenger was present. Operator 3 spent 88.6% of their operational time during tillage and fertilizing tasks in a twisted back posture. While a study by Karimi et al. (2012) revealed the operators' willingness to spend 1/3 of their time in an awkward posture. This varying inclination to look backward might be based on individual farmer preferences, experience levels, familiarity with the field, task complexities, and access to technological resources.

Figure 1. Footage of operator 2 and 3 while having their back twisted and monitoring the rear implement.

Additionally, the neck turn patterns of operators during tillage and fertilizing were observed and documented (Table 1). The data capture the percentage of time the farmer holds a twisted neck to monitor the rear implement (Twisted Neck Duration (%)) and the number of necks turns per minute he performs to the right and left, both while manually steering and while not steering (i.e., with auto-steer engaged). The data reveals distinct patterns in the neck turn behavior of tractor operators during steering and non-steering periods, highlighting the impact of auto-steering capabilities. A general conclusion can be derived from the data on right-side neck turns per minute while steering and not steering for all three operators. All operators exhibited a higher frequency of looking back while manually steering: 14.3 turns per minute for operator 1, 5.0 turns per minute for operator 2 when alone in the cab, and 1.3 turns per minute when a passenger is present, and 7 turns per minute for operator 3. When not manually steering, the frequency decreased to 4.8, 0.6, 0.5, and 1.6 turns per minute respectively. This suggests that the need to look back and forth increases while manually steering and controlling the tractor. Also, the combined twisted neck duration of right and left-side neck holding while steering and not steering for each operator indicates that they spend a significant portion of their operation time holding a twisted neck. For example, operator 3 spends 40% of the time steering with their neck twisted, and during non-steering periods, this increases to 50% (11.8% left + 38.2% right).

Operator 1 demonstrated a strong preference for right neck turns, both while steering and not steering (Table 1). This suggests a possible ergonomic or habitual preference. In contrast, Operator 2 showed a more balanced distribution, especially while not steering, and an increase in left turns when accompanied by a passenger. This could be attributed to interactions with the passenger or a need for increased situational awareness on the left side, or even the seat adjustability problems to the left side. Operator 3's data align more closely with Operator 1, with a dominant right-turn pattern. This consistency across different operators suggests that right neck turns may be a common ergonomic response during these operations, potentially influenced by the layout of the cab or the nature of the tasks performed.

However, all participants exhibited a significant inclination to look backward during their tasks, consistent with findings from Barber (1979) and Karimi et al. (2012). This underscores the importance of maintaining situational awareness and considering ergonomic factors to reduce neck strain and enhance safety.

Table 1. Twisted Neck Duration (%) and frequency of head/neck turns during manual steering and autosteer engaged activities under different operational conditions by Operator 1 + passenger (Op1 + p), Operator 2 (Op2), Operator 2 + passenger (Op2 + p), Operator 3 (Op3).

	Manual Steering				Autosteer Engaged			
	Twisted Neck Duration (%)		Turns/Min		Twisted Neck Duration (%)		Turns/Min	
	Left	Right	Left	Right	Left	Right	Left	Right
Op1 + p	5.3	47.4	0.8	14.3	6.9	31.0	0.9	4.8
Op2	4.2	23.3	1.5	5.0	32.6	7.0	1.6	0.6
Op2 + p	9.1	2.7	4.1	1.3	23.5	3.9	3.0	0.5
Op3	0.0	40.0	0.0	7.0	11.8	38.2	0.3	1.6

Prolonged exposure to awkward postures can lead to short-term effects like fatigue and reduced productivity (Singh et al., 2023). Over the long term, it can significantly affect the body, with 41% of joint troubles on the lower back and then 35% in the neck and shoulders (Gomez et al., 2003). Furthermore, when these wrong postures are combined with factors like whole-body vibration, as observed in occupations such as tractor driving, the risk of chronic low back pain significantly escalates (Pope et al., 2002). The findings emphasize the imperative of mitigating awkward postures and reducing prolonged exposure in future designs of tractors to such conditions to safeguard the long-term health and well-being of workers.

3.6.2 Frequency and Sequence of use

Often farmers engage in multitasking, which includes monitoring rear implement adjustments while attending to various other responsibilities such as steering the tractor, monitoring rearward movement to manage the machinery or implement, and operating clutch, brake, and hydraulic controls (Grandi et al., 2022; Mehta & Tewari, 2000). This may entail frequent changes in position, transitioning from facing forward to facing backward, such as during baling when adopting a twisted posture to monitor the crop entering the pickup, as well as twisting to position the bale (Morgan, 2011). In this segment of our analysis aimed at enhancing understanding of the HMI and the multitasking process within the current cab design, I aim to determine how often certain cab parameters are utilized and the sequence in which they are applied.

3.6.2.1 Frequency of use

There are several factors involved in the frequency of control usage. During a field study, it was reported that the frequencies of clutch pedal operation, brake pedal operation, draft control lever manipulation, and rearward viewing per hour as 44, 112, 90, and 169, respectively (Mehta & Tewari, 2000; Rajvir, 1995). In another research project involving experienced air seeder operators (Mastorakos, 2013), ride-along observations unveiled the use of eight control types during seeding operations. Notably, the controls associated with the air seeder's operation were activated approximately 74.2 times on average during the 1-hour ride-along, while those linked to tractor motion were only activated 21 times. In this study, I opted for a different approach from previous analyses by categorizing the frequency of control usage into periods of steering and non-steering. The reasoning behind this was to better characterize potential use patterns in a SA operating environment. It was believed that the activities performed by the operator during non-steering periods can be closely related to the future SA tractor operations, where the operator is not steering in the field except in cases of emergency.

The opportunities of ride-along with the farmers and feedback gained from interviews (Methods 3.5) have summarized factors influencing the frequency of usage. These encompass the steepness of hills, soil moisture variability, soil type variability, crop residue level/type, crop vitality, task itself, type of tractor automation, type of implement automation, time pressure, field conditions (count and type), operator level of experience, type, and style of tractor (e.g. track or wheel), precision of operator (job quality expectations, field travel speed, and roading or field work).

Due to the reasons mentioned above, the expected usage pattern varied distinctly between the observed operators, yet several points deserve attention. Figures 2 and 3 reveal different patterns in control usage among the operators, highlighting both commonalities and individual differences. Operator 1 primarily relied on hydraulic controls and the multifunction joystick while steering, indicating their central role in his tasks. Auto-steering was actively engaged for operating time of all three operators, providing the chance to not steer (Figure 2). When not steering, there was an observed shift towards using touch screen, convenience controls, communication, and safety systems, reflecting a broader engagement with vehicle functionalities beyond driving (Figure 3).

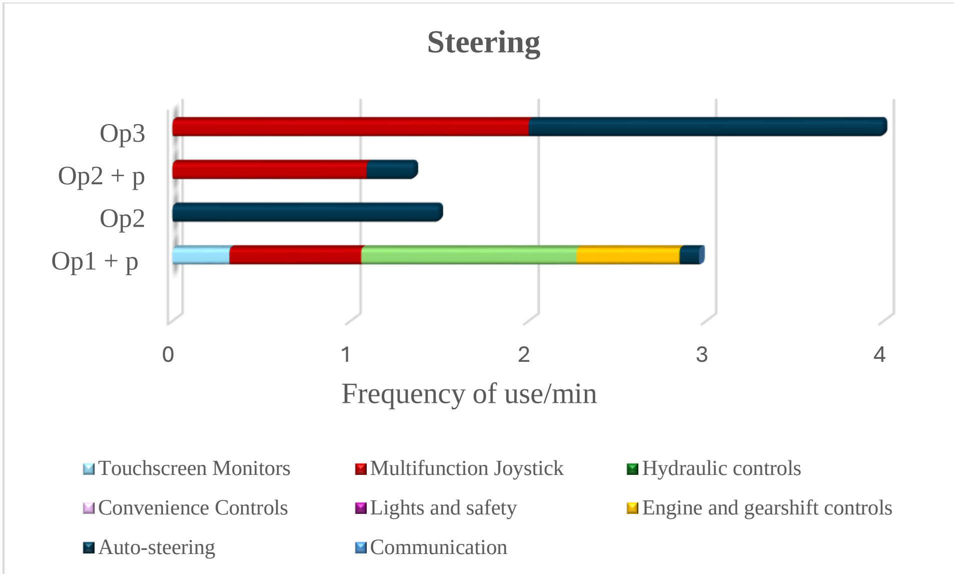

Figure 2. The frequency of control usage per minute while steering.

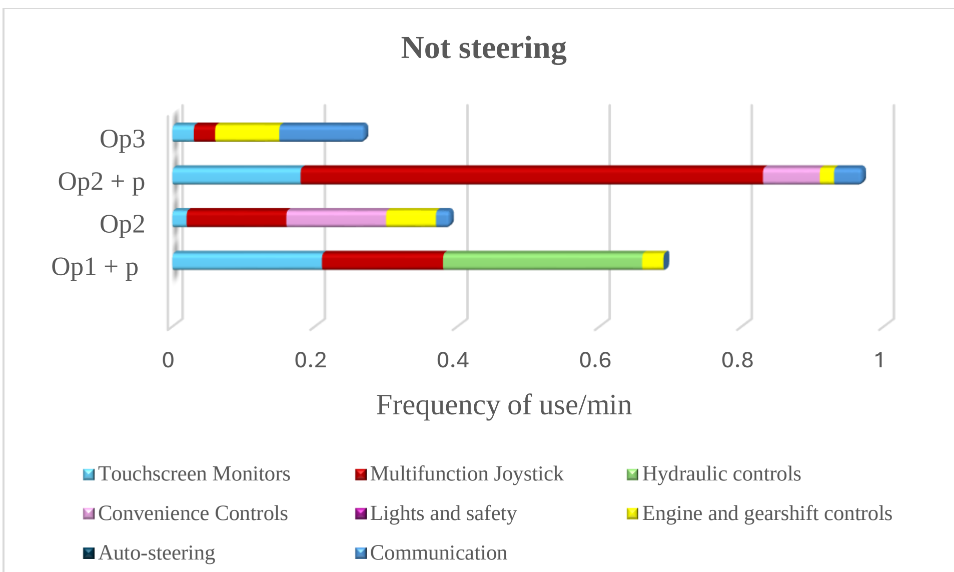

Figure 3. The frequency of control usage per minute while not steering.

This behavioral change in the frequency of usage is evident in the comparison of Figure 2 and Figure 3, supporting the idea that the ways of engagement with the machine differ during steering and non-steering activities. Therefore, this pattern change should be considered in the design process of semi-autonomous tractors, where the operator is no longer responsible for steering the tractor for prolonged periods when the autosteer function is engaged.

3.6.2.2 Sequence of control usage

During the subsequent analysis, attention was directed towards examining the sequence usage of the cab armrest. In this part I decided to understand the hand movements of the operators while activating the controls on the armrest. The analysis was conducted during the initial minutes of operation before the auto-steering button was activated.

Figure 4 reveals the initial stages of operation for the first participant exhibits a consistent pattern, commencing with the activation of the parking brake, adjustment of the throttle, engaging the tractor's cruise control, followed by manipulation of the joystick control, transitioning to adjustments on the screen, returning to the joystick for gear shifting, and ultimately activating the tractor's autosteering mode. Figure 5 visually illustrates the progression of these steps undertaken by two other farmers. This sequence entails the activation of lights, engagement with hydraulic levers, utilization of the screen situated at the far end of the armrest, manipulation of the joystick, and ends with the activation of the parking brake and autosteering.

A common observation across all instances is the occurrence of vast hand movements during operational tasks. Additionally, during the review of customer satisfaction through online materials, outlined in section 3.5.1.3 of the methods, a customer noted that the activation of parameters similarly prompts considerable hand movement. This customer experience corroborates our research findings.

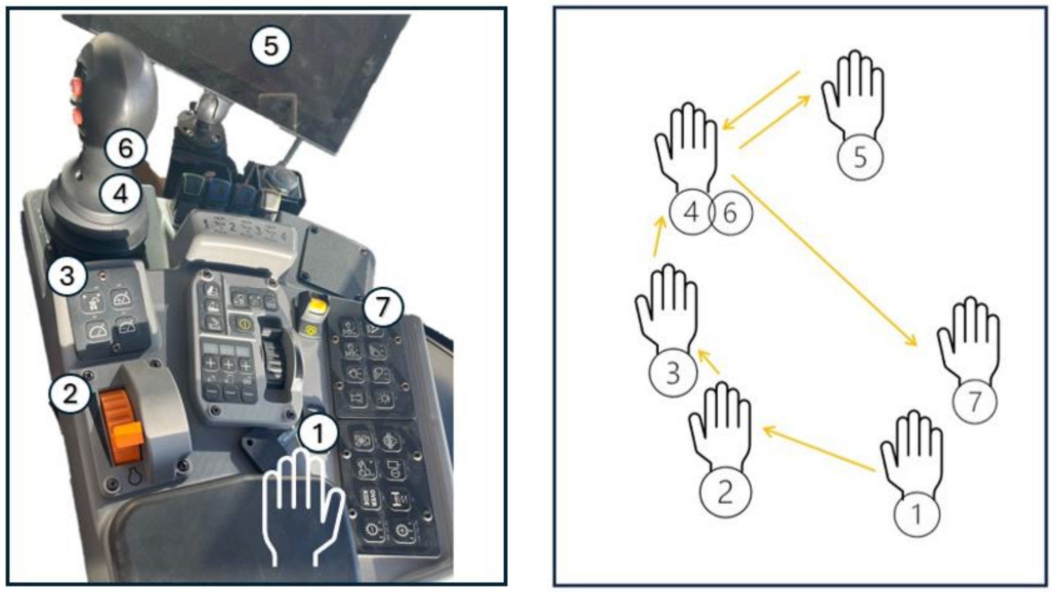

Figure 4. Sequence of physical button activations by Operator 1, along with the pattern of hand movements.

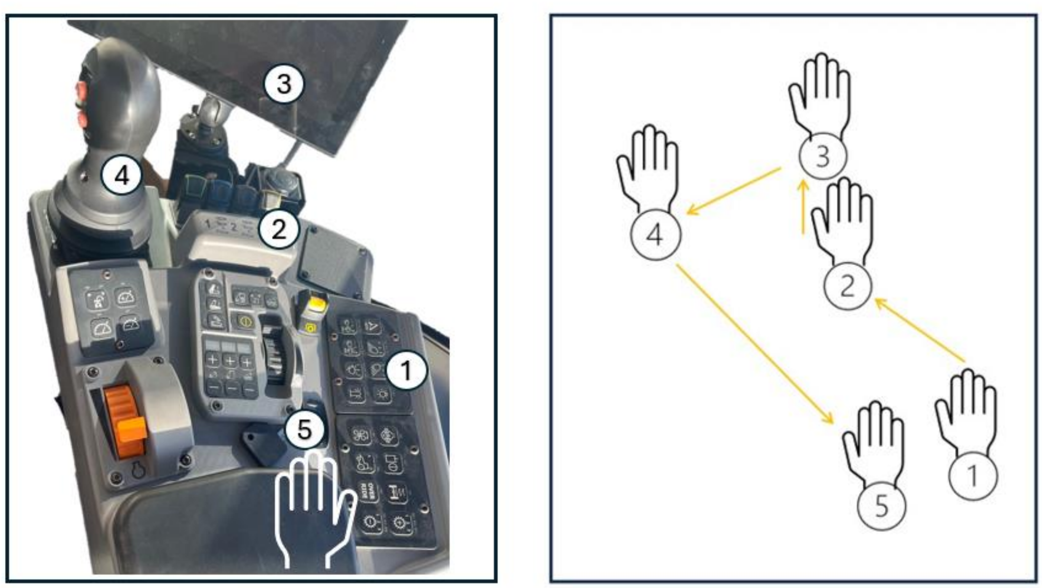

Figure 5. Sequence of physical button activations by Operator 2 and 3, along with the pattern of hand movements.

Mann (2021) argues that the specific sequence and timing of control usage may be more critical during headland turns than during the primary seeding process, suggesting distinct operational challenges during these turns that require careful consideration of control sequencing. Additionally, Mastorakos (2012) emphasized grouping similar elements together and positioning the most frequently used controls in the most favorable locations. In the armrest of these tractors, some related tasks (Figure 4 and 5) were observed to be scattered around the armrest. Grouping these tasks together or placing them in proximity, such as the engine and transmission buttons, might be beneficial. In a SA operating environment, where the tractor will be performing headland turns autonomously, these considerations become even more critical. Ensuring that controls are logically grouped and easily accessible can enhance the operator's ability to monitor and intervene during autonomous operations, especially in emergency situations. By optimizing control placement, the transition to SA operations can be more seamless, reducing the operator's workload and improving overall efficiency and safety. For example, placing Powershift Transmission Upshift/Downshift, Engine Brake, Cruise Control Buttons, and Hand Throttle near each other might improve usability (Figure 6). Alternatively, the controls utilized in sequences can be situated close together to reduce hand movement.

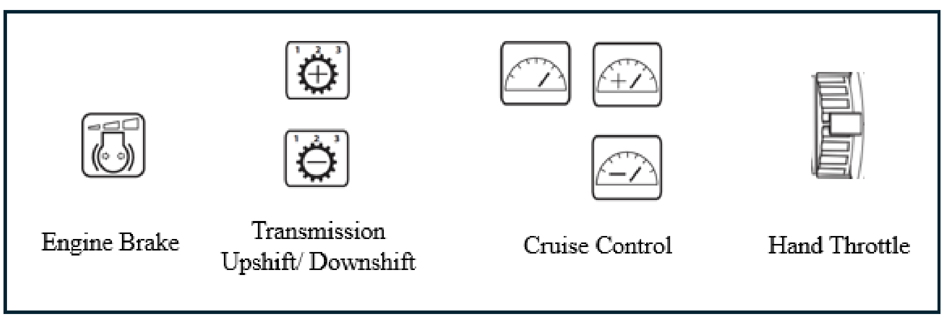

Figure 6. Grouping the physical buttons related to the engine and transmission.

3.6.3 Ergonomic triggers

During our thorough examinations of tractor cabs, it was identified that several parameters contribute to operator discomfort, which were termed as ergonomic triggers. Here in this section, my findings are summarized.

A problem identified from CW and USE was the absence of color-coding for the buttons on the armrest (Figure 7). This might present a safety concern, as buttons like the override button must be activated within seconds during emergencies. Since it shares a similar color with the other buttons, it may be difficult to quickly locate. The ISO 15077:2008 standard provides guidelines for color-coding controls based on their primary functions. According to this standard, single-function engine stop controls should be red, machine ground motion controls should be orange, and function controls involving the engagement of mechanisms should be yellow. All other controls should be black or any color except orange, red, and yellow. If implemented, the color-coding might resemble the layout shown in figure 7. Additionally, in the case of hydraulic controls, the two buttons on the right end have very similar colors (Figure 8). Using more distinctive colors could improve visual differentiation and enhance usability.

Figure 7. On the left, minimal color coding of the armrest. On the right, color-coded buttons for the engine and transmission.

Figure 8. Similar colors of two hydraulic levers.

Potential redundancies on the armrest were identified, supported by discussions with engineers about which tasks could be relocated to the screen interface and which should be retained as physical buttons (Appendix B). The features mentioned in section 3.6.2.1 that were least frequently used during operations and did not pose a safety hazard, allowing for the removal of the physical buttons, were decided to be moved to the screen. Features such as drop rate, maximum height slip threshold, travel lock, headland management, and cruise control adjustments might find better placement on the screen. It is recognized that these redundancies may enhance operator comfort and accessibility, adhering to the principle attributed to Albert Einstein, "Everything should be as simple as possible but not simpler," suggests designing toward minimalism. During interviews, emphasis was placed on determining which controls should remain in future designs, particularly in scenarios where the operator is no longer tasked with directing the tractor. Moreover, prioritizing operator and machine safety alongside minimalism ensures that in the event of autonomy breakdown, the operator can resume control safely.

Taking these considerations into account, it was decided to retain certain features (Figure 9). This includes functionalities such as gear shifting, neutral positioning both backward and forward, hydraulic levers, hydraulic activation, parking brake, PTO activation, differential lock, override button, traction control system, and front-wheel assist.

Safety and comfort concerns may arise in the cases depicted in figure 10 due to the hand's close proximity to the throttle, potentially leading to accidental activation. Furthermore, operators have expressed dissatisfaction with the location of the accelerator pedal, which may cause discomfort when spreading their feet on the left side (Figure 11, left picture). Another issue raised is the inadequate footrest placement (Figure 11, right picture), resulting in improper foot positioning. Additionally, the visibility of seat adjustments (Figure 12) is hindered by their placement on the side of the armrest, rendering them invisible. Another identified safety issue was that the cab door was designed to swing open directly towards the operator's face, posing a significant safety hazard (Figure 13). This arrangement made it difficult for the operator to enter and exit the cab safely and efficiently.

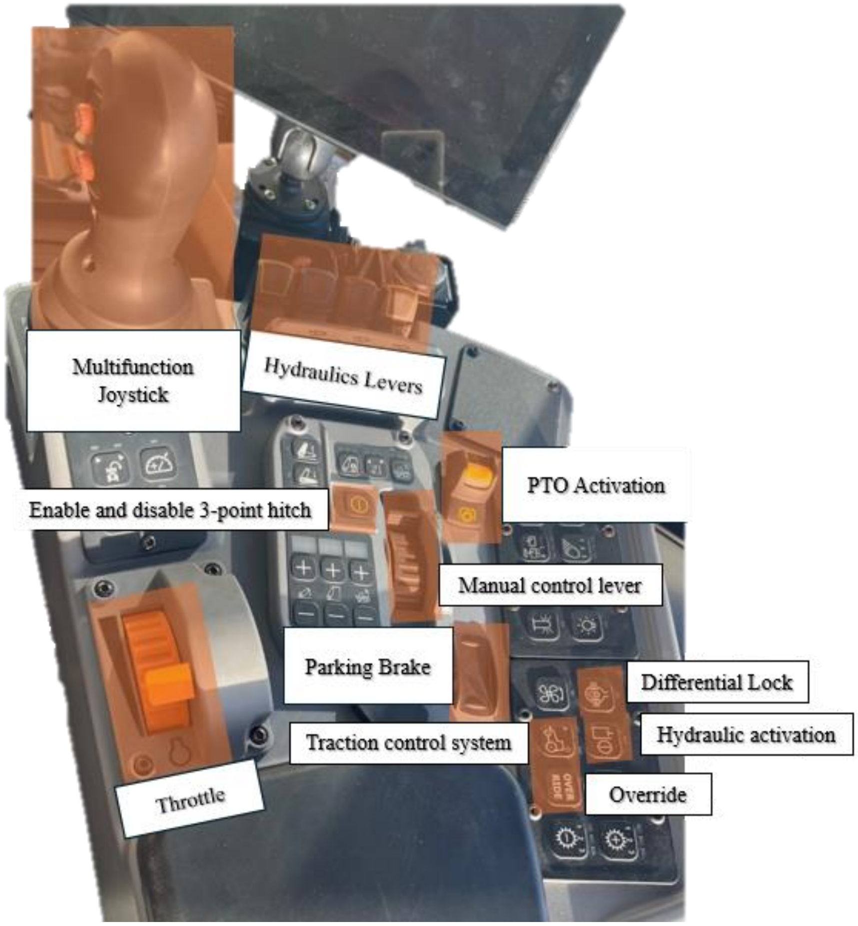

Figure 9. Selected physical buttons to retain on the armrest.

Figure 10. The forearm being positioned very close to the engine throttle poses a safety risk.

Figure 11. The placement of the accelerator pedal causes discomfort and leads to improper foot positioning.

Figure 12. The placement of seat adjustments on the side of the armrest hinders visibility.

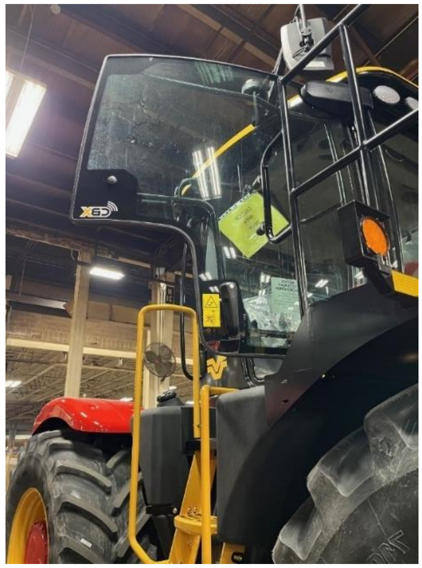

Figure 13. The doorknob's position caused the door to swing towards the operator's face, creating a safety hazard.

3.7 CONCLUSION

The study highlighted the interaction between humans and machines, identifying potential ergonomic shortcomings. Ride-along observations and detailed analysis revealed that operators often spend a significant portion of their operational time with twisted backs and frequent neck turns. These findings indicate distinct patterns in neck turn behavior and control usage, influenced by individual preferences, experience levels, and task complexities. Notably, right neck turns are a common ergonomic response, likely driven by the cab layout and nature of the tasks.

The variability in control usage while steering manually and when not steering (i.e., autosteer engaged) underscores the need for a customized approach in designing semi-autonomous tractor cabs. Operators tend to use touchscreens more frequently when autosteer is engaged, suggesting a different interaction trend compared with times when responsible for steering. Grouping related controls and color-coding buttons based on their primary functions, as recommended by the ISO 15077:2008 standard, could improve usability and safety. Additionally, the study identifies potential redundancies on the armrest and suggests relocating less frequently used controls to the screen interface. This minimalist approach could enhance operator accessibility and control while ensuring safety and comfort.

Overall, this section of the study highlights the necessity for ongoing ergonomic enhancements in tractor cab design to safeguard operators' long-term health and well-being, and to ensure the cab design adapts to the evolving role of operators from active to passive operation.

4. ANTHROPOMETRIC MODELING OF THE TRACTOR CAB

4.1 BACKGROUND

In the previous section, I described how the human operator interacts with the cab environment with an emphasis on ergonomic shortcomings. After knowing this information, it is now imperative to shift attention to the human operator, understanding comfort and discomfort felt on different body parts. This helps answer the question of what the human wants or needs and determines where designers should place tasks around the human operator.

4.2 INTRODUCTION

Operating a tractor is a task that demands significant physical and mental effort, placing considerable pressure on the driver. This role necessitates constant multitasking, as outlined in section 3.6.2, including actions such as looking backward, steering, using the clutch and brake, and managing hydraulic controls, touchscreens, and multifunction joysticks. The latest design of the cab layout is frequently overloaded with excessive information, occupies too much space, and lacks flexibility to meet the needs of all users (Grandi et al., 2022). Previous sections have thoroughly examined human behaviors and performance in interaction with current design of the machines, underscoring the critical need for these considerations in future designs.

In recent years, autonomous machines have been applied to agricultural tasks to improve work efficiency, relieve labor intensity, and enhance the quality of production and reduce cost (Bashiri & Mann, 2014; Kayacan et al., 2014; Lagnelöv et al., 2021). This shift towards autonomy has significantly altered the operator's role. Operators are transitioning from actively engaging in every aspect of driving to adopting a more passive role where they are not constantly responsible for steering (Ganesh, 2020). This trend might alter the usage patterns of the cab's elements or introduce new tasks. Therefore, developing new tractor cabs is essential to adapt to these design shifts, ensuring the driver’s comfort and the usability of the system, which greatly impacts productivity, comfort, and safety.

The goal is to go beyond mere functionality and design a solution that optimally serves the human operator. To address past physical ergonomic issues and align with modern cab development trends, it is crucial to move away from the traditional focus on machine performance. Instead, a more effective approach involves adopting a methodology that integrates innovative tools for designing a human-centric, ergonomically optimized cab (Flanagan et al., 1997; Grandi et al., 2022).

4.2.1 Prior design approaches to address ergonomic concerns

A Human-Centered Design (HCD) involves viewing tasks from the users' perspective to comprehend their emotions, motivations, and challenges (Steen, 2011). To achieve this understanding, various methods can be employed, such as interviews, surveys, questionnaires, and observations. These techniques provide direct insights into the users' experiences. In sections 3.5.1, it was discussed how these direct methods helped us identify ergonomic issues effectively.

In a work by Fagnant & Kockelman (2018), the effective implications of direct HCD methods on developing autonomous ride-sharing vehicles were explored. Through comprehensive interviews with 20 participants, the research aimed to uncover patterns in their feedback, determine needs stemming from these patterns, and create solutions to meet these needs. The findings resulted in the creation of tailored vehicles, ride-share solutions with space segmentation, and systems for automatic personal and ride-share configuration.

Another research (Alppay & Bayazit, 2015) also applied a HCD method to develop helicopter instrument panels, focusing on the importance, frequency of use, functional similarity, and sequence of use of components. Through interviews with pilots, the researchers gathered feedback on the frequency of use, importance, and general opinions of pilots on cockpit displays. This feedback informed the creation of optimized alternative display layouts and improved functional groupings.

However, while directly engaging with end-users is highly effective for designing a human-centered product and provides firsthand insights into their concerns and needs, it is crucial to have a sufficiently large sample size to make valid assumptions and generalize the findings to a broader user group. Conducting direct interviews to gather this information, while valuable, is time-consuming and may not provide a sufficiently large sample size to cover all the available options.

4.2.2 Comfort and discomfort modeling approaches

To implement an HCD, the primary emphasis should be on ensuring the operator's comfort and safety, as highlighted by Kölsch et al. (2003) and Tilley (1993). Comfort is often described as a pleasant or relaxed state experienced by an individual in response to their environment (Vink & Hallbeck, 2012), while discomfort refers to an unpleasant state of the body caused by physical factors such as muscular strain, fatigue, blood circulation issues, or pain (Zhang et al., 1996). Although there is not a universally accepted definition, it is widely acknowledged that comfort and discomfort are subjective feelings or emotions (De Looze et al., 2003; Kölsch et al., 2003).

Discomfort can be detected or felt due to its association with physical parameters, making it somewhat measurable. In contrast, comfort is linked to more emotional and intangible factors, such as design preferences, cultural background, and overall state of mind, making it harder to measure, especially once a person is already comfortable (RAMSIS Manual, 2023). Therefore, understanding the range of motion that causes discomfort for each joint and identifying where individuals feel most at ease is essential. This understanding enables the design of tasks that align with human comfort, thereby prioritizing the operator's well-being. Designing interfaces within the comfort zone prevents users from adopting alternative, potentially harmful postures (Kölsch et al., 2003).

Previous efforts to model comfort and discomfort include notable contributions by Helander & Zhang (1997), De Looze et al. (2003), and Moes (2005). Helander & Zhang (1997) differentiated comfort and discomfort as separate scales, where comfort encompasses positive experiences beyond merely the absence of discomfort. De Looze et al. (2003) advanced this understanding by connecting physical product characteristics and psychosocial factors to comfort and discomfort, stressing the significance of individual expectations and environmental influences. Moes (2005) proposed a linear model detailing the progression from product interaction to discomfort experience, emphasizing internal bodily effects and perceptions. While these models provide valuable insights into the concepts of comfort and discomfort, their practical application may be limited due to inherent complexity, subjectivity, and potential oversimplifications. Therefore, ongoing refinement and incorporation of broader factors are essential to develop more universally applicable ergonomic solutions.

4.2.3 Current work

A suggested method to assist interface designers in maintaining subtle comfort and preference limits is to define the comfort zone as a range of postures or movements that users voluntarily adopt (Kölsch et al., 2003). While defining these zones can be achieved through interviews or direct observations, as discussed in section 4.2.1, the drawbacks of these methods have been noted. To reduce reliance on direct user questionnaires and interviews, the study can leverage software developed through extensive human anthropometry research. These tools assess comfort and discomfort across a large population. Utilizing available software to create digital twins of humans could be an effective strategy for an HCD. Digital twins allow for continuous, objective data collection and scenario simulation, providing more accurate and personalized insights into user needs than traditional direct methods like interviewing end users. This approach allows designers to define comfort zones around the human and propose a method that aides interface designers to stay within these more subtle limits of comfort and preference (Kölsch et al., 2003). It allows them to prioritize tasks according to their importance around the user, enhancing design efficiency, lowering costs, and facilitating data-driven decisions for a superior user experience.

4.3 OBJECTIVES

The initial step in better understanding the human operator is identifying where they experience the most comfort and the least discomfort. Given the critical importance of prioritizing human factors in design, it is vital to realize that interfaces designed outside a user's comfort zone can result in the adoption of alternative usage patterns. While these patterns might seem comfortable, they often carry hidden risks of injury (Kölsch et al., 2003). By designing interfaces within established comfort zones, these risks can be minimized. Therefore, this segment of the research aims to achieve the following objectives:

1. Determine the active range of motion for key joints when individuals are adopting a driving posture.
2. Identify areas around these key joints that are classified as comfortable, acceptable, and unsatisfactory.

4.4 METHODOLOGY

4.4.1 Software

The RAMSIS NextGen (Version 10) Software is utilized to analyze driving postures based on task-related (dis)comfort. The database of the software was created when subjects were asked to perform a typical driving task in mock-ups for 15 min. During this task, their postures were measured in three dimensions, focusing on joint angles. Additionally, subjects rated their perceived discomfort in various body parts and their overall discomfort using a standardized questionnaire (Kris & Dodd, 2004). The specific body parts assessed were the buttocks, back, shoulders, neck, left arm, right arm, left leg, and right leg. Additionally, a detailed analysis of the comfortable vision cone was performed by defining and examining the sharp sight cone, optimum visual field cone, and maximum visual field cone.

Statistical correlation between the discomfort levels reported by subjects and their posture data was established using multi-linear regression analysis. This approach identified mathematical relationships between posture and self-perceived discomfort for each body part. It was found that discomfort levels for each body part were influenced by a limited number of joints.

The experimental data for the RAMSIS discomfort assessment were collected exclusively from subjects performing a driving task, making the assessment specifically applicable to driving postures. The neutral driving posture for truck operators was chosen as a reference due to its similarity to agricultural tractor postures. In RAMSIS NEXGEN, a digital twin of a human operator was created to represent the 95th percentile male and 5th percentile female (Table 2), based on the work of Lewis & Narayan (1993) on a North American anthropometry database. These percentiles were selected to encompass a broad range of body sizes. The assessment focused on six joints—shoulder, elbow, wrist, hip, knee, ankle and cervical—on both the right and left sides of the body (see Figure 14).

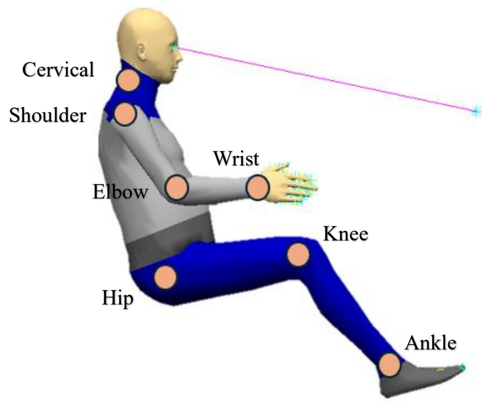

Figure 14. The joints highlighted in orange are the primary focus of the study.

Table 2. The body dimensions of the 95th percentile male and 5th percentile female for the 18-70 age group (2010 reference year).

Body Feature	95th Percentile Male	5th Percentile Female
Body height (cm)	187.66	151.58
Waist circumference (cm)	103.50	57.72
Sitting height (cm)	98.24	79.73

4.4.2 Assessment

The assessment of comfort and discomfort, done by RAMSIS, involved scaling the comfort level from 0 to 8 for various body parts, including the buttocks, back, shoulders, neck, left leg, right leg, left arm, right arm, overall health, fatigue, and discomfort. Discomfort ratings were presented by software on an 8-step ordinal scale for comparative and interpretative purposes. This ordinal scale defined in a way that a rating of 3 is "better" than a rating of 6, but not necessarily twice as good. A significant difference in discomfort perception among subjects is indicated only by a difference of one complete step (e.g., between 2.5 and 3.5), following an exponential relationship.

During the experiments, no posture was identified where all subjects experienced no discomfort in all body parts. Discomfort ratings were calibrated so that the most probable driving posture (RAMSIS' neutral posture) corresponded to the posture with the least discomfort. It is important to note that any level of discomfort is undesirable, so a low level of discomfort does not equate to comfort. Generally, discomfort ratings between 0 - 1.7 were considered comfortable, 1.7 to 2.5 were deemed acceptable, while ratings above 2.5 up to 8 were considered unsatisfactory (the information provided above are based on RAMSIS software manuals).

In this study, the ranges were specified based on the body part that the digital twin indicated had the highest discomfort score (The calculated score for each joint can be find in Appendix C). The goal was to determine the ranges in which all body parts remain in a state of comfort. For instance, figure 15 illustrates the neutral and all green comfortable posture. As the shoulder joint moved in the y-direction (Figure 16), the discomfort increased in the shoulders, neck, and right arm, with the shoulder experiencing the most discomfort. Consequently, the comfort assessment was based on the discomfort felt in the shoulder.

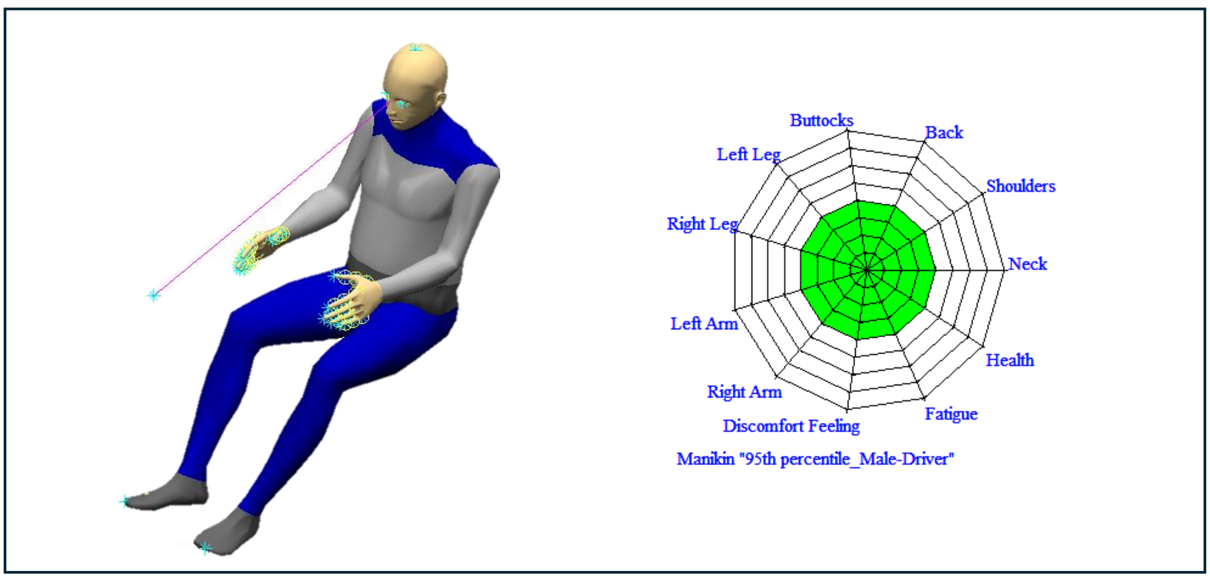

Figure 15. The neutral driving posture of the operator used as a reference of analysis.

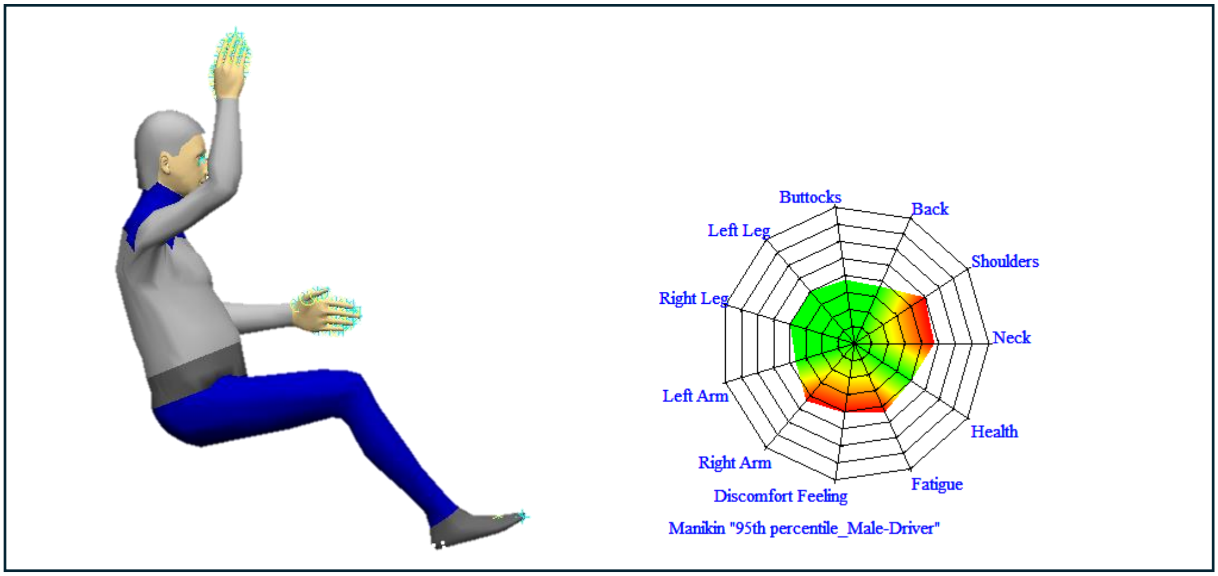

Figure 16. The shoulder was raised in the y-direction, the discomfort level increased in the shoulders, neck, and right arm.

4.4.3 Defined axis of interest

The movements of each joint have specific, well-defined names. For instance, shoulder flexion refers to the movement that decreases the angle between the arm and the front of the body, essentially raising the arm forward and upward from a resting position at the side. Each joint exhibits various movements, some with unique names and others that may overlap. To simplify understanding and avoid using multiple names for each joint movement, a coordinate system was assigned to each joint movement as predefined by the RAMSIS software (Figure 17-18). Figures 19-25 illustrate the types of motions examined in this study using RAMSIS. Each joint is considered to be located at [0,0,0] degrees in this system. Figures 19-25 also explain the assigned axis shown in figures 17 and 18 to each of these movements and the associated positive and negative values. For instance, when it is discussed -40° movement in the shoulder joint's y direction during analysis, it means flexion. Another example can be when the elbow joint's range of motion is [-95.4, 84.6] in the x direction, -95.4° stands for internal (medial) rotation while 84.6° stands for external (lateral) rotation (Figure 19). These images help to visualize the specific directions of movement and the types of movement which were studied, and thus assist in interpreting the results.

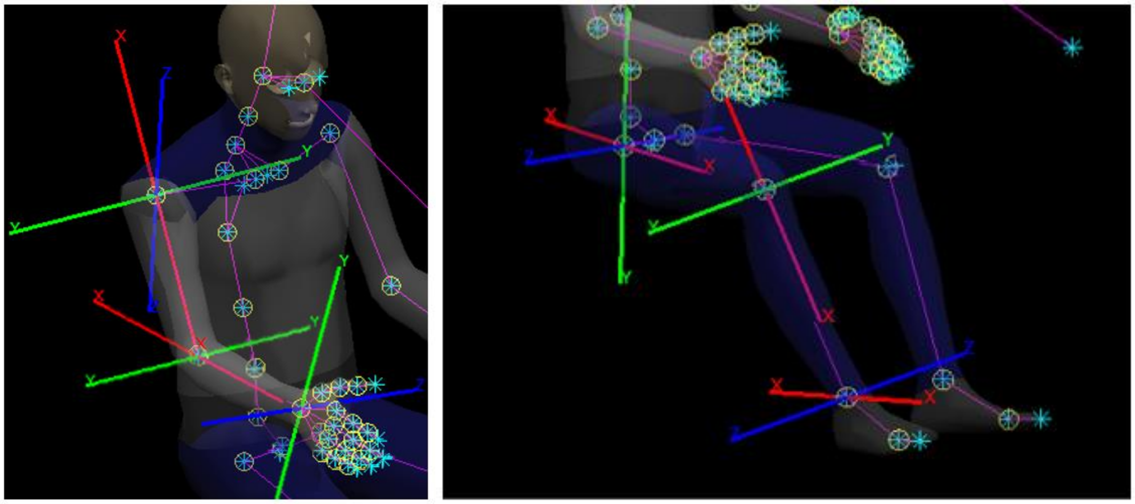

Figure 17. Assigned coordinates systems to shoulder, elbow, wrist, hip, knee and ankle joint created by RAMSIS.

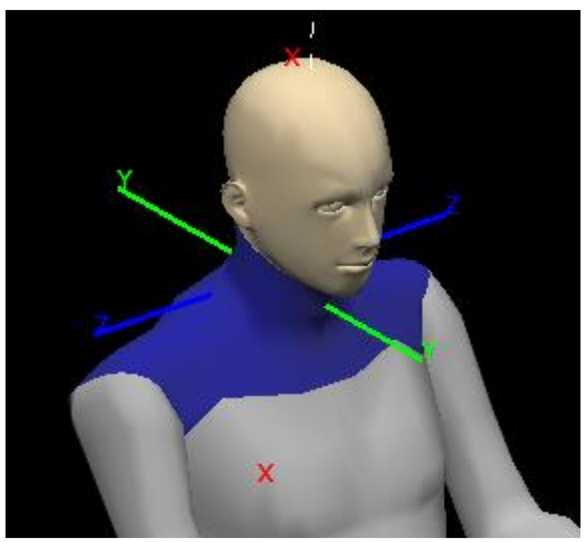

Figure 18. Assigned coordinates systems to cervical joint created by RAMSIS.

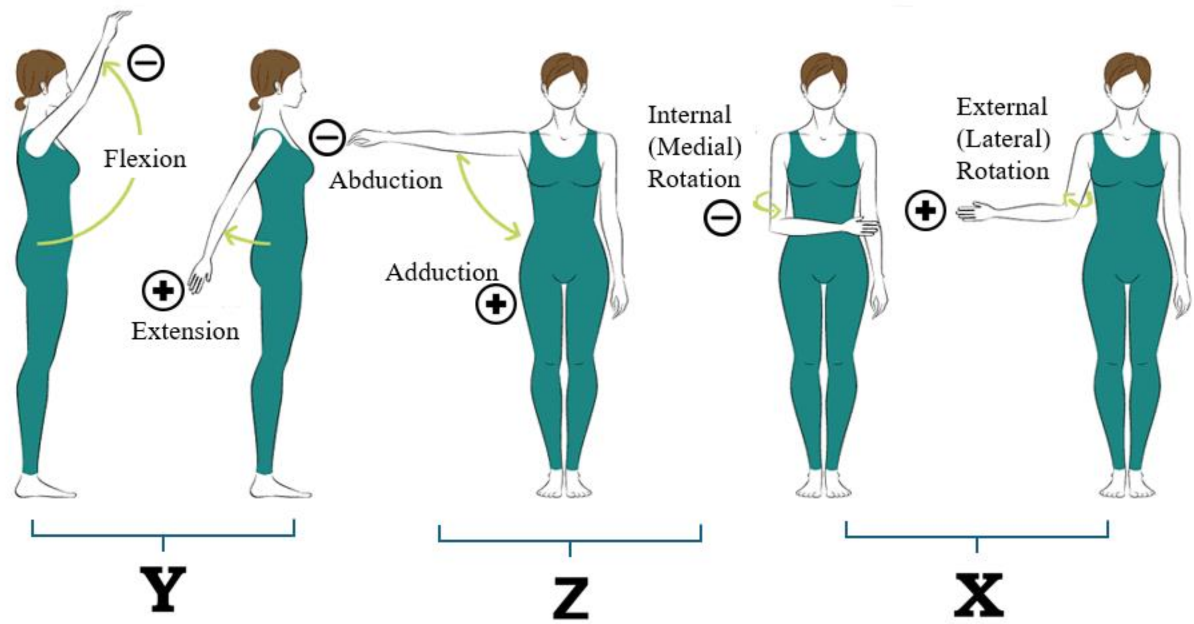

Figure 19. Types of movements at the shoulder joint, along with their respective y-z-x axes, as well as the positive and negative directions (Buonamici et al., 2019).

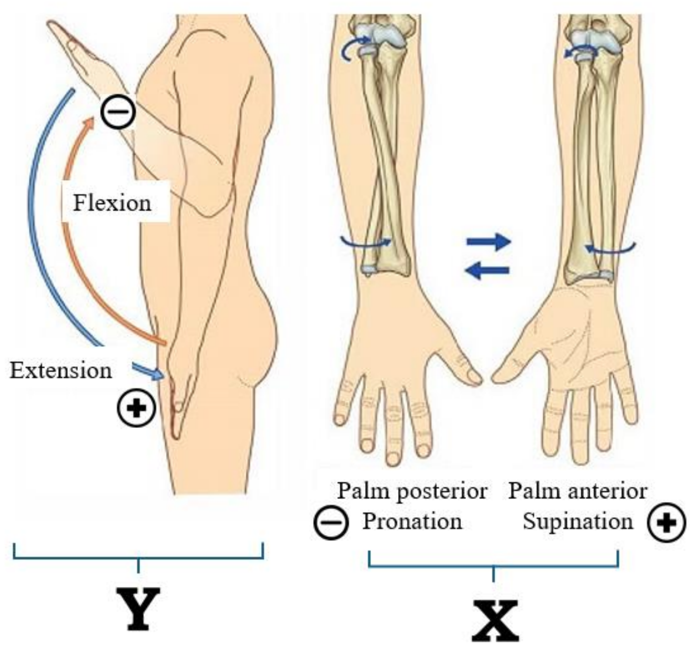

Figure 20. Types of movements at the elbow joint, along with their respective y-x axes, as well as the positive and negative directions (Shoulder Pain Explained 2024).

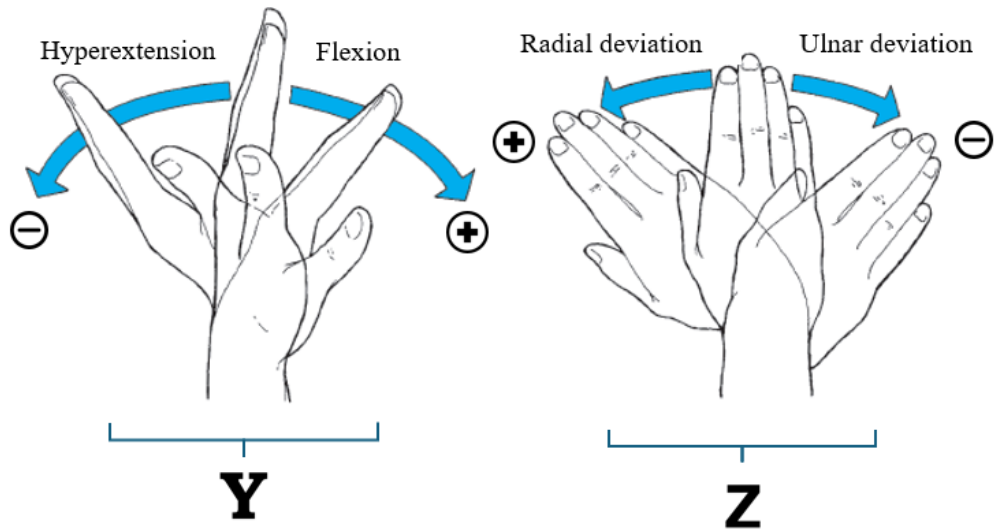

Figure 21. Types of movements at the wrist joint, along with their respective y-z axes, as well as the positive and negative directions (Buonamici et al., 2019).

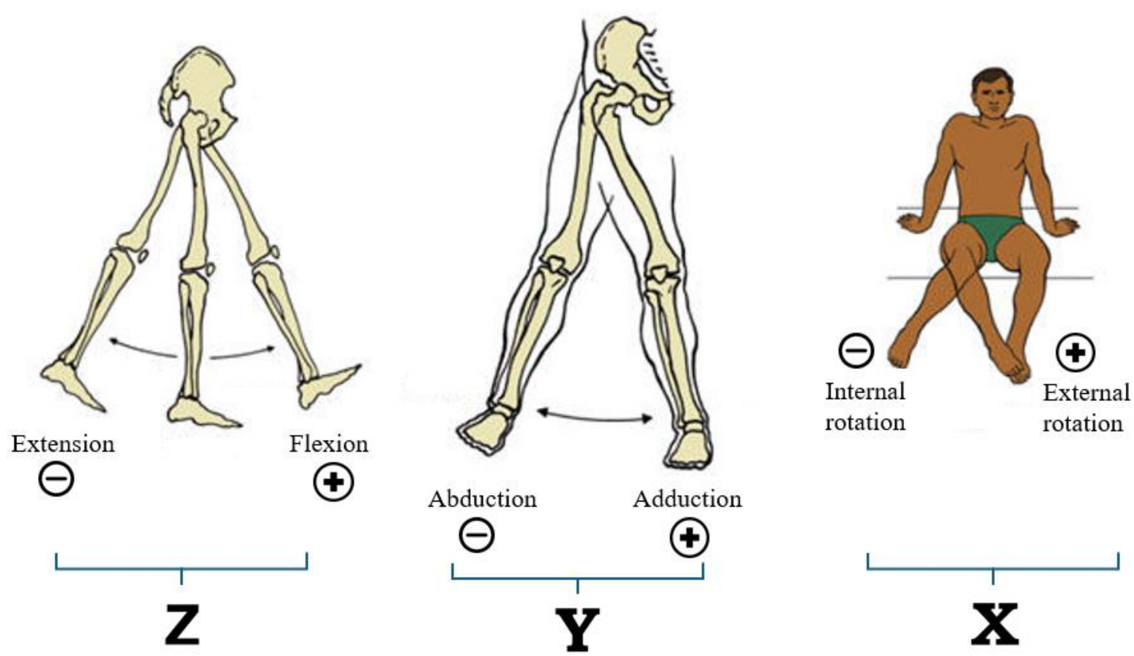

Figure 22. Types of movements at the hip joint, along with their respective y-z-x axes, as well as the positive and negative directions (Source: American Council on Exercise).

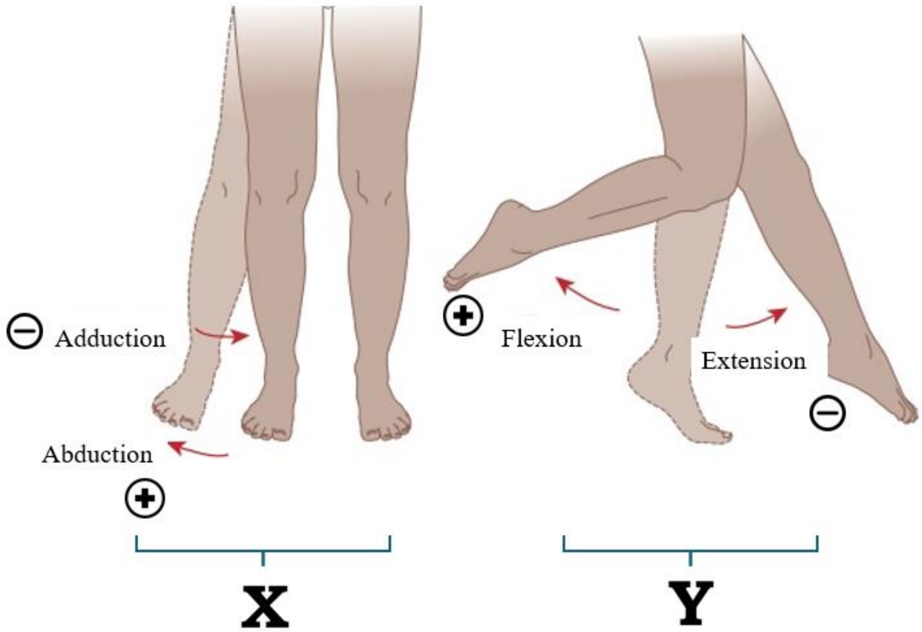

Figure 23. Types of movements at the knee joint, along with their respective y-x axes, as well as the positive and negative directions (Pharmacy 180, 2024).

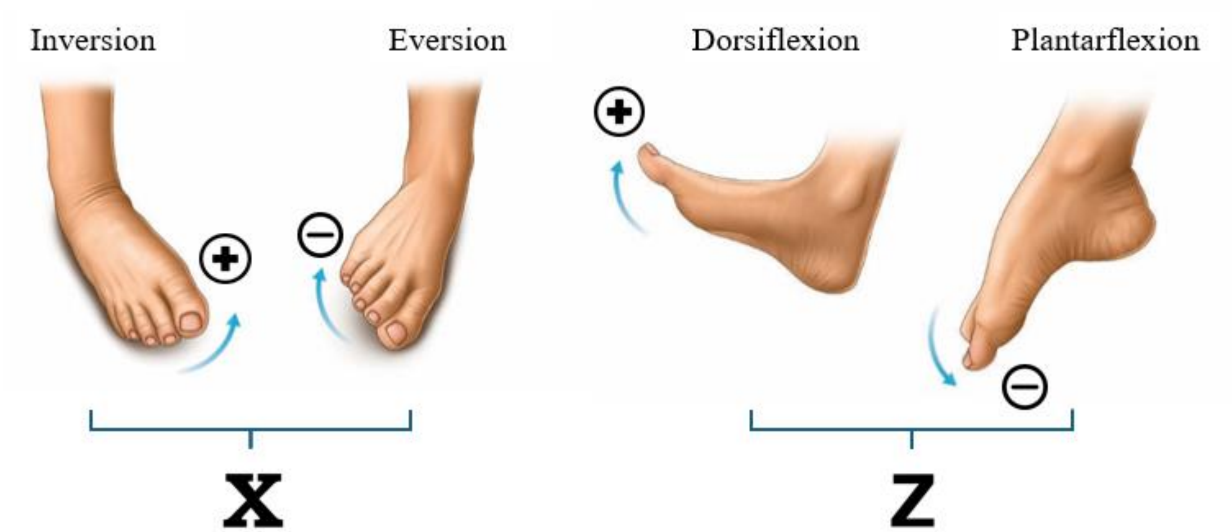

Figure 24. Types of movements at the ankle joint, along with their respective z-x axes, as well as the positive and negative directions.

(Source: https://www.anatomystuff.co.uk/)

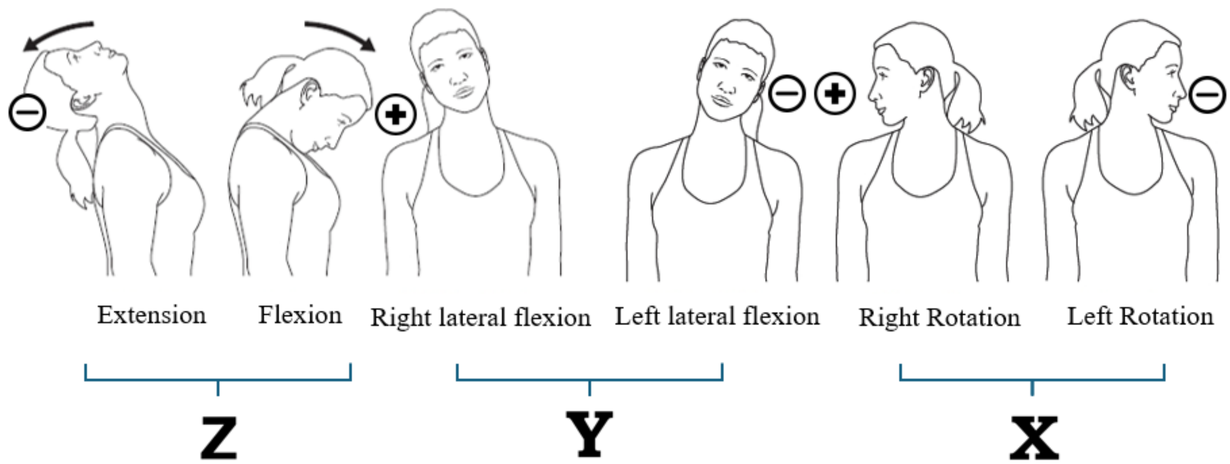

Figure 25. Types of movements at the cervical joint, along with their respective z-y-x axes, as well as the positive and negative directions.

(Source: https://musculoskeletalkey.com/neck-assessment/)

4.5 RESULTS

This section details the active range of motion (AROM) data for various joints (i.e., shoulder, elbow, wrist, hip, knee, ankle, and cervical), measured in three directions (i.e., x, y, and z). Then joint ranges were further categorized into comfortable, acceptable, and unsatisfactory for both the 5th percentile female and the 95th percentile male, on both the right and left sides of the body. The evaluations were conducted based on a neutral driving posture (Figure 15), ensuring that the right arm, left arm, right leg, left leg, buttocks, back, shoulders, and neck were within a comfortable range. Overall, feelings of fatigue and discomfort were also kept within acceptable limits.

4.5.1 AROM data

The range of motion for each joint on both sides of the body is summarized in Table 3. As observed, both sides exhibit relatively the same AROM, with a similar trend noted for both males and females. However, a slight difference in the range of motion of male and female subjects was observed in the shoulder joint.

Table 3. The active range of motion for each joint is presented in degrees, with the neutral position of each joint defined as 0 degrees.

Joint	Range of Motion (X)		Range of Motion (Y)		Range of Motion (Z)	
	Male	Female	Male	Female	Male	Female
Right Shoulder	[-56.9, 18.1]	[-89.9, 18.1]	[-124, 13.0]	[-124.0, 17.0]	[-155.6, 9.4]	[-155.6, 6.4]
Left Shoulder	[-18.1, 56.9]	[-18.1, 89.9]	[-13.0, 124.0]	[-17.0, 124.0]	[-155.6, 9.4]	[-155.6, 6.4]
Right Elbow	[-95.4, 84.6]	[-95.4, 84.6]	[-86.5, 58.5]	[-86.5, 58.5]	–	–
Left Elbow	[-84.6, 95.4]	[-84.6, 95.4]	[-86.5, 58.5]	[-86.5, 58.5]	–	–
Right Wrist	–	–	[-73.4, 86.6]	[-73.4, 86.6]	[-39.5, 28.5]	[-39.5, 28.5]
Left Wrist	–	–	[-86.6, 73.4]	[-86.6, 73.4]	[-39.5, 28.5]	[-39.5, 28.5]
Right Hip	[-48.4, 47.6]	[-48.4, 47.6]	[-33.9, 41.1]	[-33.9, 41.1]	[-102.1, 37.9]	[-102.1, 37.9]
Left Hip	[-47.6, 48.4]	[-47.6, 48.4]	[-41.1, 33.9]	[-41.1, 33.9]	[-102.1, 37.9]	[-102.1, 37.9]
Right Knee	[-20.0, 40.0]	[-20.0, 40.0]	[-63.1, 76.9]	[-63.1, 76.9]	–	–
Left Knee	[-40.0, 20.0]	[-40.0, 20.0]	[-63.1, 76.9]	[-63.1, 76.9]	–	–
Right Ankle	[-24.0, 23.0]	[-24.0, 23.0]	–	–	[-27.0, 49.0]	[-27.0, 49.0]
Left Ankle	[-23.0, 24.0]	[-23.0, 24.0]	–	–	[-27.0, 49.0]	[-27.0, 49.0]
Cervical	[-30.0, 30.0]	[-30.0, 30.0]	[-12.0, 12.0]	[-12.0, 12.0]	[-23.0, 37.0]	[-23.0, 37.0]

4.5.2 Zone classification

The aforementioned AROM was then further divided into three zones: comfortable, acceptable, and unsatisfactory, as shown in Tables 4-10. The classifications were determined by the degree of joint movement, with discomfort ratings assigned as follows: 0-1.7 were rated as comfortable, 1.7 to 2.5 were considered acceptable, and ratings above 2.5 up to 8 were deemed unsatisfactory. These values were determined using the RAMSIS software, with the range of 1.7

to 2.5 being established based on moderate levels of perceived discomfort. The complete analysis for both the right and left sides of the body, and for both females and males, is provided in Appendix C.

Table 4. Classification of joints ranges of motions for the male shoulder joint across three axes (X, Y, Z).

Zone	Range of Motion (X)	Range of Motion (Y)	Range of Motion (Z)
Comfortable	[-10, 10]	[-5, 5]	[-91, 9.4]
Acceptable	[-41, -11], [11, 15]	[-59, -6], [6, 27]	[-92, -115]
Unsatisfactory	[-57, -42], [16, 18.1]	[-124, -60], [28, 36]	[-156, -116]

Table 5. Classification of joints ranges of motions for the male elbow joint across three axes (X, Y, Z).

Zone	Range of Motion (X)	Range of Motion (Y)	Range of Motion (Z)
Comfortable	[-67.0, 60.0]	[-2.0, 2.0]	-
Acceptable	[-81.0, -68.0], [61.0, 71.0]	[-19.0, -3.0], [3.0, 19.0]	-
Unsatisfactory	[-95.4, -82.0], [72.0, 85.0]	[-86.5, -20.0], [20.0, 58.5]	-

Table 6. Classification of joints ranges of motions for the male wrist joint across three axes (X, Y, Z).

Zone	Range of Motion (X)	Range of Motion (Y)	Range of Motion (Z)
Comfortable	-	[-36.0, 42.0]	[-7.0, 20.0]
Acceptable	-	[-52.0, -37.0], [43.0, 61.0]	[-18.0, -8.0], [21.0, 24.0]
Unsatisfactory	-	[-73.4, -53.0], [62.0, 86.6]	[-39.5, -19.0], [25.0, 28.5]

Table 7. Classification of joints ranges of motions for the male hip joint across three axes (X, Y, Z).

Zone	Range of Motion (X)	Range of Motion (Y)	Range of Motion (Z)
Comfortable	[-6.0, 6.0]	[-20.0, 24.0]	[-20.0, 18.0]
Acceptable	[-24.0, -7.0], [7.0, 24.0]	[-25.0, -21.0], [25.0, 30.0]	[-39.0, -21.0], [19.0, 25.0]
Unsatisfactory	[-48.4, -25.0], [25.0, 47.6]	[-33.9, -26.0], [31.0, 41.1]	[-102.1, -40.0], [26.0, 37.9]

Table 8. Classification of joints ranges of motions for the male knee joint across three axes (X, Y, Z).

Zone	Range of Motion (X)	Range of Motion (Y)	Range of Motion (Z)
Comfortable	[-12.0, 23.0]	[-50.0, 61.0]	-
Acceptable	[-13.0, -15.0], [24.0, 29.0]	[-53.0, -51.0], [62.0, 64.0]	-
Unsatisfactory	[-20.0, -16.0], [30.0, 40.0]	[-63.1, -54.0], [65.0, 76.9]	-

Table 9. Classification of joints ranges of motions for the male ankle joint across three axes (X, Y, Z).

Zone	Range of Motion (X)	Range of Motion (Y)	Range of Motion (Z)
Comfortable	[-17.0, 17.0]	-	[-24.0, 11.0]
Acceptable	[-20.0, -18.0], [18.0, 19.0]	-	[-28.0, -25.0], [12.0, 20.0]
Unsatisfactory	[-24.0, -21.0], [20.0, 23.0]	-	[-38.0, -29.0], [21.0, 38.0]

Table 10. Classification of joints ranges of motions for the male cervical joint across three axes (X, Y, Z).

Zone	Range of Motion (X)	Range of Motion (Y)	Range of Motion (Z)
Comfortable	[-20, 20]	[-5.0, 5.0]	[-12.0, 17.0]
Acceptable	[-25.0, -21.0], [21.0, 25.0]	[-8.0, -6.0], [6.0, 8.0]	[-17.0, -13.0], [18.0, 27.0]
Unsatisfactory	[-30.0, -26.0], [26.0, 30.0]	[-12.0, -9.0], [9.0, 12.0]	[-23.0, -18.0], [28.0, 37.0]

It can be interpreted from table 4 the male right shoulder's comfort range is well-defined within a moderate X range [−10,10], a narrow Y range [−5,5], and a broad Z range [−91,9.4] for a male operator. The acceptable range includes additional extended regions on both ends for all axes: [−41,−11],[11,15] for X, [−59,−6],[6, 27] for Y, and [−92,−115] for Z. Unsatisfactory positions are observed in the extreme low and high ranges: [−57,−42], [16,18.1] for X, [−124,−60], [28,36] for Y, and [−156,−116] for Z.

A more detailed examination of the defined zones in the x-z plane and y direction is presented in Figure 26. This figure illustrates that a 10° hand movement in the y direction falls within the comfort range, while movements of 54 and 22° further are still within the acceptable range. Movements beyond this range may cause higher levels of discomfort.

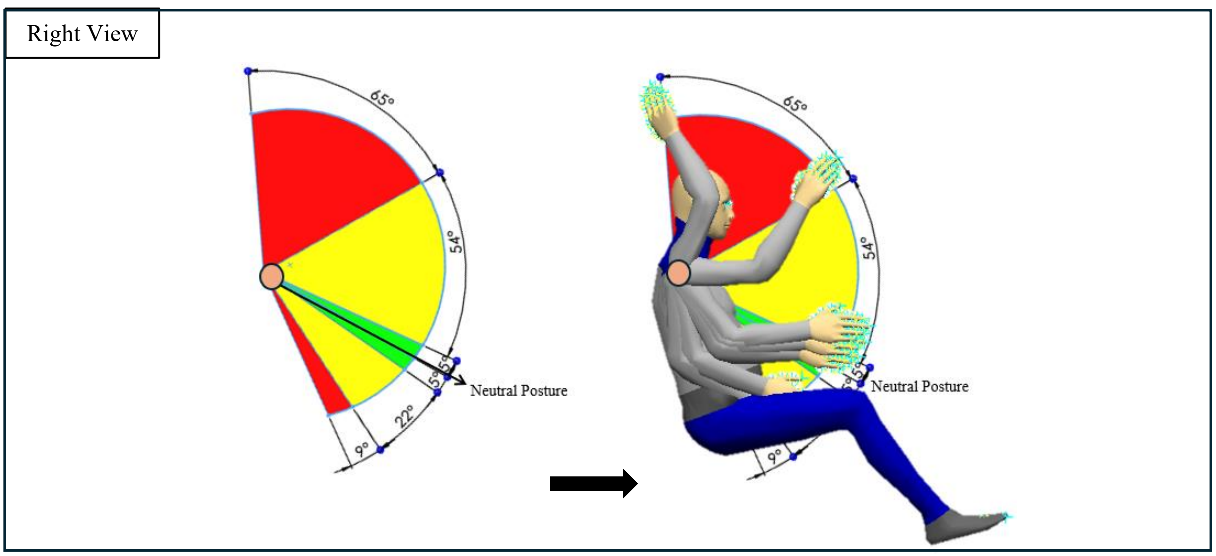

Figure 26. The defined zones of comfort, acceptable, and unsatisfactory ranges around the right shoulder joint are illustrated with a right-side view of a created manikin (y direction).

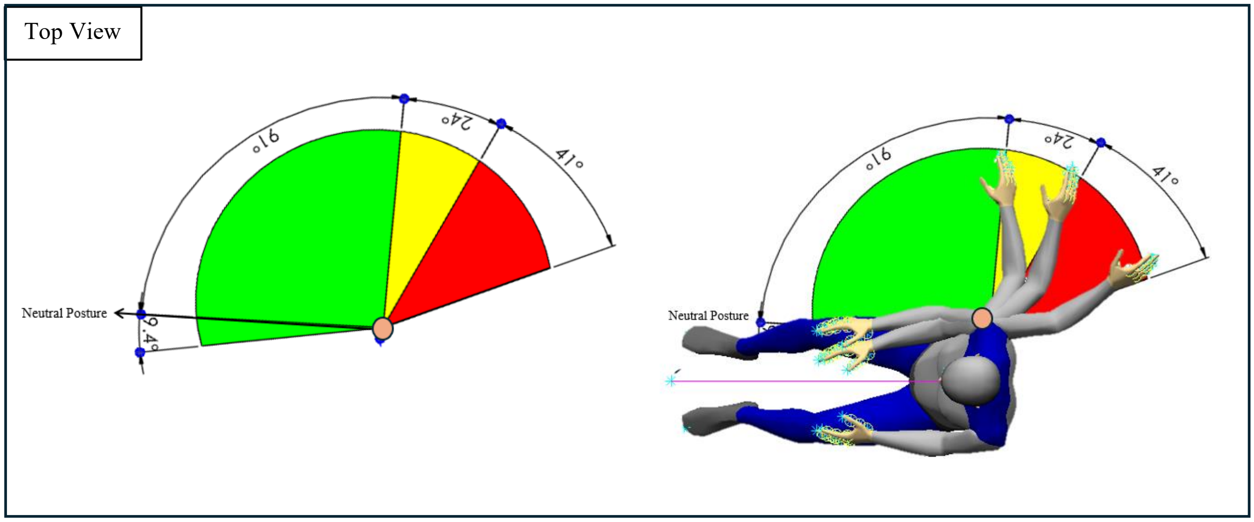

Figure 27. Top View: Showcasing the plane of motion range in the z direction.

Figure 28. Right View: Showcasing the plane of motion range in the z direction.

Additional illustrations of these zones are provided in Figures 27 and 28, which showcase a wide comfort zone in the z direction, covering 100.4°.The same process has been done for the hip joint (Figure 29). This image provides a visual and quantitative representation of the safe and risky ranges of motion for a hip joint, which is essential for ergonomic design and occupational safety.

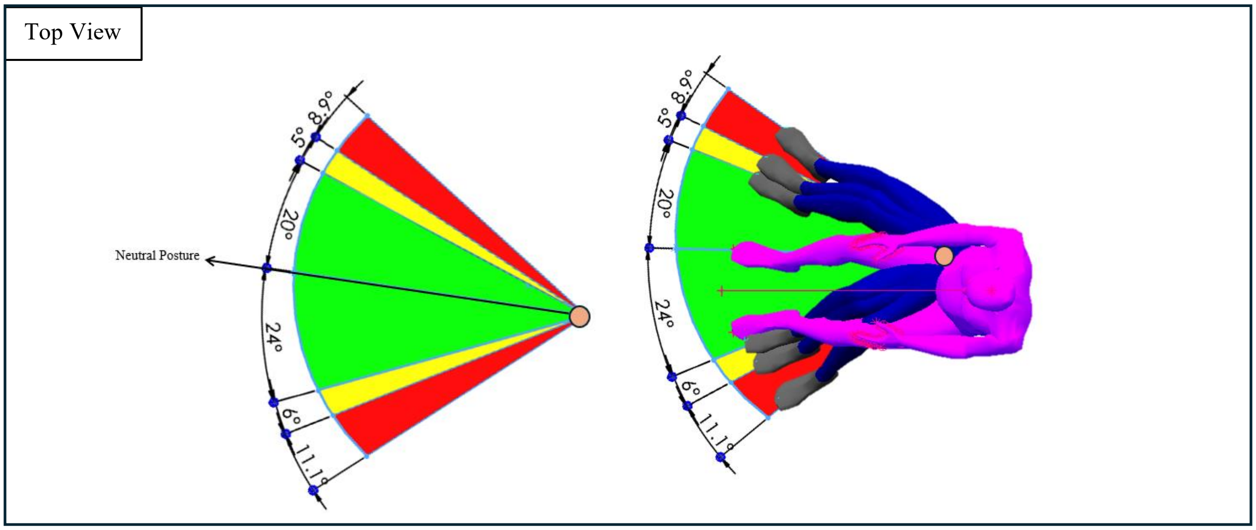

Figure 29. The top view of the hip joint movement illustrates the defined zones of comfort, acceptable, and unsatisfactory ranges.

4.5.3 Visual field classification

According to the RAMSIS software manuals, the visual capabilities of a normal-sighted observer are outlined by specific opening angles that define various viewing cones. These cones represent different aspects of visual perception, each with distinct characteristics (Figure 30):

1. Sharp Sight Cone (Green):
   Opening Angle: 2.5°
   This cone defines the sharp sight area, where the observer can perceive details with high clarity. It begins at the center of the eye and extends through the fixation point. As the distance from the eye to the fixation point increases, the diameter of this cone expands proportionally.

2. Optimum Visual Field Cone:
   Opening Angle: 15°

This cone represents the optimal viewing range, where visual comfort is achieved through eye movements while keeping the head static. It is defined for binocular vision (both eyes). This range allows the observer to comfortably perceive the environment within this angle.

3. Maximum Visual Field Cone:

   Opening Angle: 50°

   This cone indicates the maximum viewing range, where the observer utilizes peripheral vision. It is a monocular field (either left or right eye) and provides the maximum extent of the visual field with the head remaining static.

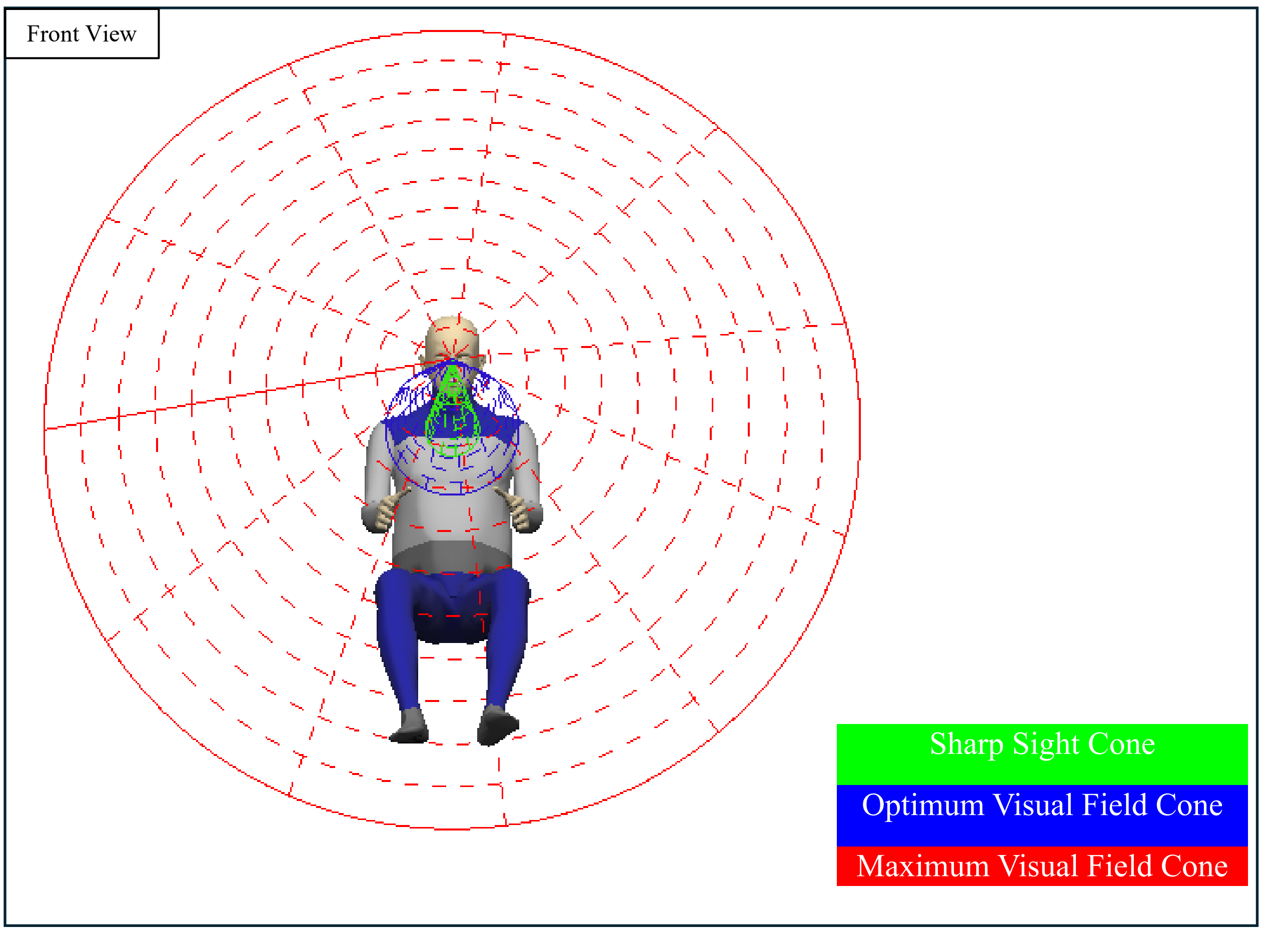

Figure 30. The visual field is segmented into three zones: the sharp sight cone, the optimum visual field cone, and the maximum visual field cone (respectively from the inside to the outer side).

4.5.4 Trend in joint movements

Analyzing the data for most joint movements revealed a bell-shaped trend (Figure 31); the closer the joint is to its neutral posture; the more comfort is observed while discomfort increases as the joint moves further away from this position. For instance, with wrist flexion and extension, perceived discomfort escalates as the wrist moves further from its neutral position.

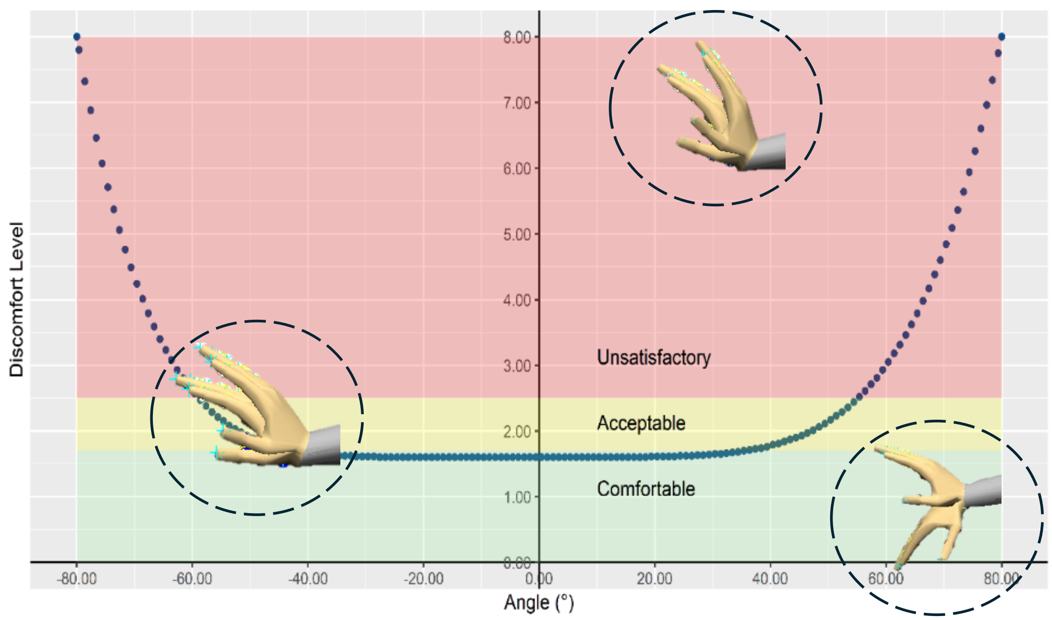

Figure 31. Wrist Range of Motion for Right Hand of Male manikins: Comfortable, Acceptable, and Unsatisfactory Zones.

4.6 DISCUSSION

The results presented in the previous section provide a comprehensive overview of the AROM for various joints, their categorization into comfortable, acceptable, and unsatisfactory zones, and visual field classifications. This discussion will delve into the implications of these findings, their alignment with existing literature, and potential applications in ergonomic design.

4.6.1 Interpretation of AROM data

The initial step in creating digital twins of human manikins was to understand the AROM for each joint, particularly when adopting a driving posture. The joint motions were determined based on Kapandji's (2007) analysis. This understanding helps classify these AROM values into comfort and discomfort zones. Our study found that the right hip joint had a range of -33.9 to 41.1° in the y direction, aligning with Roaas & Andersson's (1982) findings, which reported that hip joint movement should fall between -15 to -55° and 15 to 45°.

Comparison of knee movements in the y-axis with Roach & Miles's (1991) findings, which evaluated two age groups (25-39 and 40-59) with average AROM values of 135 and 133° respectively, and another study for the age group 60-84 with an average of 134° (Walker et al., 1984), revealed that our results showed a slightly higher AROM of 140°. Another study on shoulder joint movements reported a bending motion in the y-axis of 120° measured with still photography (Hayes et al., 2001) which is close to our result of 124°. However, the reported opposite action of straightening differed significantly. They reported 57°, while our study found only 13° for males and 17° for females. This discrepancy was attributed to the adopted driving posture in our analysis and physical barriers, such as a large abdomen in male participants, which limited further joint movement.

Analysis of the wrist's outward movement in the y-axis for individuals aged 20-54 showed a range of 74° (Boone et al., 1978), which is closely matched by our finding of 73.4° for the age group 18-70. The research suggested that this range would decrease to an average of 64° for those aged 60-84 (Walker et al., 1984). These comparisons ensure that the AROM measured in this section aligns well with the findings of previous research. While minor discrepancies exist, particularly for shoulder and hip joint movements, these can be attributed to specific postural and physical factors in our study population. Overall, this alignment with prior studies underscores the reliability of our methodology and provides a solid foundation for the development of accurate digital twins of human manikins.

4.6.2 Gender and side differences

The detailed comparison of AROM between males and females, and between the right and left sides of the body, shows that while both genders exhibited similar trends, there were slight differences, particularly in the shoulder joint. The observed greater AROM in females' shoulders is supported by the work of Sahrmann et al. (2017) who found that joint laxity is often higher in females due to hormonal differences affecting connective tissue. Additionally, studies have shown that joint movements for females are slightly higher than for males; for example, ankle inward movement was reported to be 36.0° for male subjects, while 38.1° was reported for females aged 16-30 (Chung & Wang, 2009). This study also argues that females demonstrate higher ROM in the cervical spine, upper extremity, and lower extremity joints compared to males. The greater AROM in females could be attributed to hormonal differences, anatomical and physiological factors, and lifestyle variations (Vink & Hallbeck, 2012). However, the software used in this study to develop AROM for males and females did not consistently recognize these slight differences, except in the shoulder joint.

In this study, no differences were found in the AROM between the left and right sides of the body. Similar observations were reported by Roaas & Andersson (1982) who found no statistically significant difference between the motions of the right and left sides of the body. This indicates that the range of motion in these joints is generally symmetrical in healthy individuals within the specified age group. These insights contribute to a more nuanced understanding of AROM variations across genders and body sides.

4.6.3 Zone classification and implications

In today's world, where the comfort and well-being of device operators are prioritized, and HCD has gained more attention, there has been an increasing effort to simplify the subjective concept of comfort into qualitative values. This helps to better understand this complex phenomenon and apply it effectively in interior design of future cars, tractors, and other vehicles. Various attempts, such as the development of indexes like RULA, REBA (Ansari & Sheikh, 2014; McAtamney & Corlett, 1993), and LUBA (Kee & Karwowski, 2001), have been made to better understand posture. However, these methods often involve limited scope or complex mathematical models and require computational resources, which may not be easily accessible or practical for all designers or manufacturers. Another attempt was made by Naddeo & Memoli (2009) to develop an index specifically for evaluating arm movements, but the evaluation focuses on the posture of a single arm.

My goal was to simplify this process further so that engineers can easily identify the comfortable, acceptable, and unsatisfactory ranges around a manikin. I propose a method to assist interface designers in adhering to the more subtle limits of comfort and preference. I defined the three following zones:

- Comfortable Range: Movements within this range are likely to be pain-free and sustainable over long periods,
- Acceptable Range: Movements within this range are tolerable but may cause discomfort if sustained for long periods, and
- Unsatisfactory Range: Movements within this range are likely to cause discomfort or pain and are not recommended for sustained periods.

The idea behind defining these zones is to aid design engineers in assigning tasks relative to their importance within one of these zones. For example, in Figure 32, the hip joint has a comfortable range of -31 to 12°, suggesting that features requiring hip movement should be placed within these angles. Similarly, for the shoulder joint (Figure 33), tasks requiring shoulder movement should be within a range of -5 to 5° for up and down movements, and -91 to 9° for outward to inward movements. The ranges for other joints are identified in Tables 4-10.

By identifying these areas around the human operator, engineers can assign tasks based on their importance within one of the specified zones. This approach helps designers create products and workspaces that enhance user comfort and well-being. Understanding and adhering to acceptable joint motion ranges can help reduce the risk of repetitive strain injuries and other musculoskeletal disorders. Objective data on joint movement ranges can inform better decision-making in design, leading to more effective ergonomic solutions. This method allows for the development of customizable ergonomic solutions tailored to specific tasks, user groups, or individual needs.

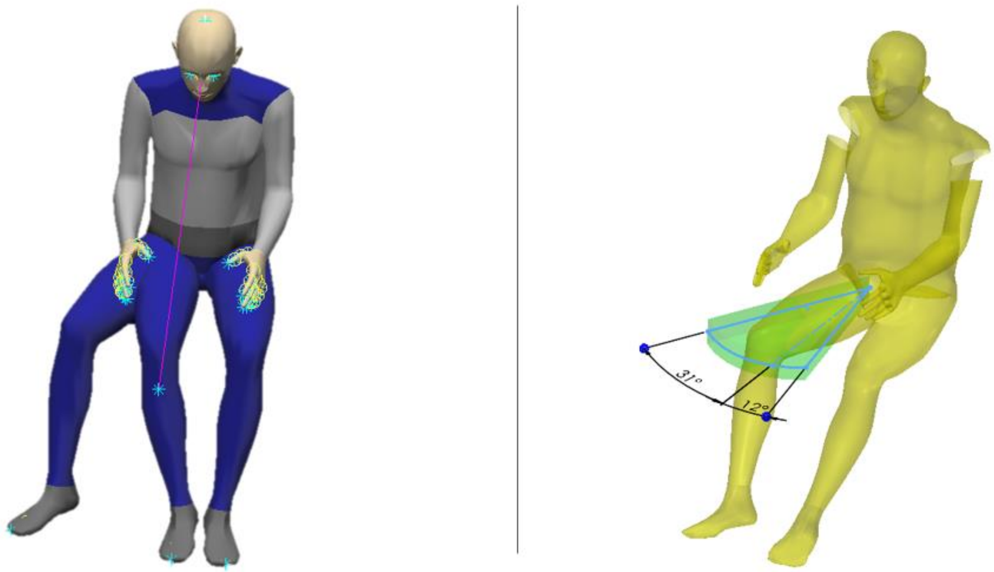

Figure 32. The defined comfort zones of hip joint movement in 3D environment.

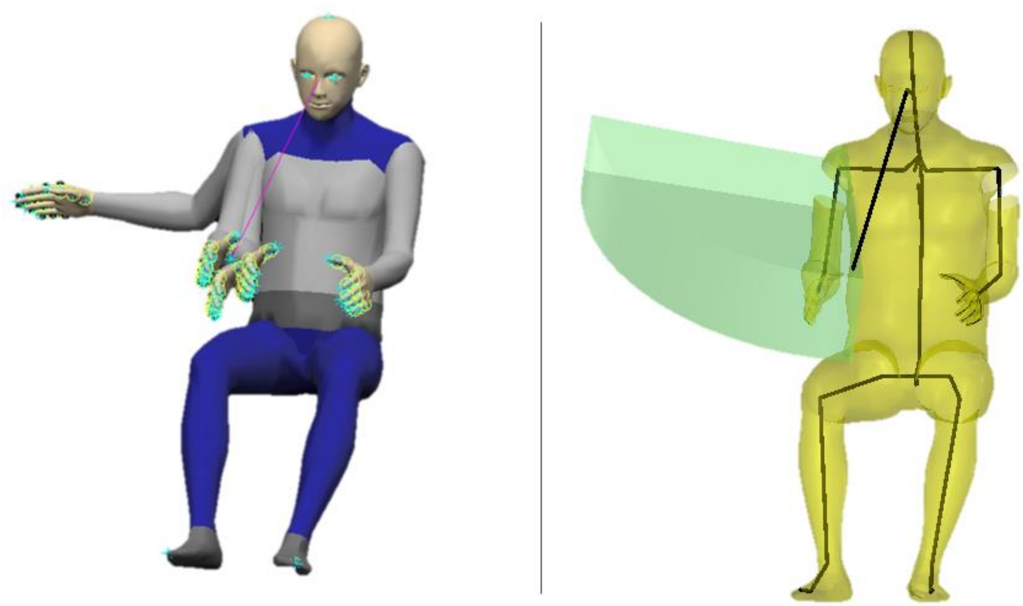

Figure 33. The defined comfort zones of shoulder joint movement in 3D environment.

4.6.4 Visual field classification

The visualization of sight cones offers a detailed understanding of how visual perception shifts with varying viewing angles and distances. The sharp sight cone, corresponding to central vision, is where visual acuity is highest, making it essential for tasks requiring precision and detail. The optimum and maximum visual field cones extend around the sharp sight cone, enhancing situational awareness by detecting peripheral movement and providing context to central vision (Figure 34). The optimal field of view is best suited for the placement of important displays and controls, as it facilitates quick eye movements and minimizes the need for significant head or body movements, thereby enhancing efficiency and comfort, especially in environments where rapid and accurate visual access is critical. By comprehending these visual fields, designers can strategically position tasks and information within these cones based on their significance and frequency of use, ensuring that key and frequently accessed information is placed within the sharp or optimum visual cone for optimal accessibility (Information extracted from reading RAMSIS manuals, copyright: Humanetics Digital Europe GmbH).

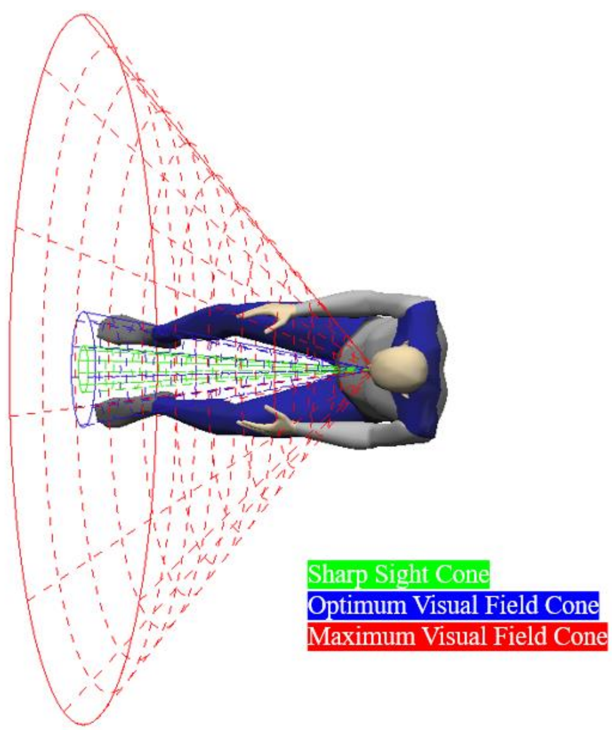

Figure 34. The visual field is segmented into three zones: the sharp sight cone, the optimum visual field cone, and the maximum visual field cone.

4.7 FUTURE RESEARCH

The findings from this study have significant implications for ergonomic design and occupational health. By understanding the specific ranges of motion that are most comfortable and those that lead to discomfort, designers can create work environments and tools that promote better postures and reduce the risk of injury. However, this was an initial step for defining these zones base on the AROM. Future research could expand on these findings by exploring dynamic tasks and different postures, as well as incorporating a larger and more diverse sample population to enhance the generalizability of the results. Also, the software typically recognizes the degree of joint movement comfort and discomfort similarly for both the male 95th percentile and the female 5th percentile, as well as for visual field classifications. This is a matter that certainly warrants further discussion. Furthermore, the differences in comfort and discomfort rates on both the right and left sides of the body were found to be almost the same. This matter should also be examined in future research.

4.8 CONCLUSION

This part of research delves into the anthropometric modeling of tractor cabs with a focus on ergonomic design to enhance the comfort and safety of human operators. By adopting a Human-Centered Design approach and focusing on ergonomic optimization, it is possible to enhance the comfort and safety of the operator, and the functional productivity of tractor cabs. The study provides valuable insights into the Active Range of Motion for various joints. These Active Range of Motion findings align with existing literature and underscore the reliability of the methodology used.

The research also emphasizes the significance of gender and side differences in Active Range of Motion, revealing that while both genders exhibit similar trends, females generally have a greater range of motion in certain joints. Additionally, the study found no significant differences between the Active Range of Motion of the right and left sides of the body, indicating symmetrical joint movements in healthy individuals. Further in the research, the Active Range of Motion for the shoulder, elbow, wrist, hip, knee, ankle, and cervical joints were categorized into three zones: comfortable, acceptable, and unsatisfactory. Defining comfort zones for joint movements allows design engineers to prioritize tasks based on their importance and assign them within the specified zones, thereby enhancing user comfort and well-being. The visual field classifications further support this by providing guidelines for optimal placement of displays and controls, ensuring that key information is within the most accessible visual cones.

Overall, this research provides a foundational framework for designing ergonomically optimized tractor cabs. By leveraging advanced anthropometric modeling tools and understanding human factors, designers can significantly enhance the operator's experience, ultimately improving productivity, safety, and overall well-being in agricultural operations.

5. HUMAN-CENTRED DESIGN OF A CAB FOR A SEMI-AUTONOMOUS TRACTOR

5.1 BACKGROUND AND OBJECTIVES

In the previous sections, I have explored the interactions between humans and the tractor cab, identifying the comfort and discomfort zones for operators. This section aims to deepen our understanding of the tasks within a SA tractor cab and assign those tasks based on the defined zones. Our objectives are as follows:

1. Define the tasks and assess the importance of each task and identify the most critical ones.
2. Develop a strategy for effectively integrating these tasks into the tractor cab design.
3. Recommend optimal placements for these tasks within the cab to enhance operator efficiency and comfort.

By addressing these objectives, I aim to ensure that the transition to SA tractor operations is human-centered and ergonomically sound.

5.2 PRIORITIZING THE TASKS FOR SEMI-AUTONOMOUS OPERATION

5.2.1 Defining tasks of a semi-autonomous tractor

The tasks were defined based on a combination of expert consultations, field observations, and literature reviews done in the section 3 of this study. The aim was to identify all critical activities performed by operators to ensure the safe and efficient operation of tractors, while also anticipating some future tasks that might be incorporated in SA tractors.

The scenario for these defined tasks assumes the operator is present in the cab of a SA tractor. I have defined a SA tractor as a machine that is capable of operating autonomously in some, but not all, situations. During field operations, the tractor relies on automation, except in emergencies or when the operator needs to take control in challenging environments. On the road, however, the operator is fully responsible for driving and controlling the tractor.

The analysis focused on five primary task categories: i) Driving Tasks, ii) Operational Tasks, iii) Monitoring and Information Tasks, iv) Safety and Emergency Tasks, and v) Comfort and Convenience Tasks. Each task was further broken down into five specific subtasks. The chosen subtasks were selected subjectively, without considering their implementation methods within the cab. Below is how each task category was defined:

- Driving Tasks:

  These tasks are critical for the safe maneuvering and control of the tractor during operations. They were defined based on common driving activities required to navigate both on-road and off-road environments.

  1. Monitoring and responding to other vehicles or obstacles on the road.
  2. Ensuring the tractor stays within designated lanes, especially on highways or large fields.
  3. Adjusting speed according to terrain, obstacles, and safety requirements.
  4. Low-speed maneuvering in tight environments such as farmyards and field edges.
  5. Backing up the tractor to an implement or with an implement already attached.

- Operational Tasks:

  These tasks involve the direct control and management of the tractor's operational functions. They were identified through an analysis of the tasks necessary to perform field operations effectively.

  1. Controlling speed based on terrain and load.
  2. Adjusting implement depth/settings.
  3. Detecting unmapped obstacles and navigating around or through them.
  4. Monitoring towed equipment for potential failures.
  5. Route planning and optimization.

- Monitoring and Information Tasks:

  These tasks are essential for maintaining awareness of the tractors and implement's performance and environmental conditions. They were defined based on the need for real-time data collection and analysis to support operational decisions.

  1. Gathering data on soil conditions and environmental factors.
  2. Analyzing data from onboard sensors and cameras.
  3. Providing feedback on operational efficiency.
  4. Real-time monitoring of engine performance and vital parameters.
  5. Monitoring fuel and Diesel Exhaust Fluid (DEF) levels.

- Safety and Emergency Tasks:

  These tasks are crucial for ensuring the safety of the operator, bystanders, and the equipment. They were defined based on potential emergency scenarios and the need for preventive measures.

  1. Emergency communication between the operator and support staff.
  2. Collision detection and avoidance.
  3. Monitoring and alerting for dangerous weather conditions.
  4. Reacting to tractor/implement starting to get stuck.
  5. Taking over from automated control of steering from the tractor.

- Comfort and Convenience Tasks:

  These tasks focus on the operator's well-being and comfort during operation. They were identified based on the need to maintain operator comfort and reduce fatigue.

  1. Fine-tuning climate control settings.
  2. Adjusting suspension systems for a smoother ride.
  3. Engaging with entertainment or connectivity options during periods of boredom.
  4. Adjusting ergonomics of controls such as seat position.

5. Eating meals.

- Recording and Documentation Tasks:

  These tasks involve the documentation and logging of operational data. They were defined based on the requirements for record-keeping and data management in modern farming operations.

  1. Maintaining records of maintenance activities and schedules.
  2. Logging operational data such as time, location, speed, and activities performed.
  3. Performing farming business management-related activities.
  4. Recording environmental/field conditions during operations.
  5. Managing precision farming files and recording field data.

5.2.2 Metrics of evaluation

To develop a comprehensive questionnaire aimed at ranking the aforementioned tasks, it is essential to define the metrics for the evaluations. Based on this scenario, there are two distinct modes of operation: on-road and in-field. Tasks were evaluated using three key criteria: i) Frequency of Use, ii) Task Priority, and iii) Safety Concerns in each mode (see Table 11). This evaluation tool was developed drawing inspiration from previous research (Dul & Weerdmeester, 2008; FMEA, 2011) and in collaboration with design engineers at Buhler Versatile. According to the literature, determining the optimal placement of controls requires understanding the frequency of their use, their relative importance compared to other controls, and the significance of the task in ensuring the operator's and machine’s safety.

Table 11. Evaluation criteria and their definition for task ranking in on-Road and in-Field operations.

Frequency of use	Task priority	Safety matters
How often a particular task is performed within the season	The relative importance or urgency of completing a task compared to other tasks.	How important is the task relative to personal, public and machine safety/health
(1) - once a season **(2)** - once a week **(3)** - day to day **(4)** - regularly during day **(5)** - critical/constant use **N/A** - Not Applicable	**(1)** - deal within a few hours **(2)** - deal within a few minutes **(3)** - deal within 30 seconds **(4)** - deal within 5 seconds **(5)** - deal within 2 seconds **N/A** - Not Applicable	**(1)** - no real safety risk **(2)** - potential minor injury or damage **(3)**- potential moderate injury or damage **(4)**- potential severe injury/ major breakdown/ environmental damage **(5)** - life threatening risk **N/A** - Not Applicable

5.2.3 Data collection and analysis

A comprehensive task analysis was conducted to evaluate and quantify the various tasks and subtasks involved in tractor operation. Based on these defined tasks and subtasks, a group of five experienced farmers was asked to rank the tasks on a scale of one to five (as defined in Table 11) according to the mode of operation (field/road) and their frequency of use, task priority, and safety concerns.

The results from all participants were then calculated. The calculation process involved first assigning a weight to each of our metrics based on their importance (Inspired from FMEA, 2011). The weights were chosen to reflect the relative significance of each criterion, with safety matters given the highest weight due to their critical importance. Specifically, the frequency of use and task priority were each assigned a weight of 0.6, while safety matters were assigned a weight of 1.

The assignment of these values is justified by the critical need to prioritize safety in the design and operation of machinery, especially in contexts where human factors and ergonomics are involved. Safety is crucial because the consequences of safety failures can be severe, including injury or loss of life. This approach is consistent with other studies and methodologies that emphasize safety in risk assessments and ergonomic evaluations. For instance, the FMEA methodology, widely used in various industries, assigns higher risk priority numbers to failure modes with severe consequences, which often translates into a higher weight for safety-related factors. Furthermore, studies in human-computer interaction and usability engineering often prioritize safety and error prevention. For example, in the work by Nielsen (1994) on usability heuristics, error prevention is highlighted as a key criterion, reflecting its importance in system design. The weights of 0.6 for frequency of use and task priority are justified by their substantial, yet secondary, importance in ensuring efficient and effective operation.

Table 12. Ranked scores for the operational subtask "control speed based on terrain and load" in both road and field modes by farmer 1.

Tasks	Subtasks/Metrics	Road			Field		
		Frequency of use	Task priority	Safety matters	Frequency of use	Task priority	Safety matters
Operational	Control speed based on terrain and load.	5	5	4	3	5	4

As an example, Table 12 provides a sample response to the operational task “Control speed based on terrain and load.” The calculation process for this response is as follows:

Score of Subtasks = (0.6×Frequency of Use) × (0.6×Task Priority) × (1×Safety Matters)

Score for the Road mode = (0.6× 5) × (0.6×5) × (1×4) = 36

Score for the Field mode = (0.6× 3) × (0.6× 5) × (1× 4) = 21.6

The average scores from the five different farmers were then measured to determine our final results (A comprehensive calculated each farmer’s response is provided in the Appendix D).

5.2.4 Ranking the tasks

The following two tables present the results of a survey completed by five participants, designed to rank tasks performed by SA tractors in both on-road and field operations (Table 13-14). In these tables, different colors are used to highlight specific categories of tasks: pink represents driving tasks, red indicates safety and emergency tasks, green signifies operational tasks, orange denotes recording and documentation tasks, blue stands for monitoring and information tasks, and yellow represents comfort and convenience tasks (Figure 35).

Driving tasks: Pink
Operational tasks: Green
Monitoring and information tasks: Blue
Safety and emergency tasks: Red
Comfort and convenience tasks: Yellow
Recording and documentation tasks: Orange

Figure 35. The color coding of the data presented in table 13 and 14.

Table 13. Ranked top 30 tasks for tractors during road mode.

Road Mode		
Tasks	Scores	Color
1. Ensuring the tractor stays within designated lanes, especially on highways or large fields.	41.40	Pink
2. Monitoring and responding to other vehicles or obstacles on the road.	36.00	Pink
3. Adjusting speed according to terrain, obstacles, and safety requirements.	29.16	Pink
4. Collision detection and avoidance.	26.76	Red
5. Control speed based on terrain and load.	21.89	Green
6. Monitoring towed equipment for potential failures	19.66	Green
7. Low speed maneuvering in tight environments such as farmyards and field edges	19.02	Pink

8. Detect unmapped obstacles and navigate around or through them.	14.40	Green
9. Reacting to tractor/implement starting to get stuck	14.26	Red
10. Emergency communication between operator and support staff.	10.22	Red
11. Back up tractor to an implement, or with an implement already attached	9.00	Pink
12. Taking over from automated control of steering from the tractor	8.93	Red
13. Performing farming business management related activities	8.26	Orange
14. Monitoring and alerting for dangerous weather conditions.	7.78	Red
15. Real-time monitoring of engine performance and vital parameters.	7.06	Blue
16. Fine tuning climate control settings	3.96	Yellow
17. Route planning and optimization.	3.53	Green
18. Monitoring fuel and DEF levels	3.53	Blue
19. Adjust implement depth/settings	3.07	Green
20. Eating meals	3.02	Yellow
21. Engaging with entertainment or connectivity options during periods of boredom	2.66	Yellow
22. Adjusting ergonomic of controls such as seat position	2.45	Yellow
23. Providing feedback on operational efficiency.	2.22	Blue
24. Adjusting suspension systems for a smoother ride.	1.90	Yellow
25. Gathering data on soil conditions and environmental factors.	1.60	Blue
26.Analyzing data from onboard sensors and cameras.	1.50	Blue
27. Logging operational data such as time, location, speed, and activities performed.	0.78	Orange
28. Maintaining records of maintenance activities and schedules.	0.63	Orange
29. Recording environmental/field conditions during operations.	0.63	Orange
30. Managing precision farming files and recording of field data	0.63	Orange

Table 14. Ranked top 30 tasks for tractors during field mode.

Field Mode		
Tasks	Scores	Colors
1. Collision detection and avoidance.	25.92	Red
2. Taking over from automated control of steering from the tractor	24.98	Red
3. Low speed maneuvering in tight environments such as farmyards and field edges	21.67	Pink
4. Adjusting speed according to terrain, obstacles, and safety requirements.	20.09	Pink
5. Control speed based on terrain and load.	19.80	Green
6. Detect unmapped obstacles and navigate around or through them.	19.58	Green
7. Ensuring the tractor stays within designated lanes, especially on highways or large fields.	18.36	Pink
8. Monitoring towed equipment for potential failures	17.64	Green
9. Reacting to tractor/implement starting to get stuck	14.90	Red
10. Emergency communication between operator and support staff.	13.37	Red
11. Back up tractor to an implement, or with an implement already attached	12.74	Pink
12. Adjust implement depth/settings	11.02	Green
13. Monitoring and responding to other vehicles or obstacles on the road.	9.63	Pink
14. Monitoring and alerting for dangerous weather conditions.	7.27	Red
15. Real-time monitoring of engine performance and vital parameters.	6.98	Blue
16. Analyzing data from onboard sensors and cameras.	5.98	Blue
17. Route planning and optimization.	4.32	Green
18. Fine tuning climate control settings	3.60	Yellow
19. Monitoring fuel and DEF levels	3.46	Blue
20. Managing precision farming files and recording of field data	2.66	Orange

21. Engaging with entertainment or connectivity options during periods of boredom	2.59	Yellow
22. Adjusting ergonomic of controls such as seat position	2.45	Yellow
23. Providing feedback on operational efficiency.	2.30	Blue
24. Eating meals	2.02	Yellow
25. Performing farming business management related activities	1.90	Orange
26. Adjusting suspension systems for a smoother ride.	1.73	Yellow
27. Gathering data on soil conditions and environmental factors.	1.37	Blue
28. Recording environmental/field conditions during operations.	1.13	Orange
29. Logging operational data such as time, location, speed, and activities performed.	1.06	Orange
30. Maintaining records of maintenance activities and schedules.	0.94	Orange

The prioritization of tasks in both road and field modes underscores the differing operational requirements across environments. In road mode, driving tasks were ranked higher due to the operator's control over the tractor, as expected. Conversely, in field mode, where autonomy plays a more significant role, safety and emergency tasks were prioritized higher. This included tasks such as low-speed maneuvering in tight spaces like farmyards and field edges, and adjusting speed according to terrain, obstacles, and safety requirements. Operational tasks followed in importance.

Trust in automation is increasingly critical in our interactions with technology due to its rapidly expanding capabilities (Kohn et al., 2021). As defined by Duffy (2023), trust will be influenced by key factors such as system reliability, predictability, and the occurrence of faults. The paper also highlights the dynamic nature of trust, which can evolve through phases such as formation, dissolution, and restoration.

Due to the reason, they were considering a hypothetical situation and had not physically or cognitively experienced the trustworthiness of the SA tractor. Our results suggest that the farmers who completed the questionnaire did not have a mindset built upon trust in autonomy. Consequently, the top two ranked tasks in field mode were collision detection and avoidance and taking over from automated control of steering from the tractor. These tasks were considered more crucial than operational tasks, indicating a preference for the ability to quickly resume manual control. This lack of trust in autonomy reflects the need for farmers to have the opportunity to intervene promptly. However, these differences in task prioritization between road and field modes suggest that tractor interior design must be easily accessible in both scenarios and accommodate the operator's needs of both environments.

5.3 IMPLEMENTATION STRATEGY

In the previous section, the tasks that an operator is likely to perform within the cab of a semi-autonomous tractor were ranked. The tasks discussed in both road and field mode (Table 13 and 14) were further grouped into three importance categories based on their scores: high importance (scored above 14), medium importance (scored between 7 and 14), and low importance (scored below 7). Tasks with scores above 14 are considered high importance because they represent critical activities that operators must frequently monitor or perform to ensure safe and efficient tractor operation. These tasks are essential for both road and field modes, highlighting their significance. Tasks scored between 7 and 14 fall into the medium importance category. These tasks are important but not as critical as those in the high category. They require attention but may not need constant monitoring or immediate action. Tasks with scores below 7 are classified as low importance. These tasks are less critical and may be performed less frequently. They might be supportive activities or ones that can be done when the operator has spare time.

Effectively carrying out the tasks listed in Tables 13 and 14 requires specific features. For example, the highest-ranked task in road mode, "Ensuring the tractor stays within designated lanes, especially on highways or large fields," necessitates features such as speed reduction, gear shifting, speed control, steering, braking systems, lane departure warning, and operator displays. The comprehensive assignment of features to the tasks in Tables 13 and 14 is available in Appendix E. These features have been grouped according to their importance in Table 15.

Table 15. Categorization of features by importance for tractor task execution.

Importance	
High	Speed reduction, gear shifting, speed control, steering, braking system, lane departure warning, operator display, operator alerts, traction control, engine management systems, emergency shutdown, hydraulic control, differential lock, wheel slip control, and interactive touch screen.
Medium	3-point hitch control systems, smooth transition mechanism, real-time data display, communication systems, weather monitoring systems.
Low	Climate controls, fleet management, refrigerated storage, storage, eating tray, cup holders, microwave, trash bins, charging ports, axle suspension systems, and ergonomic adjustment of seat.

In Section 3.6.3, the redundancies present on the armrest of the Versatile tractor were discussed. Some features were eliminated to retain only those controls essential for the operator's safety and convenience (Figure 36). The necessary features to be retained as physical components on the armrest were then highlighted. However, this section focused exclusively on the importance of the features, irrespective of the type of control used to present them on the armrest. For instance, while the current armrest includes a joystick for gear shifting, this section does not specify how each feature should be presented; it simply emphasizes the significance of the features instead. The presentation of each feature depends on specific circumstances and the preferences of the design engineers.

Moreover, the comparison between the questionnaire results and the interviews with design engineers conducted at the start of the research is in complete agreement, confirming and highlighting the features that should be included in semi-autonomous tractors.

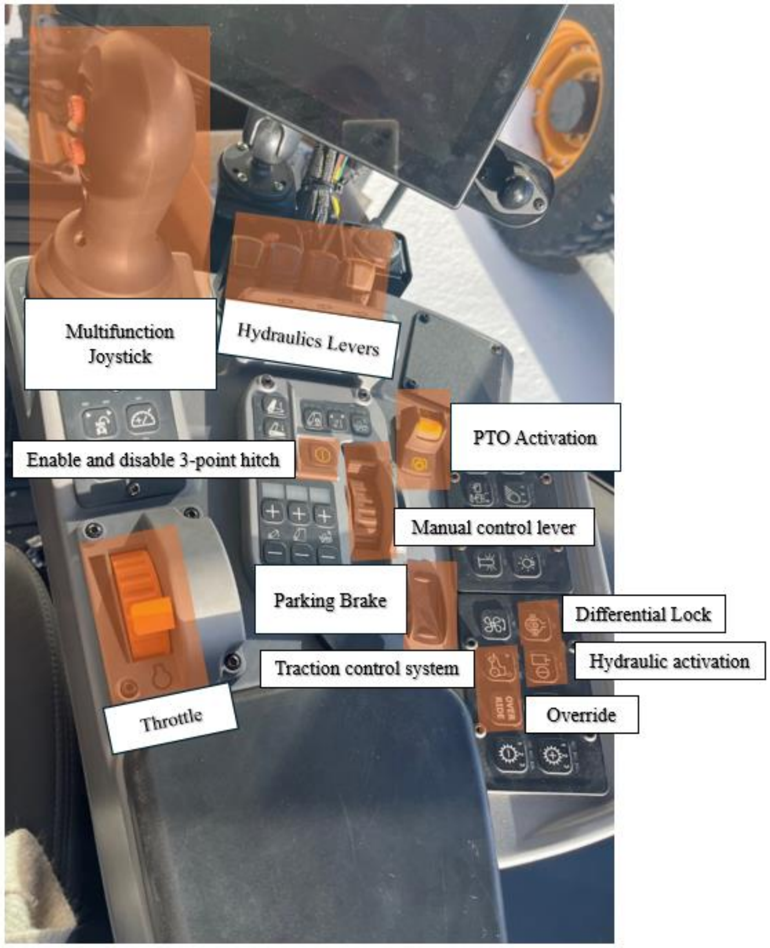

Figure 36. The selected physical buttons to retain on the armrest of a semi-autonomous tractor.

5.4 OPTIMAL FEATURES PLACEMENT

5.4.1 General recommendations

Control placement is a critical aspect of the design process as it impacts the efficiency, safety, and comfort of the operator. Ideally, controls (features) should be strategically positioned to minimize the necessity for operators to adjust their posture solely to operate them (Drakopoulos & Mann, 2006; Van Cott & Kinkade, 1963). Previous research on comfort and reach zones for controls, such as ISO-6682 (1986), focused primarily on the hand and foot. This information aids designers in positioning hand and foot controls for optimal comfort and efficiency (Purcell, 1982).

The task allocation decision will follow the principle that controls with the highest importance must be optimally placed (Dul & Weerdmeester, 2008). Therefore, it is determined that the features with high importance (as shown in Table 15) should be positioned within the wrist and ankle comfort zones, considering the nature of the task and the type of physical control to be applied. Another study by Woodson et al. (1992) confirmed this suggestion. They demonstrated that controls should be placed in such a manner that operators can use them without significantly shifting their eye reference point, thereby avoiding the risk of missing critical events outside or on the main internal display (Drakopoulos & Mann, 2006). Wrist and ankle comfort zones are in immediate access of the operator so they should accommodate the highest priority tasks (Figure 37, 38).

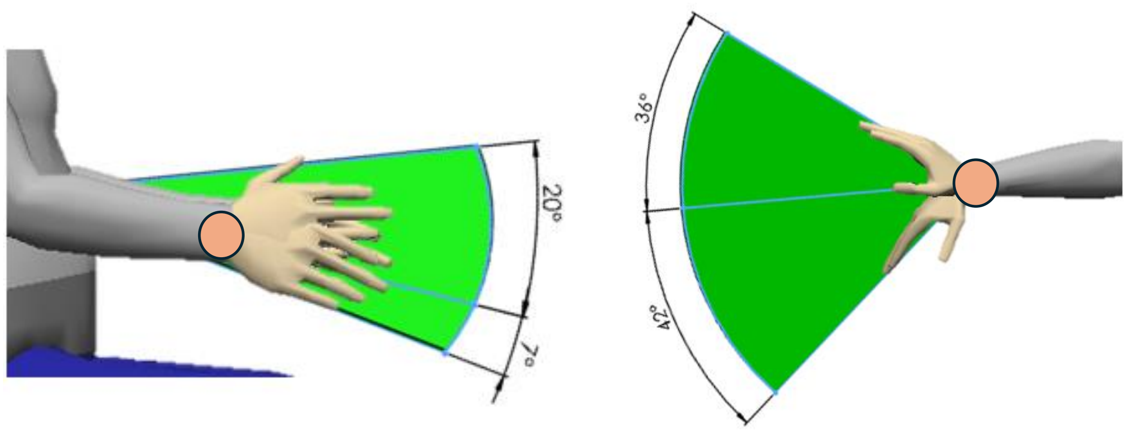

Figure 37. Identified degrees of wrist joint comfort ideal for high priority task placement.

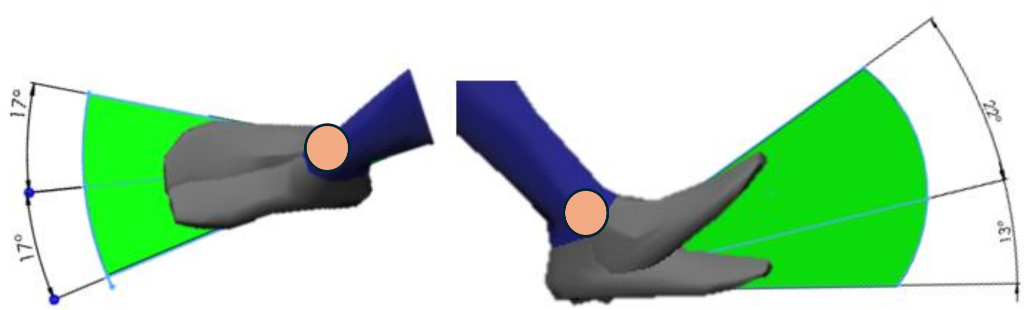

Figure 38. Identified degrees of ankle joint comfort ideal for high priority task placement.

Both medium and low importance tasks should ideally be positioned within the shoulder comfort zones, which encompass a larger area. However, medium importance features should be placed closer than those of low importance. According to Dul & Weerdmeester (2008), features other than those of high importance should be within the 'maximum reach envelope'. Nevertheless, by adopting a minimalist approach and potentially combining features, it is possible to keep all controls within the comfort range rather than the maximum reach envelope.

In general, the placement of features around the user depends on the designer's preferences and the nature of the task being performed. While humans are highly adaptable to various circumstances, designers should prioritize assigning features to the comfort zones. If necessary, the least important features can be located within the defined acceptable zones.

5.4.2 Specific recommendations

Organizing specific features within the tractor cab can lead to space savings and increased efficiency by minimizing hand movement and promoting a minimalist design. Several researchers have worked on developing models for optimal placement zones, including Casey & Kiso (1990), who proposed ideal positions for transmission, throttle, and hydraulic controls. They argued that controls should be optimally positioned to avoid interference with other features. In 1982, Purcell created guidelines for incorporating human factors into farm equipment design. He recommended that all controls in the tractor cab requiring precise manipulation should be positioned on the right-hand side of the operator, allowing the left hand to remain free for steering. Following this logic, features such as speed reduction, gear shifting, and speed control, which require frequent and precise manipulation, should typically be located where the dominant right hand can manage them more effectively (Figure 39). Supporting this, the standard (ISO 15077:2008) specifies that the engine speed control on agricultural field equipment should be operable with the right hand.

Positioning the steering within the left-hand comfort zone offers several advantages. First, it allows the left arm to remain in a more relaxed and natural position while steering, preventing strain and promoting better posture, which reduces the risk of repetitive stress injuries. Second, since many operators are right-handed, keeping the right hand free for tasks that require fine motor skills and frequent adjustments (such as touchscreen interactions and gear shifting) ensures these actions can be executed with greater precision and speed. Additionally, safety features that do not require constant adjustment can be managed with the left hand. Furthermore, additional features such as the lane departure system and a smooth transition mechanism from autonomy to manual control can also be integrated into the steering system on the left-hand side for easier access and increased efficiency.

According to ASAE Standard S335.4 DEC98, the braking system is a crucial function typically controlled by foot. When a foot pedal is used, it should be operated by the operator's left foot, with the motion being forward and/or downward for disengagement. However, if new tractors were to place this critical feature within the comfort zones of the hands, it should be positioned on the left hand for quick and precise operation. Even potentially integrating with the steering system to enhance ergonomics, improve reaction time, and simplify the control layout.

Hydraulic controls are essential for operational tasks and should be placed in high-priority areas, ideally on the right-hand side of the operator. The interactive touchscreen is typically positioned on the right for easy access and frequent interaction. Additionally, the interactive touchscreen should be placed within the operator's optimal vision cones to provide better visibility. Features such as communication systems, ergonomic adjustments of the cab, axle suspension systems, fleet management systems and engine management systems can also be incorporated into the touchscreen as they are not frequently used. Incorporating such features to the touch screen will save more space for frequently used and more important features.

Another suggestion by Purcell (1982) is that less frequently used controls, such as the PTO control, parking brake, and differential lock, can be assigned to left-hand or foot operation. Consequently, features like traction control, emergency shutdown, differential lock, and wheel slip control can be positioned within the left-hand comfort zones. Although these controls are not frequently used, they should be located close enough for easy access during emergency situations.

During our interviews with design engineers, a common understanding emerged that in FWD tractors, the three-point hitch adjustments on the armrest might be redundant (as discussed in section 3.6.3) and are infrequently used. However, features such as enabling and disabling the three-point hitch system should be retained for emergency shutdowns. The manual control lever, which allows the operator to precisely control the position and operation of the attached implement, remains essential for efficient tractor operation. Therefore, the critical operational features of the three-point hitch control system should be placed on the right-hand side within the operator's comfort zones. Given its medium importance, it can be situated in the shoulder comfort zones, which are further away, unlike speed reduction and gear shifting controls that need to be in closer proximity for ease of access.

The operator display is crucial for perceiving real-time information. Incorporating features such as weather monitoring and real-time alerts, and positioning the display within the optimal vision cone, can be highly beneficial (Figure 40). Other features, such as refrigerated storage, general storage, cup holders, microwave, trash bins, and charging ports, can be assigned to the broader comfort zones. These features have lower importance compared to other critical elements of the cab and therefore do not require prime positioning.

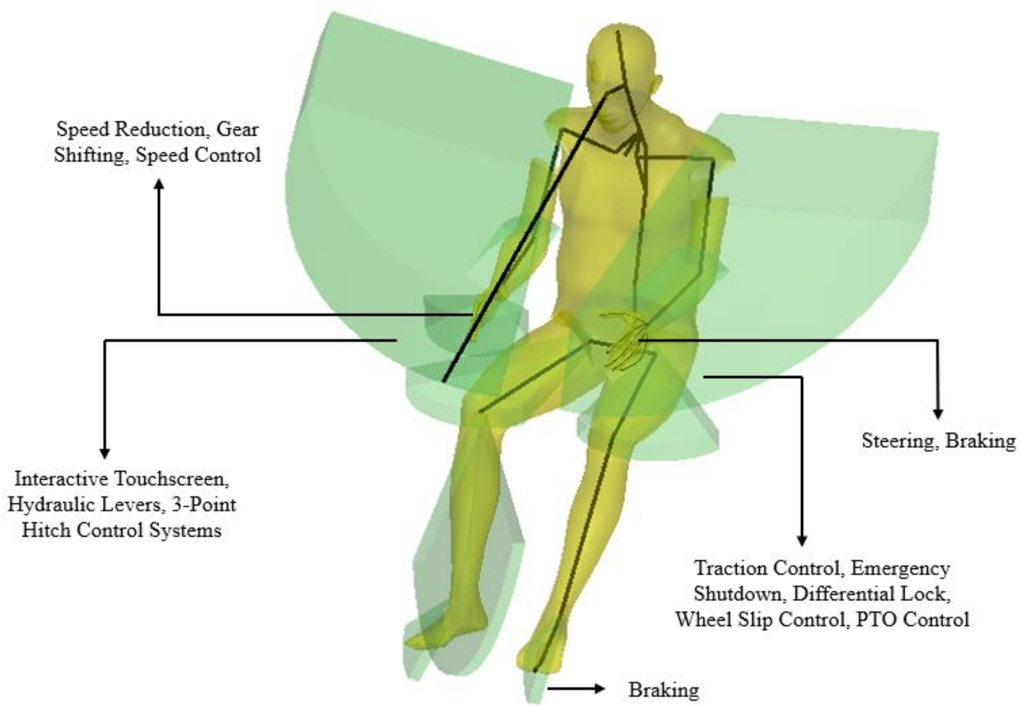

Figure 39. Proposed feature assignments to the human operator comfort zones created by RAMSIS software.

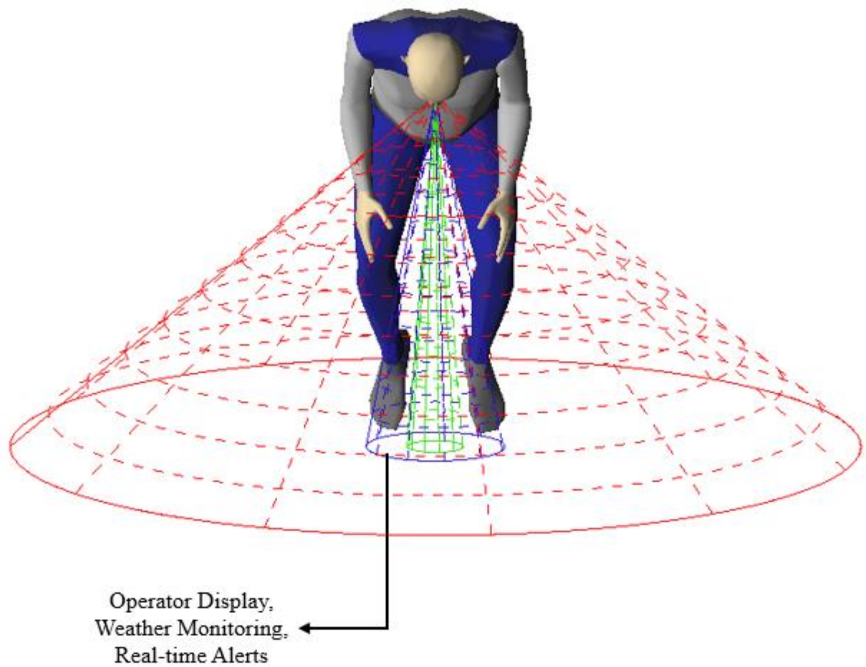

Figure 40. Proposed feature assignments to the human operator optimal vision cone created by RAMSIS software.

Based on the recommendations provided above and the research conducted in section 3.6.3 on the features to be retained for the future cab, an alternative arrangement of the current cab configuration can be conceptualized (Figure 41). This conceptualization broadly illustrates where the cab features might be placed according to the recommendations. It should be noted that the specific types of controls and joysticks were not examined in this study, nor were the ergonomics of these controls assessed. This visualization is solely intended to map out the tasks based on the earlier discussions.

Figure 41. Proposed feature assignment for the cab of semi-autonomous tractor.

All features in the tractor cab should be adjustable to accommodate different sizes, allowing individuals to modify the settings based on their own preferences. The touchscreen can be adjusted to be closer or further from the operator, providing better access or adjusting as needed. This suggested interior layout should be further examined ergonomically, and the interaction between human and machine should be studied more extensively for both female and male operators. However, this provides a rough idea of how the cab can be organized differently. In Figure 42, a top view of the operator within the cab of Versatile can be seen.

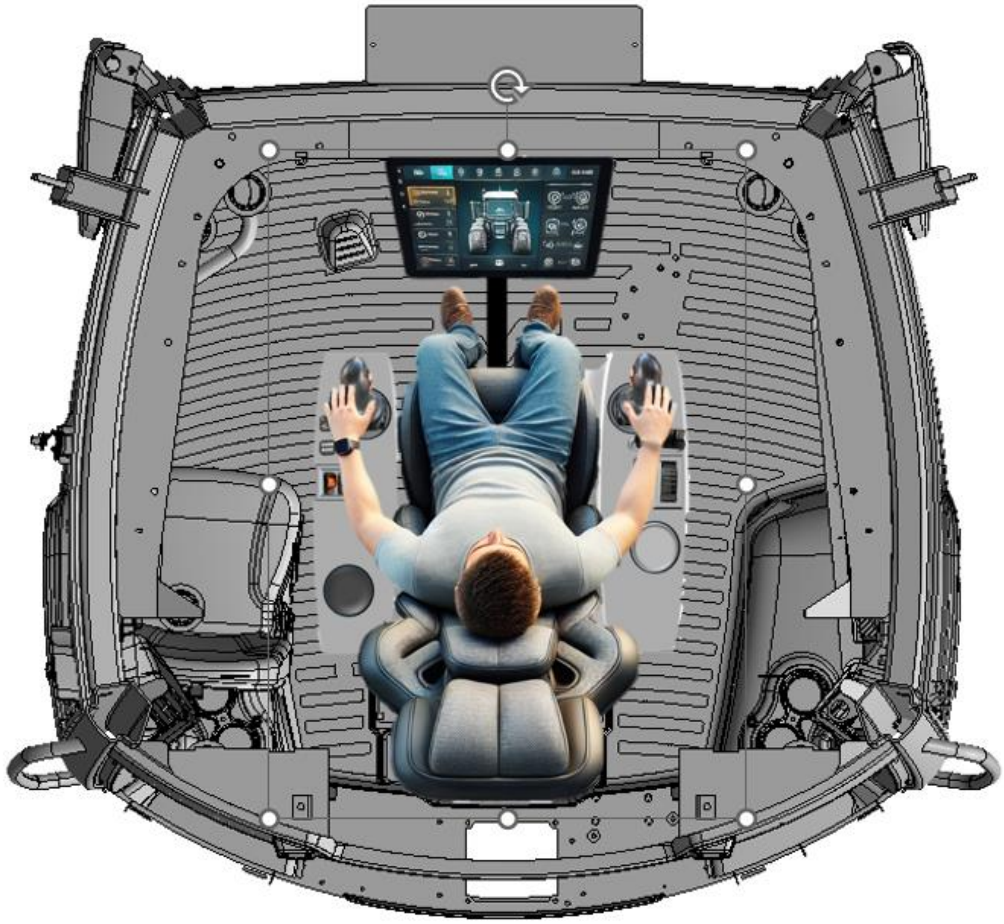

Figure 42. A manikin is placed in the cab of the Versatile tractor with modifications to the placement of features.

These are merely some recommendations for how to incorporate these features ergonomically into a future cab. The primary focus is on the task at hand, but the methods of implementation may change in the future. Previous standards, such as ISO 15077, included dedicated sections on the appearance and placement of controls. However, they failed to account for future changes in the design of controls and the cab itself. These standards provided a broad framework without prioritizing the human element. In contrast, the current focus is on the operator, emphasizing comfort over maximum reach. The prevailing ideology has shifted to prioritize human needs, and with technological advancements and the introduction of new features, existing regulations may require updates or modifications.

5.5 CONCLUSION

In this section, we have delved into the human-centered design of a cab for a semi-autonomous tractor, focusing on understanding and prioritizing the tasks that operators perform. By examining the interactions within the tractor cab and identifying critical tasks, we developed a framework for integrating these tasks into the cab design. The prioritization of tasks was based on their frequency of use, urgency, and safety concerns, ensuring that the most important tasks are given optimal placement for efficiency and comfort.

The task analysis and subsequent ranking provided insights into the varying requirements of on-road and in-field operations. While driving tasks dominated the road mode, safety, and emergency tasks were prioritized in field mode, reflecting the need for quick manual intervention in autonomous operations. This prioritization underscores the importance of designing tractor interiors that are adaptable to both environments.

The implementation strategy highlighted the necessary features for each task, grouping them based on their importance. High-priority features, such as speed control, steering, and emergency systems, were recommended to be placed within the immediate reach of the operator's hands and feet, ensuring quick and easy access. Medium and low-priority features were suggested to be placed further away but still within comfortable reach.

Finally, the optimal placement of controls was discussed, emphasizing the need for ergonomic design to enhance operator efficiency and comfort. The recommendations provided a conceptual layout for the cab, suggesting the best positions for various controls and features based on their importance and frequency of use.

Overall, this section aims to ensure that the transition to semi-autonomous tractor operations remains human-centered and ergonomically sound. By prioritizing tasks and strategically placing controls, we can enhance the safety, efficiency, and comfort of tractor operators, ultimately contributing to a more effective and user-friendly design for future tractor cabs.

6. LIMITATIONS AND FUTURE WORK

Throughout this project, efforts were dedicated to developing a methodology for design engineers to create a user-centered tractor cab for a semi-autonomous tractor. Despite these efforts, the study faced several limitations and identified areas for improvement in future research

- **Sample Size and Diversity**: The research was conducted with a limited sample size of experienced farmers and experts. While their insights are valuable, the small sample size may not represent the broader population of tractor operators. Additionally, the diversity in terms of age, gender, and experience levels among the participants was not explicitly addressed, which could impact the generalizability of the findings. Therefore, future research should encompass a broader group of participants to gather more comprehensive insights and enhance the validity of the findings.

- **Observational Constraints**: Observations of the farmers in the context of section 3 were primarily conducted during tillage and fertilizing tasks. These activities might not fully capture the variability and complexity of real-world tractor operation scenarios. Therefore, future research should include a wider range of operations, such as seeding, baling, harvesting, spraying, plowing, and haymaking. This broader approach will ensure a more comprehensive understanding of the ergonomic and operational needs of tractor operators across different contexts.

- **Software Limitations**: The study relied on a specific software tool, such as RAMSIS for anthropometric modeling. While this tool is advanced, it may have limitations in accurately simulating all possible ergonomic scenarios and human movements, especially given the dynamic nature of tractor operations. Further studies should verify the findings, particularly regarding gender and size differences, by including a broad group of participants to ensure the results are representative and comprehensive.

- **Focus on Semi-Autonomous Tractors**: As such, some of the interviewees' responses might reflect a conservative mindset, influenced by current practices and tasks. Future questionnaires should emphasize placing interviewees in the context of future cab designs and operations, encouraging them to consider the potential advancements and changes that semi-autonomous tractors will bring. This approach will help gather insights that are more aligned with the forward-looking objectives of the study.

- **Scope of Tasks**: The research focused on a predefined set of tasks based on expert consultations and literature reviews. While comprehensive, this approach may have overlooked certain tasks or interactions that are less common but still significant in specific operational contexts. A broader research initiative could be undertaken to form a comprehensive list of tasks, ensuring all possible interactions and activities are accounted for, and then rank them accordingly. This would provide a more complete understanding of operator needs and enhance the design process.

Addressing these limitations in future research can enhance the robustness and applicability of the findings, leading to more comprehensive ergonomic solutions for tractor cab design.

7. GENERAL CONCLUSION

This research set out to explore and enhance the ergonomic design of tractor cabs with a focus on human-centered design principles for semi-autonomous tractor operations. The primary objectives were:

- **Identify Ergonomic Shortcomings:** The study conducted an in-depth analysis of current tractor cab designs, identifying ergonomic flaws that impact operator comfort, safety, and efficiency. Issues such as awkward seating postures and frequent neck and back twisting were highlighted. Observational techniques, usability assessments, and interviews with design engineers provided insights into these ergonomic challenges. The findings emphasized the need for improvements in control placement, and overall cab layout to reduce physical strain and enhance operator comfort.

- **Understand Human-Machine Interaction:** The research examined how operators interact with semi-autonomous tractor systems, focusing on the transition from manual to automated operations and the resulting changes in operator roles and tasks. The study found that while semi-autonomous features reduce the need for constant manual control, operators still engage in critical tasks requiring immediate attention. This highlights the importance of designing interfaces that support both manual and automated operations seamlessly.

- **Comfort and Discomfort Modeling**: Using RAMSIS software, the research modeled the comfort and discomfort zones for various joints and body parts of tractor operators. The study classified these movements into comfortable, acceptable, and unsatisfactory zones, providing a detailed understanding of how different body parts react to prolonged tasks. This information is vital for guiding the ergonomic design process, ensuring that controls and features are placed within the operator's comfort zones to minimize physical strain and enhance usability.

- **Develop Task Prioritization Framework:** The study created a comprehensive framework to prioritize tasks based on their frequency of use, urgency, and safety concerns in both on-road and in-field operations. This framework guides the strategic placement of controls, ensuring that high-priority tasks are easily accessible. The findings indicate that driving and safety tasks are more critical in road mode, whereas operational tasks take precedence in field mode, reflecting the differing operational requirements.

- **Optimize Control Placement:** Recommendations were provided for the optimal placement of controls and features within the tractor cab to enhance operator efficiency and comfort. High-priority features such as speed control, steering, and emergency systems were suggested to be placed within immediate reach. Medium and low-priority features were recommended to be placed further away but still within comfortable reach. This strategic placement ensures that operators can access critical controls quickly and easily, reducing physical and cognitive load.

In conclusion, this research provides a comprehensive framework for the human-centered design of semi-autonomous tractor cabs. By integrating ergonomic principles, prioritizing operator needs, and strategically placing controls, the proposed design aims to enhance the overall user experience, ensuring that future tractor cabs are not only functional but also comfortable and safe for operators. This approach will contribute to increased productivity, reduced operator fatigue, and a safer working environment in agricultural operations.

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APPENDICES

Appendix A

Interview Questions for Designers

Appendix A: **INTERVIEW QUESTIONS FOR DESIGNERS**

Objectives: Our goal is to examine the current design of Versatile's tractor cab, analyzing it for any ergonomic challenges and pinpointing possible redundancies. Furthermore, we intend to gain insights into the best practices adopted by our competitors in the industry.

Section 1: Usability and Ergonomics

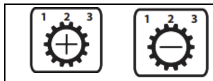
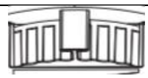
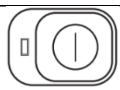
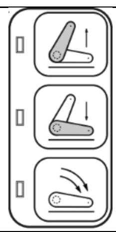
Are there any difficulties or discomforts encountered when interacting with the tractor components listed below?

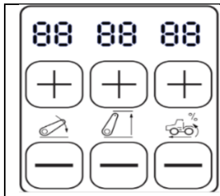
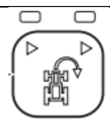
1. Steering
2. Foot pedal
3. Engine and gearshift controls
4. Hydraulic controls
5. Multifunction joystick
6. Auxiliary joystick
7. Touchscreen monitors
8. Lights and safety
9. Convenience controls (seat adjustment, radio, HVAC, etc.)

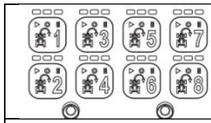
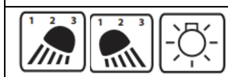
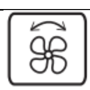
Section 2: Please review the attached images of the armrest buttons, and kindly answer the subsequent questions.

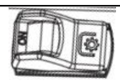
Emergency Button Definition: The ISO 13850 standard, which pertains to emergency stop functions on machinery, suggests that the emergency stop should bring the machinery to a complete stop within a time frame of 0.3 seconds to 1 second.

Tasks\ Questions	**Function**	**Will you keep this feature?**	**If yes, why would you keep this button?**	**Do you consider this as an emergency button?**
Engine and Transmission		Yes/No/ Keep it but move it to the screen.		Yes/No

	Power Transmission Upshift/ Downshift			
	Override Button			
	Engine Brake			
	Cruise Control Buttons			
	Hand Throttle			
	Transmission Shift Lever			
3-Point Hitch				
	Enable and Disable 3-Point Hitch			
	Fast Rise Fast Work Fast Drop			
	Travel Lock, Calibrate, Slip Control			

	Drop Rate, Maximum Height, Slip Threshold			
	Manual Control Lever			
Headland Management System				
	Located on the Cruise Control Panel			

	Located Under the Armrest			
Hydraulics				
	Hydraulic Levers			
	Activating Hydraulic Levers			
Main Control Panel 1				
	Autosteering			
	Lights			
	Rotary Beacon			
	Windshield Wipers			
Main Control Panel 2				
	Differential Lock			
	Fan			

	Suspended Axle			
	Traction Control System and Front Wheel Assist			
PTO Controls				
	Activate PTO			

Section 3: Usability and Ergonomics

What are some of the best practices you have seen in sections below?

1. Steering
2. Foot pedal
3. Engine and gearshift controls
4. Hydraulic controls
5. Multifunction joystick
6. Auxiliary joystick
7. Touchscreen monitors
8. Lights and safety

Section 4: Final Comments

If you have any additional suggestions for enhancing the armrest and control system of the autonomous tractor, please share them.

Appendix B

Results Driven from Interviews with Designers

Appendix B: RESULTS DRIVEN FROM INTERVIEWS WITH DESIGNERS

Section 1: Usability and Ergonomics

Are there any difficulties or discomforts encountered when interacting with the tractor components listed below?

1. Steering

The steering wheel's adjustability falls short as the extension is inadequate. Another respondent highlighted challenges in accommodating operators of various sizes, expressing difficulty with the telescopic function's operation, especially for those with less physical strength.

2. Foot pedal

To engage or readjust your foot, you must lift it. The foot pedal lacks positive feedback and does not offer precise fine-tuning capabilities.

3. Engine and gearshift controls

The hand throttle features a resistance point to indicate your position. However, the hand throttle is positioned too far back, leading to instances where your hand obstructs it. It is not possible to establish a consistent engine RPM, and the neutral button is not conveniently located for visibility.

The resistance level needs to be increased. It is suggested to integrate two hydraulic controls onto the command lever for convenience, positioning them higher up to avoid extended reaching. When operating hydraulics while looking backward, it is crucial to identify the hydraulic in use without constant back-and-forth glances. Placing the controls near the main shift lever is recommended to minimize strain on the hand, favoring pivoting over back-and-forth arm and shoulder movements. The placement should be determined by both the frequency of use and the specific tractor model being designed.

5. Command Lever:

The command lever design is outdated, featuring a large size with minimal functionality and proving uncomfortable to operate. Incorporating a hand rest would enhance the usability of the command lever, and the overall size is notably excessive.

6. Auxiliary joystick

Automation for this item is not anticipated in the near future, and it's likely that human intervention will remain necessary. The joystick's sensitivity for road use is not optimal, and it might be beneficial to integrate two distinct modes for road and farm applications.

8. Touchscreen monitors

Navigating the touchscreen proves challenging when in the field and experiencing constant bouncing. Introducing a screen navigator could be advantageous, and there is a need for improved vertical adjustments for the touchscreen.

9. Lights and safety:

The lights on the armrest come with three settings, and transitioning between them should be made simpler. For safety buttons, it is recommended to incorporate an instant system kill switch onto the armrest. Additionally, starting the tractor with a push button that can also serve as an emergency stop button is suggested.

10. Convenience controls (seat adjustment, radio, HVAC, etc.)

The buttons should be placed in a more convenient location, such as on the screen, since you only need to set them once and then leave them. The seating must have the capability to lock after swiveling, preventing unintended movement after adjustment, and other seat modifications should be relocated to the screen. The air conditioning controls are positioned too high.

Section 2: Please review the attached images of the armrest buttons, and kindly answer the subsequent questions.

Engine and Transmission:

1. Powershift transmission upshift and downshift (increment):

   Out of a group of five individuals, three preferred retaining the existing button, one proposed relocating it to the screen, and another suggested its complete removal. Additionally, one participant recommended moving the button to the command lever. The consensus leaned towards making it a built-in feature for convenience. In my view, placing this function on the screen is suitable, given that manually shifting gears by 2 or 3 steps is not likely to be a common occurrence in an autonomous tractor. Users could configure the desired number of upshifts through the screen interface when manually operating the tractor.

2. Override button:

   All five individuals agreed that the button functions as an emergency button, and there is a mutual agreement to maintain the current button positioned on the armrest.
   My own opinion: An override button for the case of an emergency shut down of the semi-autonomous tractor is necessary and should be kept. In my perspective, it is essential to retain an override button for emergency situations.

3. Engine brake (FWD):

   The discussion on this feature presented some contradictions. Two out of the five participants expressed their intention not to preserve the feature, considering it irrelevant. On the other hand, two participants opted to keep the existing button, citing its importance when descending hills and needing to decelerate the tractor, emphasizing the need for a lever or switch. Meanwhile, three out of five participants agreed that the feature serves as an emergency button. My opinion: I hold the view that this button serves as an emergency control, particularly crucial during hilly terrain drives, and it should be retained. However, there is uncertainty regarding the frequency of use and references to the current button. It could potentially be redundant and duplicative of tasks, given the ambiguity about its actual usage. Perhaps in a format distinct from pedals or a trio of button presses.

4. Cruise Control Buttons: Among the 5 participants, 3 proposed retaining only the activation and deactivation buttons and relocating the remaining two for adjustments onto the screen. Meanwhile, the other 2 recommended transferring all functions to the screen. In my view, considering that this tractor is anticipated to transition between fields, it makes sense to program cruise control settings for both road and field modes. The activation can be retained in the armrest, while adjustments can be executed through the screens or incorporated in a way that is not taking a lot of space.

5. Hand Throttle: All five participants express a desire to retain this feature.
   In my view, it is essential to preserve it as we will require the ability to establish an engine RPM.

6. Transmission shift lever:
   All participants agreed on retaining the command lever. However, they emphasized a preference for a more ergonomic design, suggesting alternatives like a knob instead of a joystick. Some also proposed adding more functions to the command lever. In my perspective, it is crucial to keep the command lever, but the format doesn't necessarily have to remain unchanged.

3-Point hitch (MFWD):

1. Enable and disable 3-point hitch:
   Four out of the five individuals opted to retain an enable/disable button for the 3-point hitch. The rationale behind this decision was the need to ensure that when on the road, it can be turned off, serving as a safety measure. In my viewpoint, having a button to deactivate the 3-point hitch wouldn't be a bad suggestion.

2. Fast raise, Fast work, and fast drop: Four out of five participants concluded that it should be relocated to the screen, while one proposed it should be conveniently accessible in their hand. In my perspective, they should be to transfer all functions to the screen.

3. Travel lock, calibrate, slip control:

   Everyone agreed on the idea of shifting this to the screen. In my viewpoint, the recommendation is to transfer all functions to the screen.

4. Drop rate, maximum height, slip threshold:
   Everyone believed it should be relocated to the screen. In my perspective, we should shift all functions to the screen.

5. Manual control lever:

   Two out of five participants advocated for transferring it to the screen, but the remaining three preferred retaining the current lever. Their rationale centered on the need to preserve it for fine-tuning depth and depth control, emphasizing its quick accessibility. While endorsing the retention, they proposed that it doesn't have to be in the form of a lever, citing Dodge's use of a knob as an alternative.

6. Headland management system:
   Three out of five participants held the view that this feature would not be relevant for semi-autonomous tractors. Conversely, the remaining two suggested retaining the enable and disable button for headland management but moving those under the armrest to the screen. In my perspective, the recommendation is to transfer all functions to the screen, given the anticipation that autonomy will handle the operations for the majority of the time.

Hydraulics:

1. Hydraulic activation button: One participant recommended having two activation buttons instead of one, with one for field activation and the other for road deactivation. Two participants favored retaining the hydraulic buttons, while one suggested integrating them into other parts of the design. The final participant proposed eliminating the activation buttons. In my perspective, integrating the activation button onto the hydraulic levers would be a favorable suggestion.

2. Hydraulic levers: All five participants agreed that the hydraulic lever should be retained. In my opinion, we should keep the hydraulic levers.

Main control panel 1:

1. Autosteering: All five participants reached an agreement to retain it, but they expressed a desire to relocate it to the command lever. In my perspective, despite its complexity, placing this function on the corner seems redundant with the introduction of autonomy to the tractor. Contrary to others' opinions, I believe it should be transferred to the screen.

2. Lights, rotary beacon, windshield wipers:

All five participants agreed on transferring these features to the screen. In my viewpoint, I also agree on moving these to the screen.

Main Control panel 2:

1. Differential lock:

Three out of five participants preferred retaining the physical buttons, emphasizing that this feature contributes to traction. The other two suggested placing them on the screen. Additionally, one participant mentioned the auto differential lock function. In my perspective, I believe it would be a beneficial idea to maintain the physical buttons, as it offers convenience and safety.

2. Fan Reversing:

Three individuals recommended moving the function to the screen, mentioning it would be a more favorable idea. The remaining participants preferred retaining the actual button, emphasizing its convenience. In my perspective, categorizing it under the convenience section would be a suitable suggestion.

3. Suspended front axle:

One person preferred retaining the on/off button on the armrest or relocating it to the command lever, while another individual wanted having the button specifically on the armrest. On the contrary, three others favored relocating the button to the screen. I believe it should be relocated to the screen.

4. Traction control system and front-wheel-assist:

One person preferred having both an on/off button and an automatic option. Another supported retaining the feature, emphasizing its significance as a safety measure in cold climates. I believe it serves as a safety feature, and therefore, we should maintain it.

5. Activate PTO:

All five individuals expressed a desire to retain the PTO activation, emphasizing its role as an emergency button. The kill switches for the autonomous tractor serve as safeguards, with the start and stop button functioning as a comprehensive kill switch that shuts down the entire system. I believe it serves as a safety feature, and therefore, we should maintain it.

Section 3: Best Practices

1. Steering:
   Case, John Deere, and New Holland exhibit superior steering with an improved Electronic Instrument Cluster (EIC) placement.

2. Foot Pedal:
   There is a need for more ergonomic footrests to facilitate easier foot movement. Positive feedback on Massey Ferguson and John Deere's pedals, including a heel rest.

3. Engine and Gearshift Controls:
   Case and John Deere's Command Pro are recognized for their advanced engine and gearshift controls.

4. Hydraulic Controls:

   Improved identification of levers is required for hydraulic controls.

5. Multifunction Joystick:

   When placing buttons on the joystick, careful consideration must be given to finger power.

6. Auxiliary Joystick:
7. Touchscreen Monitors:

   Enhanced touchscreen monitors with increased power and functionality are crucial as they serve as the central hub for autonomy. Features include an adjustable touchscreen and stability for hand movements.

8. Lights and Safety:

   Lights and safety controls are suggested to be integrated into the touchscreen, with separate sections for road and field lighting. Emphasis on improved color coding.

9. Convenience Controls (Seat Adjustments, Radio, HVAC, etc.):

   Seat adjustments are relocated to the touchscreen, while the radio is placed on the side of the armrest. Overall convenience controls are recommended to be centralized on the monitor.

Appendix C

Joints Degrees of Movement and Assigned Discomfort Levels

Appendix C: **RIGHT MALE SHOULDER JOINT**

Range of Motion of Right Shoulder Joint:	In X direction [10.0000, 85.0000] In Y direction [-80.0000, 57.0000] In Z direction [-80.0000, 85.0000]
The Neutral Position of Right Shoulder Joint:	[66.90, 44.00, 75.60]

Male 95% , Age Group: 18-70, Reference Year: 2010
Body Height:187.66 cm
Waist Circumference: 103.50 cm
Sitting Height: 98.24 cm

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
85.00	8.00	8.00
84.90	7.59	7.61
83.90	4.61	4.77
82.90	3.05	3.26
81.90	2.27	2.48
80.90	1.89	2.08
79.90	1.72	1.89
78.90	1.65	1.79
77.90	1.62	1.74
76.90	1.61	1.70
75.90	1.60	1.67
74.90	1.60	1.64
73.90	1.60	1.62
72.90	1.60	1.59
71.90	1.60	1.56
70.90	1.60	1.54
69.90	1.60	1.51
68.90	1.60	1.49
67.90	1.60	1.46
66.90	1.60	1.44

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
80.00	8.00	7.85	3.86
79.00	6.79	6.74	3.63
78.00	5.78	5.80	3.42
77.00	4.94	5.03	3.23
76.00	4.26	4.38	3.06
75.00	3.70	3.85	2.91
74.00	3.24	3.41	2.77
73.00	2.87	3.06	2.65
72.00	2.58	2.77	2.54
71.00	2.35	2.53	2.44
70.00	2.16	2.34	2.35
69.00	2.02	2.19	2.28
68.00	1.91	2.07	2.21
67.00	1.83	1.98	2.15
66.00	1.76	1.90	2.09
65.00	1.71	1.84	2.05
64.00	1.68	1.79	2.01
63.00	1.65	1.75	1.97
62.00	1.64	1.72	1.94
61.00	1.62	1.69	1.91

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
85.00	1.37	1.45
84.60	1.38	1.45
83.60	1.41	1.45
82.60	1.43	1.45
81.60	1.46	1.45
80.60	1.48	1.45
79.60	1.50	1.45
78.60	1.53	1.45
77.60	1.55	1.45
76.60	1.58	1.45
75.60	1.60	1.45
74.60	1.58	1.45
73.60	1.55	1.45
72.60	1.53	1.45
71.60	1.50	1.45
70.60	1.48	1.45
69.60	1.46	1.45
68.60	1.43	1.45
67.60	1.41	1.45
66.60	1.38	1.45

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
65.90	1.60	1.46
64.90	1.60	1.49
63.90	1.60	1.51
62.90	1.60	1.54
61.90	1.60	1.56
60.90	1.60	1.59
59.90	1.60	1.62
58.90	1.60	1.64
57.90	1.60	1.67
56.90	1.60	1.69
55.90	1.60	1.72
54.90	1.60	1.75
53.90	1.60	1.77
52.90	1.60	1.80
51.90	1.60	1.82
50.90	1.60	1.85
49.90	1.60	1.87
48.90	1.60	1.90
47.90	1.60	1.93
46.90	1.60	1.95
45.90	1.60	1.98
44.90	1.60	2.00
43.90	1.60	2.03
42.90	1.60	2.05
41.90	1.60	2.08
40.90	1.60	2.11
39.90	1.60	2.13
38.90	1.60	2.16
37.90	1.60	2.18
36.90	1.60	2.21

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
60.00	1.61	1.67	1.88
59.00	1.61	1.65	1.86
58.00	1.61	1.63	1.84
57.00	1.60	1.62	1.82
56.00	1.60	1.60	1.80
55.00	1.60	1.59	1.79
54.00	1.60	1.57	1.77
53.00	1.60	1.56	1.76
52.00	1.60	1.55	1.74
51.00	1.60	1.53	1.73
50.00	1.60	1.52	1.72
49.00	1.60	1.50	1.70
48.00	1.60	1.49	1.69
47.00	1.60	1.48	1.68
46.00	1.60	1.46	1.67
45.00	1.60	1.45	1.65
44.00	1.60	1.44	1.64
43.00	1.60	1.45	1.65
42.00	1.60	1.46	1.67
41.00	1.60	1.48	1.68
40.00	1.60	1.49	1.69
39.00	1.60	1.50	1.70
38.00	1.60	1.52	1.72
37.00	1.60	1.53	1.73
36.00	1.60	1.55	1.74
35.00	1.60	1.56	1.75
34.00	1.60	1.57	1.77
33.00	1.60	1.59	1.78
32.00	1.60	1.60	1.79
31.00	1.60	1.61	1.81

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
65.60	1.36	1.45
64.60	1.33	1.45
63.60	1.31	1.45
62.60	1.29	1.45
61.60	1.26	1.45
60.60	1.24	1.45
59.60	1.21	1.45
58.60	1.19	1.45
57.60	1.17	1.45
56.60	1.14	1.45
55.60	1.12	1.45
54.60	1.09	1.45
53.60	1.07	1.45
52.60	1.05	1.45
51.60	1.02	1.45
50.60	1.00	1.45
49.60	0.97	1.45
48.60	0.95	1.45
47.60	0.92	1.45
46.60	0.90	1.45
45.60	0.88	1.45
44.60	0.85	1.45
43.60	0.83	1.45
42.60	0.80	1.45
41.60	0.78	1.45
40.60	0.76	1.45
39.60	0.73	1.45
38.60	0.71	1.45
37.60	0.68	1.45
36.60	0.66	1.45

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
35.90	1.60	2.24
34.90	1.60	2.26
33.90	1.60	2.29
32.90	1.60	2.31
31.90	1.60	2.34
30.90	1.60	2.37
29.90	1.60	2.39
28.90	1.60	2.42
27.90	1.60	2.44
26.90	1.60	2.47
25.90	1.60	2.50
24.90	1.60	2.52
23.90	1.60	2.55
22.90	1.60	2.58
21.90	1.60	2.60
20.90	1.60	2.63
19.90	1.60	2.66
18.90	1.60	2.68
17.90	1.60	2.71
16.90	1.61	2.74
15.90	1.61	2.76
14.90	1.61	2.79
13.90	1.61	2.82
12.90	1.61	2.85
11.90	1.61	2.87
10.00	1.61	2.90

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
30.00	1.60	1.63	1.82
29.00	1.60	1.64	1.83
28.00	1.60	1.66	1.85
27.00	1.60	1.67	1.86
26.00	1.60	1.68	1.87
25.00	1.60	1.70	1.89
24.00	1.60	1.71	1.90
23.00	1.60	1.72	1.91
22.00	1.60	1.74	1.93
21.00	1.60	1.75	1.94
20.00	1.60	1.77	1.95
19.00	1.60	1.78	1.97
18.00	1.60	1.79	1.98
17.00	1.60	1.81	1.99
16.00	1.60	1.82	2.01
15.00	1.60	1.84	2.02
14.00	1.60	1.85	2.04
13.00	1.60	1.86	2.05
12.00	1.60	1.88	2.07
11.00	1.60	1.89	2.08
10.00	1.60	1.91	2.09
9.00	1.60	1.92	2.11
8.00	1.60	1.93	2.12
7.00	1.60	1.95	2.14
6.00	1.60	1.96	2.15
5.00	1.60	1.98	2.17
4.00	1.60	1.99	2.18
3.00	1.60	2.01	2.20
2.00	1.61	2.02	2.21
1.00	1.61	2.04	2.23

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
35.60	0.64	1.45
34.60	0.61	1.45
33.60	0.59	1.45
32.60	0.56	1.45
31.60	0.54	1.45
30.60	0.52	1.45
29.60	0.49	1.45
28.60	0.47	1.45
27.60	0.44	1.45
26.60	0.42	1.46
25.60	0.40	1.46
24.60	0.37	1.46
23.60	0.35	1.46
22.60	0.33	1.46
21.60	0.30	1.46
20.60	0.28	1.46
19.60	0.26	1.46
18.60	0.23	1.46
17.60	0.21	1.46
16.60	0.19	1.47
15.60	0.17	1.47
14.60	0.14	1.47
13.60	0.12	1.47
12.60	0.10	1.47
11.60	0.08	1.48
10.60	0.06	1.48
9.60	0.03	1.48
8.60	0.01	1.49
7.60	0.00	1.49
6.60	0.00	1.49

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
0.00	1.61	2.05	2.25
-1.00	1.61	2.07	2.26
-2.00	1.61	2.08	2.28
-3.00	1.61	2.10	2.29
-4.00	1.61	2.11	2.31
-5.00	1.61	2.13	2.33
-6.00	1.62	2.14	2.34
-7.00	1.62	2.16	2.36
-8.00	1.62	2.18	2.38
-9.00	1.62	2.19	2.39
-10.00	1.63	2.21	2.41
-11.00	1.63	2.23	2.43
-12.00	1.64	2.25	2.44
-13.00	1.64	2.26	2.46
-14.00	1.64	2.28	2.48
-15.00	1.65	2.30	2.50
-16.00	1.66	2.32	2.52
-17.00	1.66	2.34	2.53
-18.00	1.67	2.36	2.55
-19.00	1.68	2.38	2.57
-20.00	1.68	2.41	2.59
-21.00	1.69	2.43	2.61
-22.00	1.70	2.45	2.63
-23.00	1.71	2.48	2.65
-24.00	1.73	2.50	2.67
-25.00	1.74	2.53	2.69
-26.00	1.75	2.55	2.71
-27.00	1.77	2.58	2.73
-28.00	1.78	2.61	2.75
-29.00	1.80	2.64	2.77

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
5.60	0.00	1.50
4.60	0.00	1.50
3.60	0.00	1.51
2.60	0.00	1.51
1.60	0.00	1.52
0.60	0.00	1.52
-0.40	0.00	1.53
-1.40	0.00	1.54
-2.40	0.00	1.54
-3.40	0.00	1.55
-4.40	0.00	1.56
-5.40	0.00	1.57
-6.40	0.00	1.58
-7.40	0.00	1.59
-8.40	0.00	1.60
-9.40	0.00	1.61
-10.40	0.00	1.62
-11.40	0.00	1.63
-12.40	0.00	1.65
-13.40	0.00	1.66
-14.40	0.00	1.67
-15.40	0.00	1.69
-16.40	0.00	1.71
-17.40	0.00	1.72
-18.40	0.00	1.74
-19.40	0.00	1.76
-20.40	0.00	1.78
-21.40	0.00	1.81
-22.40	0.00	1.83
-23.40	0.00	1.85

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
-30.00	1.82	2.67	2.79
-31.00	1.84	2.70	2.81
-32.00	1.86	2.74	2.83
-33.00	1.88	2.77	2.85
-34.00	1.91	2.81	2.87
-35.00	1.94	2.85	2.89
-36.00	1.96	2.88	2.92
-37.00	2.00	2.93	2.94
-38.00	2.03	2.97	2.96
-39.00	2.06	3.01	2.98
-40.00	2.10	3.06	3.01
-41.00	2.14	3.11	3.03
-42.00	2.18	3.16	3.05
-43.00	2.23	3.21	3.08
-44.00	2.28	3.27	3.10
-45.00	2.33	3.33	3.12
-46.00	2.39	3.39	3.15
-47.00	2.45	3.45	3.17
-48.00	2.51	3.52	3.20
-49.00	2.58	3.59	3.22
-50.00	2.65	3.66	3.25
-51.00	2.72	3.73	3.27
-52.00	2.80	3.81	3.30
-53.00	2.88	3.90	3.33
-54.00	2.97	3.98	3.35
-55.00	3.07	4.07	3.38
-56.00	3.17	4.17	3.41
-57.00	3.27	4.26	3.43
-58.00	3.38	4.37	3.46
-59.00	3.50	4.47	3.49

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-24.40	0.00	1.88
-25.40	0.00	1.91
-26.40	0.00	1.94
-27.40	0.00	1.97
-28.40	0.00	2.00
-29.40	0.00	2.03
-30.40	0.00	2.07
-31.40	0.00	2.10
-32.40	0.00	2.14
-33.40	0.00	2.18
-34.40	0.00	2.22
-35.40	0.00	2.27
-36.40	0.00	2.31
-37.40	0.00	2.36
-38.40	0.02	2.41
-39.40	0.07	2.47
-40.40	0.13	2.52
-41.40	0.18	2.58
-42.40	0.24	2.64
-43.40	0.31	2.71
-44.40	0.38	2.77
-45.40	0.46	2.84
-46.40	0.54	2.92
-47.40	0.62	2.99
-48.40	0.71	3.07
-49.40	0.81	3.15
-50.40	0.91	3.24
-51.40	1.02	3.33
-52.40	1.13	3.42
-53.40	1.25	3.52

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
-60.00	3.63	4.59	3.52
-61.00	3.76	4.70	3.55
-62.00	3.89	4.82	3.57
-63.00	4.04	4.95	3.60
-64.00	4.19	5.08	3.63
-65.00	4.35	5.22	3.66
-66.00	4.52	5.37	3.69
-67.00	4.70	5.52	3.72
-68.00	4.89	5.67	3.75
-69.00	5.09	5.84	3.78
-70.00	5.29	6.01	3.81
-71.00	5.51	6.19	3.84
-72.00	5.74	6.37	3.88
-73.00	5.98	6.56	3.91
-74.00	6.23	6.76	3.94
-75.00	6.49	6.97	3.97
-76.00	6.76	7.19	4.01
-77.00	7.05	7.42	4.04
-78.00	7.35	7.65	4.07
-79.00	7.67	7.90	4.11
-80.00	8.00	8.00	4.14

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-54.40	1.38	3.62
-55.40	1.52	3.72
-56.40	1.66	3.83
-57.40	1.81	3.94
-58.40	1.97	4.06
-59.40	2.14	4.19
-60.40	2.31	4.31
-61.40	2.49	4.44
-62.40	2.69	4.58
-63.40	2.89	4.72
-64.40	3.10	4.87
-65.40	3.33	5.03
-66.40	3.56	5.19
-67.40	3.80	5.35
-68.40	4.06	5.52
-69.40	4.33	5.70
-70.40	4.61	5.88
-71.40	4.90	6.07
-72.40	5.20	6.27
-73.40	5.52	6.47
-74.40	5.86	6.69
-75.40	6.20	6.91
-76.40	6.57	7.13
-77.40	6.94	7.37
-78.40	7.34	7.61
-79.40	7.75	7.86
-80.00	8.00	8.00

Appendix C: **LEFT MALE SHOULDER JOINT**

Range of Motion of Left Shoulder Joint:	In X direction [-10.0000, -85.0000] In Y direction [-57.0000, 80.0000] In Z direction [-80.0000, 85.0000]
The Neutral Position of Left Shoulder Joint:	[-66.90, -44.00, 75.60]

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-10.00	1.61	2.93
-11.90	1.61	2.87
-12.90	1.61	2.85
-13.90	1.61	2.82
-14.90	1.61	2.79
-15.90	1.61	2.76
-16.90	1.61	2.74
-17.90	1.60	2.71
-18.90	1.60	2.68
-19.90	1.60	2.66
-20.90	1.60	2.63
-21.90	1.60	2.60
-22.90	1.60	2.58
-23.90	1.60	2.55
-24.90	1.60	2.52
-25.90	1.60	2.50
-26.90	1.60	2.47
-27.90	1.60	2.44
-28.90	1.60	2.42
-29.90	1.60	2.39
-30.90	1.60	2.37
-31.90	1.60	2.34

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
-80.00	8.00	7.85	3.86
-79.00	6.79	6.74	3.63
-78.00	5.78	5.80	3.42
-77.00	4.94	5.03	3.23
-76.00	4.26	4.38	3.06
-75.00	3.70	3.85	2.91
-74.00	3.24	3.41	2.77
-73.00	2.87	3.06	2.65
-72.00	2.58	2.77	2.54
-71.00	2.35	2.53	2.44
-70.00	2.16	2.34	2.35
-69.00	2.02	2.19	2.28
-68.00	1.91	2.07	2.21
-67.00	1.83	1.98	2.15
-66.00	1.76	1.90	2.09
-65.00	1.71	1.84	2.05
-64.00	1.68	1.79	2.01
-63.00	1.65	1.75	1.97
-62.00	1.64	1.72	1.94
-61.00	1.62	1.69	1.91
-60.00	1.61	1.67	1.88
-59.00	1.61	1.65	1.86

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
85.00	1.37	1.45
84.60	1.38	1.45
83.60	1.41	1.45
82.60	1.43	1.45
81.60	1.46	1.45
80.60	1.48	1.45
79.60	1.50	1.45
78.60	1.53	1.45
77.60	1.55	1.45
76.60	1.58	1.45
75.60	1.60	1.45
74.60	1.58	1.45
73.60	1.55	1.45
72.60	1.53	1.45
71.60	1.50	1.45
70.60	1.48	1.45
69.60	1.46	1.45
68.60	1.43	1.45
67.60	1.41	1.45
66.60	1.38	1.45
65.60	1.36	1.45
64.60	1.33	1.45

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-32.90	1.60	2.31
-33.90	1.60	2.29
-34.90	1.60	2.26
-35.90	1.60	2.24
-36.90	1.60	2.21
-37.90	1.60	2.18
-38.90	1.60	2.16
-39.90	1.60	2.13
-40.90	1.60	2.11
-41.90	1.60	2.08
-42.90	1.60	2.05
-43.90	1.60	2.03
-44.90	1.60	2.00
-45.90	1.60	1.98
-46.90	1.60	1.95
-47.90	1.60	1.93
-48.90	1.60	1.90
-49.90	1.60	1.87
-50.90	1.60	1.85
-51.90	1.60	1.82
-52.90	1.60	1.80
-53.90	1.60	1.77
-54.90	1.60	1.75
-55.90	1.60	1.72
-56.90	1.60	1.69
-57.90	1.60	1.67
-58.90	1.60	1.64
-59.90	1.60	1.62
-60.90	1.60	1.59
-61.90	1.60	1.56

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
-58.00	1.61	1.63	1.84
-57.00	1.60	1.62	1.82
-56.00	1.60	1.60	1.80
-55.00	1.60	1.59	1.79
-54.00	1.60	1.57	1.77
-53.00	1.60	1.56	1.76
-52.00	1.60	1.55	1.74
-51.00	1.60	1.53	1.73
-50.00	1.60	1.52	1.72
-49.00	1.60	1.50	1.70
-48.00	1.60	1.49	1.69
-47.00	1.60	1.48	1.68
-46.00	1.60	1.46	1.67
-45.00	1.60	1.45	1.65
-44.00	1.60	1.44	1.64
-43.00	1.60	1.45	1.65
-42.00	1.60	1.46	1.67
-41.00	1.60	1.48	1.68
-40.00	1.60	1.49	1.69
-39.00	1.60	1.50	1.70
-38.00	1.60	1.52	1.72
-37.00	1.60	1.53	1.73
-36.00	1.60	1.55	1.74
-35.00	1.60	1.56	1.75
-34.00	1.60	1.57	1.77
-33.00	1.60	1.59	1.78
-32.00	1.60	1.60	1.79
-31.00	1.60	1.61	1.81
-30.00	1.60	1.63	1.82
-29.00	1.60	1.64	1.83

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
63.60	1.31	1.45
62.60	1.29	1.45
61.60	1.26	1.45
60.60	1.24	1.45
59.60	1.21	1.45
58.60	1.19	1.45
57.60	1.17	1.45
56.60	1.14	1.45
55.60	1.12	1.45
54.60	1.09	1.45
53.60	1.07	1.45
52.60	1.05	1.45
51.60	1.02	1.45
50.60	1.00	1.45
49.60	0.97	1.45
48.60	0.95	1.45
47.60	0.92	1.45
46.60	0.90	1.45
45.60	0.88	1.45
44.60	0.85	1.45
43.60	0.83	1.45
42.60	0.80	1.45
41.60	0.78	1.45
40.60	0.76	1.45
39.60	0.73	1.45
38.60	0.71	1.45
37.60	0.68	1.45
36.60	0.66	1.45
35.60	0.64	1.45
34.60	0.61	1.45

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-62.90	1.60	1.54
-63.90	1.60	1.51
-64.90	1.60	1.49
-65.90	1.60	1.46
-66.90	1.60	1.44
-67.90	1.60	1.46
-68.90	1.60	1.49
-69.90	1.60	1.51
-70.90	1.60	1.54
-71.90	1.60	1.56
-72.90	1.60	1.59
-73.90	1.60	1.62
-74.90	1.60	1.64
-75.90	1.60	1.67
-76.90	1.61	1.70
-77.90	1.62	1.74
-78.90	1.65	1.79
-79.90	1.72	1.89
-80.90	1.89	2.08
-81.90	2.27	2.48
-82.90	3.05	3.26
-83.90	4.61	4.77
-84.90	7.59	7.61
-85.00	8.00	8.00

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
-28.00	1.60	1.66	1.85
-27.00	1.60	1.67	1.86
-26.00	1.60	1.68	1.87
-25.00	1.60	1.70	1.89
-24.00	1.60	1.71	1.90
-23.00	1.60	1.72	1.91
-22.00	1.60	1.74	1.93
-21.00	1.60	1.75	1.94
-20.00	1.60	1.77	1.95
-19.00	1.60	1.78	1.97
-18.00	1.60	1.79	1.98
-17.00	1.60	1.81	1.99
-16.00	1.60	1.82	2.01
-15.00	1.60	1.84	2.02
-14.00	1.60	1.85	2.04
-13.00	1.60	1.86	2.05
-12.00	1.60	1.88	2.07
-11.00	1.60	1.89	2.08
-10.00	1.60	1.91	2.09
-9.00	1.60	1.92	2.11
-8.00	1.60	1.93	2.12
-7.00	1.60	1.95	2.14
-6.00	1.60	1.96	2.15
-5.00	1.60	1.98	2.17
-4.00	1.60	1.99	2.18
-3.00	1.60	2.01	2.20
-2.00	1.61	2.02	2.21
-1.00	1.61	2.04	2.23
0.00	1.61	2.05	2.25
1.00	1.61	2.07	2.26

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
33.60	0.59	1.45
32.60	0.56	1.45
31.60	0.54	1.45
30.60	0.52	1.45
29.60	0.49	1.45
28.60	0.47	1.45
27.60	0.44	1.45
26.60	0.42	1.46
25.60	0.40	1.46
24.60	0.37	1.46
23.60	0.35	1.46
22.60	0.33	1.46
21.60	0.30	1.46
20.60	0.28	1.46
19.60	0.26	1.46
18.60	0.23	1.46
17.60	0.21	1.46
16.60	0.19	1.47
15.60	0.17	1.47
14.60	0.14	1.47
13.60	0.12	1.47
12.60	0.10	1.47
11.60	0.08	1.48
10.60	0.06	1.48
9.60	0.03	1.48
8.60	0.01	1.49
7.60	0.00	1.49
6.60	0.00	1.49
5.60	0.00	1.50
4.60	0.00	1.50

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
2.00	1.61	2.08	2.28
3.00	1.61	2.10	2.29
4.00	1.61	2.11	2.31
5.00	1.61	2.13	2.33
6.00	1.62	2.14	2.34
7.00	1.62	2.16	2.36
8.00	1.62	2.18	2.38
9.00	1.62	2.19	2.39
10.00	1.63	2.21	2.41
11.00	1.63	2.23	2.43
12.00	1.64	2.25	2.44
13.00	1.64	2.26	2.46
14.00	1.64	2.28	2.48
15.00	1.65	2.30	2.50
16.00	1.66	2.32	2.52
17.00	1.66	2.34	2.53
18.00	1.67	2.36	2.55
19.00	1.68	2.38	2.57
20.00	1.68	2.41	2.59
21.00	1.69	2.43	2.61
22.00	1.70	2.45	2.63
23.00	1.71	2.48	2.65
24.00	1.73	2.50	2.67
25.00	1.74	2.53	2.69
26.00	1.75	2.55	2.71
27.00	1.77	2.58	2.73
28.00	1.78	2.61	2.75
29.00	1.80	2.64	2.77
30.00	1.82	2.67	2.79
31.00	1.84	2.70	2.81

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
3.60	0.00	1.51
2.60	0.00	1.51
1.60	0.00	1.52
0.60	0.00	1.52
-0.40	0.00	1.53
-1.40	0.00	1.54
-2.40	0.00	1.54
-3.40	0.00	1.55
-4.40	0.00	1.56
-5.40	0.00	1.57
-6.40	0.00	1.58
-7.40	0.00	1.59
-8.40	0.00	1.60
-9.40	0.00	1.61
-10.40	0.00	1.62
-11.40	0.00	1.63
-12.40	0.00	1.65
-13.40	0.00	1.66
-14.40	0.00	1.67
-15.40	0.00	1.69
-16.40	0.00	1.71
-17.40	0.00	1.72
-18.40	0.00	1.74
-19.40	0.00	1.76
-20.40	0.00	1.78
-21.40	0.00	1.81
-22.40	0.00	1.83
-23.40	0.00	1.85
-24.40	0.00	1.88
-25.40	0.00	1.91

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
32.00	1.86	2.74	2.83
33.00	1.88	2.77	2.85
34.00	1.91	2.81	2.87
35.00	1.94	2.85	2.89
36.00	1.96	2.88	2.92
37.00	2.00	2.93	2.94
38.00	2.03	2.97	2.96
39.00	2.06	3.01	2.98
40.00	2.10	3.06	3.01
41.00	2.14	3.11	3.03
42.00	2.18	3.16	3.05
43.00	2.23	3.21	3.08
44.00	2.28	3.27	3.10
45.00	2.33	3.33	3.12
46.00	2.39	3.39	3.15
47.00	2.45	3.45	3.17
48.00	2.51	3.52	3.20
49.00	2.58	3.59	3.22
50.00	2.65	3.66	3.25
51.00	2.72	3.73	3.27
52.00	2.80	3.81	3.30
53.00	2.88	3.90	3.33
54.00	2.97	3.98	3.35
55.00	3.07	4.07	3.38
56.00	3.17	4.17	3.41
57.00	3.27	4.26	3.43
58.00	3.38	4.37	3.46
59.00	3.50	4.47	3.49
60.00	3.63	4.59	3.52
61.00	3.76	4.70	3.55

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-26.40	0.00	1.94
-27.40	0.00	1.97
-28.40	0.00	2.00
-29.40	0.00	2.03
-30.40	0.00	2.07
-31.40	0.00	2.10
-32.40	0.00	2.14
-33.40	0.00	2.18
-34.40	0.00	2.22
-35.40	0.00	2.27
-36.40	0.00	2.31
-37.40	0.00	2.36
-38.40	0.02	2.41
-39.40	0.07	2.47
-40.40	0.13	2.52
-41.40	0.18	2.58
-42.40	0.24	2.64
-43.40	0.31	2.71
-44.40	0.38	2.77
-45.40	0.46	2.84
-46.40	0.54	2.92
-47.40	0.62	2.99
-48.40	0.71	3.07
-49.40	0.81	3.15
-50.40	0.91	3.24
-51.40	1.02	3.33
-52.40	1.13	3.42
-53.40	1.25	3.52
-54.40	1.38	3.62
-55.40	1.52	3.72

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
62.00	3.89	4.82	3.57
63.00	4.04	4.95	3.60
64.00	4.19	5.08	3.63
65.00	4.35	5.22	3.66
66.00	4.52	5.37	3.69
67.00	4.70	5.52	3.72
68.00	4.89	5.67	3.75
69.00	5.09	5.84	3.78
70.00	5.29	6.01	3.81
71.00	5.51	6.19	3.84
72.00	5.74	6.37	3.88
73.00	5.98	6.56	3.91
74.00	6.23	6.76	3.94
75.00	6.49	6.97	3.97
76.00	6.76	7.19	4.01
77.00	7.05	7.42	4.04
78.00	7.35	7.65	4.07
79.00	7.67	7.90	4.11
80.00	8.00	8.00	4.14

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-56.40	1.66	3.83
-57.40	1.81	3.94
-58.40	1.97	4.06
-59.40	2.14	4.19
-60.40	2.31	4.31
-61.40	2.49	4.44
-62.40	2.69	4.58
-63.40	2.89	4.72
-64.40	3.10	4.87
-65.40	3.33	5.03
-66.40	3.56	5.19
-67.40	3.80	5.35
-68.40	4.06	5.52
-69.40	4.33	5.70
-70.40	4.61	5.88
-71.40	4.90	6.07
-72.40	5.20	6.27
-73.40	5.52	6.47
-74.40	5.86	6.69
-75.40	6.20	6.91
-76.40	6.57	7.13
-77.40	6.94	7.37
-78.40	7.34	7.61
-79.40	7.75	7.86
-80.00	8.00	8.00

Appendix C: **RIGHT FEMALE SHOULDER JOINT**

Range of Motion of Right Shoulder Joint:	In X direction [-23.0000, 85.0000] In Y direction [-80.0000, 61.0000] In Z direction [-80.0000, 82.0000]
The Neutral Position of Right Shoulder Joint:	[66.90, 44.00, 75.60]

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
85.00	8.00	8.00
84.90	7.59	7.61
83.90	4.61	4.77
82.90	3.05	3.26
81.90	2.27	2.48
80.90	1.89	2.08
79.90	1.72	1.89
78.90	1.65	1.79
77.90	1.62	1.74
76.90	1.61	1.70
75.90	1.60	1.67
74.90	1.60	1.64
73.90	1.60	1.62
72.90	1.60	1.59
71.90	1.60	1.56
70.90	1.60	1.54
69.90	1.60	1.51
68.90	1.60	1.49
67.90	1.60	1.46
66.90	1.60	1.44

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
80.00	8.00	7.85	3.86
79.00	6.79	6.74	3.63
78.00	5.78	5.80	3.42
77.00	4.94	5.03	3.23
76.00	4.26	4.38	3.06
75.00	3.70	3.85	2.91
74.00	3.24	3.41	2.77
73.00	2.87	3.06	2.65
72.00	2.58	2.77	2.54
71.00	2.35	2.53	2.44
70.00	2.16	2.34	2.35
69.00	2.02	2.19	2.28
68.00	1.91	2.07	2.21
67.00	1.83	1.98	2.15
66.00	1.76	1.90	2.09
65.00	1.71	1.84	2.05
64.00	1.68	1.79	2.01
63.00	1.65	1.75	1.97
62.00	1.64	1.72	1.94
61.00	1.62	1.69	1.91

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
82.00	1.45	1.44
81.60	1.46	1.44
80.60	1.48	1.44
79.60	1.50	1.44
78.60	1.53	1.44
77.60	1.55	1.44
76.60	1.58	1.44
75.60	1.60	1.44
74.60	1.58	1.44
73.60	1.55	1.44
72.60	1.53	1.44
71.60	1.50	1.44
70.60	1.48	1.44
69.60	1.46	1.44
68.60	1.43	1.44
67.60	1.41	1.44
66.60	1.38	1.44
65.60	1.36	1.44
64.60	1.33	1.44
63.60	1.31	1.44

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
65.90	1.60	1.46
64.90	1.60	1.49
63.90	1.60	1.51
62.90	1.60	1.54
61.90	1.60	1.56
60.90	1.60	1.59
59.90	1.60	1.62
58.90	1.60	1.64
57.90	1.60	1.67
56.90	1.60	1.69
55.90	1.60	1.72
54.90	1.60	1.75
53.90	1.60	1.77
52.90	1.60	1.80
51.90	1.60	1.82
50.90	1.60	1.85
49.90	1.60	1.87
48.90	1.60	1.90
47.90	1.60	1.93
46.90	1.60	1.95
45.90	1.60	1.98
44.90	1.60	2.00
43.90	1.60	2.03
42.90	1.60	2.05
41.90	1.60	2.08
40.90	1.60	2.11
39.90	1.60	2.13
38.90	1.60	2.16
37.90	1.60	2.18
36.90	1.60	2.21

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
60.00	1.61	1.67	1.88
59.00	1.61	1.65	1.86
58.00	1.61	1.63	1.84
57.00	1.60	1.62	1.82
56.00	1.60	1.60	1.80
55.00	1.60	1.59	1.79
54.00	1.60	1.57	1.77
53.00	1.60	1.56	1.76
52.00	1.60	1.55	1.74
51.00	1.60	1.53	1.73
50.00	1.60	1.52	1.72
49.00	1.60	1.50	1.70
48.00	1.60	1.49	1.69
47.00	1.60	1.48	1.68
46.00	1.60	1.46	1.67
45.00	1.60	1.45	1.65
44.00	1.60	1.44	1.64
43.00	1.60	1.45	1.65
42.00	1.60	1.46	1.67
41.00	1.60	1.48	1.68
40.00	1.60	1.49	1.69
39.00	1.60	1.50	1.70
38.00	1.60	1.52	1.72
37.00	1.60	1.53	1.73
36.00	1.60	1.55	1.74
35.00	1.60	1.56	1.75
34.00	1.60	1.57	1.77
33.00	1.60	1.59	1.78
32.00	1.60	1.60	1.79
31.00	1.60	1.61	1.81

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
62.60	1.29	1.44
61.60	1.26	1.44
60.60	1.24	1.44
59.60	1.21	1.44
58.60	1.19	1.44
57.60	1.17	1.44
56.60	1.14	1.44
55.60	1.12	1.44
54.60	1.09	1.44
53.60	1.07	1.44
52.60	1.05	1.44
51.60	1.02	1.44
50.60	1.00	1.44
49.60	0.97	1.44
48.60	0.95	1.44
47.60	0.92	1.44
46.60	0.90	1.44
45.60	0.88	1.44
44.60	0.85	1.44
43.60	0.83	1.44
42.60	0.80	1.44
41.60	0.78	1.44
40.60	0.76	1.44
39.60	0.73	1.44
38.60	0.71	1.44
37.60	0.68	1.44
36.60	0.66	1.44
35.60	0.64	1.44
34.60	0.61	1.44
33.60	0.59	1.44

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
35.90	1.60	2.24
34.90	1.60	2.26
33.90	1.60	2.29
32.90	1.60	2.31
31.90	1.60	2.34
30.90	1.60	2.37
29.90	1.60	2.39
28.90	1.60	2.42
27.90	1.60	2.44
26.90	1.60	2.47
25.90	1.60	2.50
24.90	1.60	2.52
23.90	1.60	2.55
22.90	1.60	2.58
21.90	1.60	2.60
20.90	1.60	2.63
19.90	1.60	2.66
18.90	1.60	2.68
17.90	1.60	2.71
16.90	1.61	2.74
15.90	1.61	2.76
14.90	1.61	2.79
13.90	1.61	2.82
12.90	1.61	2.85
11.90	1.61	2.87
10.90	1.61	2.90
9.90	1.61	2.93
8.90	1.61	2.96
7.90	1.62	2.99
6.90	1.62	3.01

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
30.00	1.60	1.63	1.82
29.00	1.60	1.64	1.83
28.00	1.60	1.66	1.85
27.00	1.60	1.67	1.86
26.00	1.60	1.68	1.87
25.00	1.60	1.70	1.89
24.00	1.60	1.71	1.90
23.00	1.60	1.72	1.91
22.00	1.60	1.74	1.93
21.00	1.60	1.75	1.94
20.00	1.60	1.77	1.95
19.00	1.60	1.78	1.97
18.00	1.60	1.79	1.98
17.00	1.60	1.81	1.99
16.00	1.60	1.82	2.01
15.00	1.60	1.84	2.02
14.00	1.60	1.85	2.04
13.00	1.60	1.86	2.05
12.00	1.60	1.88	2.07
11.00	1.60	1.89	2.08
10.00	1.60	1.91	2.09
9.00	1.60	1.92	2.11
8.00	1.60	1.93	2.12
7.00	1.60	1.95	2.14
6.00	1.60	1.96	2.15
5.00	1.60	1.98	2.17
4.00	1.60	1.99	2.18
3.00	1.60	2.01	2.20
2.00	1.61	2.02	2.21
1.00	1.61	2.04	2.23

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
32.60	0.56	1.44
31.60	0.54	1.44
30.60	0.52	1.44
29.60	0.49	1.44
28.60	0.47	1.44
27.60	0.44	1.44
26.60	0.42	1.44
25.60	0.40	1.44
24.60	0.37	1.44
23.60	0.35	1.44
22.60	0.33	1.44
21.60	0.30	1.45
20.60	0.28	1.45
19.60	0.26	1.45
18.60	0.23	1.45
17.60	0.21	1.45
16.60	0.19	1.45
15.60	0.17	1.45
14.60	0.14	1.46
13.60	0.12	1.46
12.60	0.10	1.46
11.60	0.08	1.46
10.60	0.06	1.47
9.60	0.03	1.47
8.60	0.01	1.47
7.60	0.00	1.48
6.60	0.00	1.48
5.60	0.00	1.48
4.60	0.00	1.49
3.60	0.00	1.49

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
5.90	1.62	3.05
4.90	1.62	3.07
3.90	1.62	3.10
2.90	1.63	3.13
1.90	1.63	3.16
0.90	1.64	3.19
-0.10	1.64	3.22
-1.10	1.64	3.25
-2.10	1.64	3.28
-3.10	1.65	3.31
-4.10	1.65	3.34
-5.10	1.66	3.37
-6.10	1.66	3.40
-7.10	1.67	3.43
-8.10	1.67	3.46
-9.10	1.68	3.49
-10.10	1.69	3.53
-11.10	1.69	3.56
-12.10	1.70	3.59
-13.10	1.71	3.62
-14.10	1.72	3.66
-15.10	1.73	3.69
-16.10	1.74	3.73
-17.10	1.75	3.76
-18.10	1.76	3.79
-19.10	1.77	3.83
-20.10	1.79	3.87
-21.10	1.80	3.90
-22.10	1.82	3.94
-23.00	1.83	3.97

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
0.00	1.61	2.05	2.25
-1.00	1.61	2.07	2.26
-2.00	1.61	2.08	2.28
-3.00	1.61	2.10	2.29
-4.00	1.61	2.11	2.31
-5.00	1.61	2.13	2.33
-6.00	1.62	2.14	2.34
-7.00	1.62	2.16	2.36
-8.00	1.62	2.18	2.38
-9.00	1.62	2.19	2.39
-10.00	1.63	2.21	2.41
-11.00	1.63	2.23	2.43
-12.00	1.64	2.25	2.44
-13.00	1.64	2.26	2.46
-14.00	1.64	2.28	2.48
-15.00	1.65	2.30	2.50
-16.00	1.66	2.32	2.52
-17.00	1.66	2.34	2.53
-18.00	1.67	2.36	2.55
-19.00	1.68	2.38	2.57
-20.00	1.68	2.41	2.59
-21.00	1.69	2.43	2.61
-22.00	1.70	2.45	2.63
-23.00	1.71	2.48	2.65
-24.00	1.73	2.50	2.67
-25.00	1.74	2.53	2.69
-26.00	1.75	2.55	2.71
-27.00	1.77	2.58	2.73
-28.00	1.78	2.61	2.75
-29.00	1.80	2.64	2.77

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
2.60	0.00	1.50
1.60	0.00	1.51
0.60	0.00	1.51
-0.40	0.00	1.52
-1.40	0.00	1.52
-2.40	0.00	1.53
-3.40	0.00	1.54
-4.40	0.00	1.54
-5.40	0.00	1.55
-6.40	0.00	1.56
-7.40	0.00	1.57
-8.40	0.00	1.58
-9.40	0.00	1.59
-10.40	0.00	1.61
-11.40	0.00	1.62
-12.40	0.00	1.63
-13.40	0.00	1.65
-14.40	0.00	1.66
-15.40	0.00	1.68
-16.40	0.00	1.69
-17.40	0.00	1.71
-18.40	0.00	1.73
-19.40	0.00	1.75
-20.40	0.00	1.77
-21.40	0.00	1.79
-22.40	0.00	1.82
-23.40	0.00	1.84
-24.40	0.00	1.87
-25.40	0.00	1.89
-26.40	0.00	1.92

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
-30.00	1.82	2.67	2.79
-31.00	1.84	2.70	2.81
-32.00	1.86	2.74	2.83
-33.00	1.88	2.77	2.85
-34.00	1.91	2.81	2.87
-35.00	1.94	2.85	2.89
-36.00	1.96	2.88	2.92
-37.00	2.00	2.93	2.94
-38.00	2.03	2.97	2.96
-39.00	2.06	3.01	2.98
-40.00	2.10	3.06	3.01
-41.00	2.14	3.11	3.03
-42.00	2.18	3.16	3.05
-43.00	2.23	3.21	3.08
-44.00	2.28	3.27	3.10
-45.00	2.33	3.33	3.12
-46.00	2.39	3.39	3.15
-47.00	2.45	3.45	3.17
-48.00	2.51	3.52	3.20
-49.00	2.58	3.59	3.22
-50.00	2.65	3.66	3.25
-51.00	2.72	3.73	3.27
-52.00	2.80	3.81	3.30
-53.00	2.88	3.90	3.33
-54.00	2.97	3.98	3.35
-55.00	3.07	4.07	3.38
-56.00	3.17	4.17	3.41
-57.00	3.27	4.26	3.43
-58.00	3.38	4.37	3.46
-59.00	3.50	4.47	3.49

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-27.40	0.00	1.95
-28.40	0.00	1.98
-29.40	0.00	2.02
-30.40	0.00	2.05
-31.40	0.00	2.09
-32.40	0.00	2.13
-33.40	0.00	2.17
-34.40	0.00	2.21
-35.40	0.00	2.25
-36.40	0.00	2.30
-37.40	0.00	2.35
-38.40	0.02	2.40
-39.40	0.07	2.45
-40.40	0.13	2.51
-41.40	0.18	2.57
-42.40	0.24	2.63
-43.40	0.31	2.69
-44.40	0.38	2.76
-45.40	0.46	2.83
-46.40	0.54	2.90
-47.40	0.62	2.98
-48.40	0.71	3.06
-49.40	0.81	3.14
-50.40	0.91	3.22
-51.40	1.02	3.31
-52.40	1.13	3.41
-53.40	1.25	3.50
-54.40	1.38	3.60
-55.40	1.52	3.71
-56.40	1.66	3.82

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
-60.00	3.63	4.59	3.52
-61.00	3.76	4.70	3.55
-62.00	3.89	4.82	3.57
-63.00	4.04	4.95	3.60
-64.00	4.19	5.08	3.63
-65.00	4.35	5.22	3.66
-66.00	4.52	5.37	3.69
-67.00	4.70	5.52	3.72
-68.00	4.89	5.67	3.75
-69.00	5.09	5.84	3.78
-70.00	5.29	6.01	3.81
-71.00	5.51	6.19	3.84
-72.00	5.74	6.37	3.88
-73.00	5.98	6.56	3.91
-74.00	6.23	6.76	3.94
-75.00	6.49	6.97	3.97
-76.00	6.76	7.19	4.01
-77.00	7.05	7.42	4.04
-78.00	7.35	7.65	4.07
-79.00	7.67	7.90	4.11
-80.00	8.00	8.00	4.14

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-57.40	1.81	3.93
-58.40	1.97	4.05
-59.40	2.14	4.17
-60.40	2.31	4.30
-61.40	2.49	4.43
-62.40	2.69	4.57
-63.40	2.89	4.71
-64.40	3.10	4.86
-65.40	3.33	5.01
-66.40	3.56	5.17
-67.40	3.80	5.34
-68.40	4.06	5.51
-69.40	4.33	5.69
-70.40	4.61	5.87
-71.40	4.90	6.06
-72.40	5.20	6.26
-73.40	5.52	6.46
-74.40	5.86	6.67
-75.40	6.20	6.89
-76.40	6.57	7.12
-77.40	6.94	7.35
-78.40	7.34	7.59
-79.40	7.75	7.85
-80.00	8.00	8.00

Appendix C: **LEFT FEMALE SHOULDER JOINT**

Range of Motion of Left Shoulder Joint:	In X direction [-85.0000, 23.0000] In Y direction [-61.0000, 80.0000] In Z direction [-80.0000, 82.0000]
The Neutral Position of Left Shoulder Joint:	[-66.90,-44.00 , 75.60]

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-85.00	8.00	8.00
-84.90	7.59	7.61
-83.90	4.61	4.77
-82.90	3.05	3.26
-81.90	2.27	2.48
-80.90	1.89	2.08
-79.90	1.72	1.89
-78.90	1.65	1.79
-77.90	1.62	1.74
-76.90	1.61	1.70
-75.90	1.60	1.67
-74.90	1.60	1.64
-73.90	1.60	1.62
-72.90	1.60	1.59
-71.90	1.60	1.56
-70.90	1.60	1.54
-69.90	1.60	1.51
-68.90	1.60	1.49
-67.90	1.60	1.46
-66.90	1.60	1.44
-65.90	1.60	1.46
-64.90	1.60	1.49
-63.90	1.60	1.51

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
-80.00	8.00	7.85	3.86
-79.00	6.79	6.74	3.63
-78.00	5.78	5.80	3.42
-77.00	4.94	5.03	3.23
-76.00	4.26	4.38	3.06
-75.00	3.70	3.85	2.91
-74.00	3.24	3.41	2.77
-73.00	2.87	3.06	2.65
-72.00	2.58	2.77	2.54
-71.00	2.35	2.53	2.44
-70.00	2.16	2.34	2.35
-69.00	2.02	2.19	2.28
-68.00	1.91	2.07	2.21
-67.00	1.83	1.98	2.15
-66.00	1.76	1.90	2.09
-65.00	1.71	1.84	2.05
-64.00	1.68	1.79	2.01
-63.00	1.65	1.75	1.97
-62.00	1.64	1.72	1.94
-61.00	1.62	1.69	1.91
-60.00	1.61	1.67	1.88
-59.00	1.61	1.65	1.86
-58.00	1.61	1.63	1.84

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
82.00	1.45	1.44
81.60	1.46	1.44
80.60	1.48	1.44
79.60	1.50	1.44
78.60	1.53	1.44
77.60	1.55	1.44
76.60	1.58	1.44
75.60	1.60	1.44
74.60	1.58	1.44
73.60	1.55	1.44
72.60	1.53	1.44
71.60	1.50	1.44
70.60	1.48	1.44
69.60	1.46	1.44
68.60	1.43	1.44
67.60	1.41	1.44
66.60	1.38	1.44
65.60	1.36	1.44
64.60	1.33	1.44
63.60	1.31	1.44
62.60	1.29	1.44
61.60	1.26	1.44
60.60	1.24	1.44

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-62.90	1.60	1.54
-61.90	1.60	1.56
-60.90	1.60	1.59
-59.90	1.60	1.62
-58.90	1.60	1.64
-57.90	1.60	1.67
-56.90	1.60	1.69
-55.90	1.60	1.72
-54.90	1.60	1.75
-53.90	1.60	1.77
-52.90	1.60	1.80
-51.90	1.60	1.82
-50.90	1.60	1.85
-49.90	1.60	1.87
-48.90	1.60	1.90
-47.90	1.60	1.93
-46.90	1.60	1.95
-45.90	1.60	1.98
-44.90	1.60	2.00
-43.90	1.60	2.03
-42.90	1.60	2.05
-41.90	1.60	2.08
-40.90	1.60	2.11
-39.90	1.60	2.13
-38.90	1.60	2.16
-37.90	1.60	2.18
-36.90	1.60	2.21
-35.90	1.60	2.24
-34.90	1.60	2.26
-33.90	1.60	2.29

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
-57.00	1.60	1.62	1.82
-56.00	1.60	1.60	1.8
-55.00	1.60	1.59	1.79
-54.00	1.60	1.57	1.77
-53.00	1.60	1.56	1.76
-52.00	1.60	1.55	1.74
-51.00	1.60	1.53	1.73
-50.00	1.60	1.52	1.72
-49.00	1.60	1.50	1.7
-48.00	1.60	1.49	1.69
-47.00	1.60	1.48	1.68
-46.00	1.60	1.46	1.67
-45.00	1.60	1.45	1.65
-44.00	1.60	1.44	1.64
-43.00	1.60	1.45	1.65
-42.00	1.60	1.46	1.67
-41.00	1.60	1.48	1.68
-40.00	1.60	1.49	1.69
-39.00	1.60	1.50	1.7
-38.00	1.60	1.52	1.72
-37.00	1.60	1.53	1.73
-36.00	1.60	1.55	1.74
-35.00	1.60	1.56	1.75
-34.00	1.60	1.57	1.77
-33.00	1.60	1.59	1.78
-32.00	1.60	1.60	1.79
-31.00	1.60	1.61	1.81
-30.00	1.60	1.63	1.82
-29.00	1.60	1.64	1.83
-28.00	1.60	1.66	1.85

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
59.60	1.21	1.44
58.60	1.19	1.44
57.60	1.17	1.44
56.60	1.14	1.44
55.60	1.12	1.44
54.60	1.09	1.44
53.60	1.07	1.44
52.60	1.05	1.44
51.60	1.02	1.44
50.60	1.00	1.44
49.60	0.97	1.44
48.60	0.95	1.44
47.60	0.92	1.44
46.60	0.90	1.44
45.60	0.88	1.44
44.60	0.85	1.44
43.60	0.83	1.44
42.60	0.80	1.44
41.60	0.78	1.44
40.60	0.76	1.44
39.60	0.73	1.44
38.60	0.71	1.44
37.60	0.68	1.44
36.60	0.66	1.44
35.60	0.64	1.44
34.60	0.61	1.44
33.60	0.59	1.44
32.60	0.56	1.44
31.60	0.54	1.44
30.60	0.52	1.44

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-32.90	1.60	2.31
-31.90	1.60	2.34
-30.90	1.60	2.37
-29.90	1.60	2.39
-28.90	1.60	2.42
-27.90	1.60	2.44
-26.90	1.60	2.47
-25.90	1.60	2.50
-24.90	1.60	2.52
-23.90	1.60	2.55
-22.90	1.60	2.58
-21.90	1.60	2.60
-20.90	1.60	2.63
-19.90	1.60	2.66
-18.90	1.60	2.68
-17.90	1.60	2.71
-16.90	1.61	2.74
-15.90	1.61	2.76
-14.90	1.61	2.79
-13.90	1.61	2.82
-12.90	1.61	2.85
-11.90	1.61	2.87
-10.90	1.61	2.90
-9.90	1.61	2.93
-8.90	1.61	2.96
-7.90	1.62	2.99
-6.90	1.62	3.01
-5.90	1.62	3.04
-4.90	1.62	3.07
-3.90	1.62	3.10

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
-27.00	1.60	1.67	1.86
-26.00	1.60	1.68	1.87
-25.00	1.60	1.70	1.89
-24.00	1.60	1.71	1.9
-23.00	1.60	1.72	1.91
-22.00	1.60	1.74	1.93
-21.00	1.60	1.75	1.94
-20.00	1.60	1.77	1.95
-19.00	1.60	1.78	1.97
-18.00	1.60	1.79	1.98
-17.00	1.60	1.81	1.99
-16.00	1.60	1.82	2.01
-15.00	1.60	1.84	2.02
-14.00	1.60	1.85	2.04
-13.00	1.60	1.86	2.05
-12.00	1.60	1.88	2.07
-11.00	1.60	1.89	2.08
-10.00	1.60	1.91	2.09
-9.00	1.60	1.92	2.11
-8.00	1.60	1.93	2.12
-7.00	1.60	1.95	2.14
-6.00	1.60	1.96	2.15
-5.00	1.60	1.98	2.17
-4.00	1.60	1.99	2.18
-3.00	1.60	2.01	2.2
-2.00	1.61	2.02	2.21
-1.00	1.61	2.04	2.23
0.00	1.61	2.05	2.25
1.00	1.61	2.07	2.26
2.00	1.61	2.08	2.28

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
29.60	0.49	1.44
28.60	0.47	1.44
27.60	0.44	1.44
26.60	0.42	1.44
25.60	0.40	1.44
24.60	0.37	1.44
23.60	0.35	1.44
22.60	0.33	1.44
21.60	0.30	1.45
20.60	0.28	1.45
19.60	0.26	1.45
18.60	0.23	1.45
17.60	0.21	1.45
16.60	0.19	1.45
15.60	0.17	1.45
14.60	0.14	1.46
13.60	0.12	1.46
12.60	0.10	1.46
11.60	0.08	1.46
10.60	0.06	1.47
9.60	0.03	1.47
8.60	0.01	1.47
7.60	0.00	1.48
6.60	0.00	1.48
5.60	0.00	1.48
4.60	0.00	1.49
3.60	0.00	1.49
2.60	0.00	1.50
1.60	0.00	1.51
0.60	0.00	1.51

X(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-2.90	1.63	3.13
-1.90	1.63	3.16
-0.90	1.63	3.19
0.10	1.64	3.22
1.10	1.64	3.25
2.10	1.64	3.28
3.10	1.65	3.31
4.10	1.65	3.34
5.10	1.66	3.37
6.10	1.66	3.40
7.10	1.67	3.43
8.10	1.67	3.46
9.10	1.68	3.49
10.10	1.69	3.53
11.10	1.69	3.56
12.10	1.70	3.59
13.10	1.71	3.62
14.10	1.72	3.66
15.10	1.73	3.69
16.10	1.74	3.73
17.10	1.75	3.76
18.10	1.76	3.79
19.10	1.77	3.83
20.10	1.79	3.87
21.10	1.80	3.90
22.10	1.82	3.94
23.00	1.83	3.97

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
3.00	1.61	2.10	2.29
4.00	1.61	2.11	2.31
5.00	1.61	2.13	2.33
6.00	1.62	2.14	2.34
7.00	1.62	2.16	2.36
8.00	1.62	2.18	2.38
9.00	1.62	2.19	2.39
10.00	1.63	2.21	2.41
11.00	1.63	2.23	2.43
12.00	1.64	2.25	2.44
13.00	1.64	2.26	2.46
14.00	1.64	2.28	2.48
15.00	1.65	2.30	2.5
16.00	1.66	2.32	2.52
17.00	1.66	2.34	2.53
18.00	1.67	2.36	2.55
19.00	1.68	2.38	2.57
20.00	1.68	2.41	2.59
21.00	1.69	2.43	2.61
22.00	1.70	2.45	2.63
23.00	1.71	2.48	2.65
24.00	1.73	2.50	2.67
25.00	1.74	2.53	2.69
26.00	1.75	2.55	2.71
27.00	1.77	2.58	2.73
28.00	1.78	2.61	2.75
29.00	1.80	2.64	2.77
30.00	1.82	2.67	2.79
31.00	1.84	2.70	2.81
32.00	1.86	2.74	2.83

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-0.40	0.00	1.52
-1.40	0.00	1.52
-2.40	0.00	1.53
-3.40	0.00	1.54
-4.40	0.00	1.54
-5.40	0.00	1.55
-6.40	0.00	1.56
-7.40	0.00	1.57
-8.40	0.00	1.58
-9.40	0.00	1.59
-10.40	0.00	1.61
-11.40	0.00	1.62
-12.40	0.00	1.63
-13.40	0.00	1.65
-14.40	0.00	1.66
-15.40	0.00	1.68
-16.40	0.00	1.69
-17.40	0.00	1.71
-18.40	0.00	1.73
-19.40	0.00	1.75
-20.40	0.00	1.77
-21.40	0.00	1.79
-22.40	0.00	1.82
-23.40	0.00	1.84
-24.40	0.00	1.87
-25.40	0.00	1.89
-26.40	0.00	1.92
-27.40	0.00	1.95
-28.40	0.00	1.98
-29.40	0.00	2.02

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
33.00	1.88	2.77	2.85
34.00	1.91	2.81	2.87
35.00	1.94	2.85	2.89
36.00	1.96	2.88	2.92
37.00	2.00	2.93	2.94
38.00	2.03	2.97	2.96
39.00	2.06	3.01	2.98
40.00	2.10	3.06	3.01
41.00	2.14	3.11	3.03
42.00	2.18	3.16	3.05
43.00	2.23	3.21	3.08
44.00	2.28	3.27	3.1
45.00	2.33	3.33	3.12
46.00	2.39	3.39	3.15
47.00	2.45	3.45	3.17
48.00	2.51	3.52	3.2
49.00	2.58	3.59	3.22
50.00	2.65	3.66	3.25
51.00	2.72	3.73	3.27
52.00	2.80	3.81	3.3
53.00	2.88	3.90	3.33
54.00	2.97	3.98	3.35
55.00	3.07	4.07	3.38
56.00	3.17	4.17	3.41
57.00	3.27	4.26	3.43
58.00	3.38	4.37	3.46
59.00	3.50	4.47	3.49
60.00	3.63	4.59	3.52
61.00	3.76	4.70	3.55
62.00	3.89	4.82	3.57

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-30.40	0.00	2.05
-31.40	0.00	2.09
-32.40	0.00	2.13
-33.40	0.00	2.17
-34.40	0.00	2.21
-35.40	0.00	2.25
-36.40	0.00	2.30
-37.40	0.00	2.35
-38.40	0.02	2.40
-39.40	0.07	2.45
-40.40	0.13	2.51
-41.40	0.18	2.57
-42.40	0.24	2.63
-43.40	0.31	2.69
-44.40	0.38	2.76
-45.40	0.46	2.83
-46.40	0.54	2.90
-47.40	0.62	2.98
-48.40	0.71	3.06
-49.40	0.81	3.14
-50.40	0.91	3.22
-51.40	1.02	3.31
-52.40	1.13	3.41
-53.40	1.25	3.50
-54.40	1.38	3.60
-55.40	1.52	3.71
-56.40	1.66	3.82
-57.40	1.81	3.93
-58.40	1.97	4.05
-59.40	2.14	4.17

Y(degrees)	Discomfort feeling out of 8		
	Right Arm	Shoulders	Neck
63.00	4.04	4.95	3.6
64.00	4.19	5.08	3.63
65.00	4.35	5.22	3.66
66.00	4.52	5.37	3.69
67.00	4.70	5.52	3.72
68.00	4.89	5.67	3.75
69.00	5.09	5.84	3.78
70.00	5.29	6.01	3.81
71.00	5.51	6.19	3.84
72.00	5.74	6.37	3.88
73.00	5.98	6.56	3.91
74.00	6.23	6.76	3.94
75.00	6.49	6.97	3.97
76.00	6.76	7.19	4.01
77.00	7.05	7.42	4.04
78.00	7.35	7.65	4.07
79.00	7.67	7.90	4.11
80.00	8.00	8.00	4.14

Z(degrees)	Discomfort feeling out of 8	
	Right Arm	Shoulders
-60.40	2.31	4.30
-61.40	2.49	4.43
-62.40	2.69	4.57
-63.40	2.89	4.71
-64.40	3.10	4.86
-65.40	3.33	5.01
-66.40	3.56	5.17
-67.40	3.80	5.34
-68.40	4.06	5.51
-69.40	4.33	5.69
-70.40	4.61	5.87
-71.40	4.90	6.06
-72.40	5.20	6.26
-73.40	5.52	6.46
-74.40	5.86	6.67
-75.40	6.20	6.89
-76.40	6.57	7.12
-77.40	6.94	7.35
-78.40	7.34	7.59
-79.40	7.75	7.85
-80.00	8.00	8.00

Appendix C: **RIGHT MALE AND FEMALE ELBOW JOINT**

Range of Motion of Right Elbow Joint:	In X direction [-100.0000, 80.0000] In Y direction [-145.0000, 0.0000] In Z direction [0, 0]
The Neutral Position of Right Elbow Joint:	[-4.6, -58.5, 0.0◦]

X(degrees)	Discomfort Feeling Right Arm (out of 8)
80.00	8.00
79.40	7.62
78.40	6.83
77.40	6.14
76.40	5.53
75.40	5.00
74.40	4.55
73.40	4.15
72.40	3.66
71.40	3.36
70.40	3.10
69.40	2.88
68.40	2.68
67.40	2.52
66.40	2.37
65.40	2.25
64.40	2.15
63.40	2.06
62.40	1.99
61.40	1.92
60.40	1.87
59.40	1.82
58.40	1.78

Y(degrees)	Discomfort Feeling Right Arm (out of 8)
-145.00	8.00
-144.50	7.71
-143.50	7.55
-142.50	7.40
-141.50	7.25
-140.50	7.10
-139.50	6.96
-138.50	6.83
-137.50	6.70
-136.50	5.57
-135.50	6.44
-134.50	6.32
-133.50	6.21
-132.50	6.09
-131.50	5.98
-130.50	5.88
-129.50	5.77
-128.50	5.67
-127.50	5.57
-126.50	5.48
-125.50	5.39
-124.50	5.30
-123.50	5.21

X(degrees)	Discomfort Feeling Right Arm (out of 8)
57.40	1.75
56.40	1.72
55.40	1.70
54.40	1.68
53.40	1.67
52.40	1.65
51.40	1.64
50.40	1.64
49.40	1.63
48.40	1.62
47.40	1.62
46.40	1.61
45.40	1.61
44.40	1.61
43.40	1.61
42.40	1.61
41.40	1.60
40.40	1.60
39.40	1.60
38.40	1.60
37.40	1.60
36.40	1.60
35.40	1.60
34.40	1.60
33.40	1.60
32.40	1.60
31.40	1.60
30.40	1.60
29.40	1.60
28.40	1.60
27.40	1.60

Y(degrees)	Discomfort Feeling Right Arm (out of 8)
-122.50	5.12
-121.50	5.04
-120.50	4.96
-119.50	4.88
-118.50	4.80
-117.50	4.72
-116.50	4.65
-115.50	4.58
-114.50	4.51
-113.50	4.44
-112.50	4.37
-111.50	4.30
-110.50	4.24
-109.50	4.17
-108.50	4.11
-107.50	4.05
-106.50	3.99
-105.50	3.93
-104.50	3.87
-103.50	3.81
-102.50	3.76
-101.50	3.70
-100.50	3.65
-99.50	3.59
-98.50	3.54
-97.50	3.49
-96.50	3.43
-95.50	3.38
-94.50	3.33
-93.50	3.28
-92.50	3.23

X(degrees)	Discomfort Feeling Right Arm (out of 8)
26.40	1.60
25.40	1.60
24.40	1.60
23.40	1.60
22.40	1.60
21.40	1.60
20.40	1.60
19.40	1.60
18.40	1.60
17.40	1.60
16.40	1.60
15.40	1.60
14.40	1.60
13.40	1.60
12.40	1.60
11.40	1.60
10.40	1.60
9.40	1.60
8.40	1.60
7.40	1.60
6.40	1.60
5.40	1.60
4.40	1.60
3.40	1.60
2.40	1.60
1.40	1.60
0.40	1.60
-0.60	1.60
-1.60	1.60
-2.60	1.60
-3.60	1.60

Y(degrees)	Discomfort Feeling Right Arm (out of 8)
-91.50	3.18
-90.50	3.13
-89.50	3.08
-88.50	3.03
-87.50	2.98
-86.50	2.93
-85.50	2.88
-84.50	2.83
-83.50	2.78
-82.50	2.74
-81.50	2.69
-80.50	2.64
-79.50	2.59
-78.50	2.54
-77.50	2.50
-76.50	2.45
-75.50	2.40
-74.50	2.36
-73.50	2.31
-72.50	2.26
-71.50	2.21
-70.50	2.17
-69.50	2.12
-68.50	2.07
-67.50	2.02
-66.50	1.98
-65.50	1.93
-64.50	1.88
-63.50	1.84
-62.50	1.79
-61.50	1.74

X(degrees)	Discomfort Feeling Right Arm (out of 8)
-4.60	1.60
-5.60	1.60
-6.60	1.60
-7.60	1.60
-8.60	1.60
-9.60	1.60
-10.60	1.60
-11.60	1.60
-12.60	1.60
-13.60	1.60
-14.60	1.60
-15.60	1.60
-16.60	1.60
-17.60	1.60
-18.60	1.60
-19.60	1.60
-20.60	1.60
-21.60	1.60
-22.60	1.60
-23.60	1.60
-24.60	1.60
-25.60	1.60
-26.60	1.60
-27.60	1.60
-28.60	1.60
-29.60	1.60
-30.60	1.60
-31.60	1.60
-32.60	1.60
-33.60	1.60
-34.60	1.60

Y(degrees)	Discomfort Feeling Right Arm (out of 8)
-60.50	1.69
-59.50	1.65
-58.50	1.60
-57.50	1.65
-56.50	1.69
-55.50	1.74
-54.50	1.79
-53.50	1.84
-52.50	1.88
-51.50	1.93
-50.50	1.98
-49.50	2.02
-48.50	2.07
-47.50	2.12
-46.50	2.17
-45.50	2.21
-44.50	2.26
-43.50	2.31
-42.50	2.35
-41.50	2.40
-40.50	2.45
-39.50	2.50
-38.50	2.54
-37.50	2.59
-36.50	2.64
-35.50	2.68
-34.50	2.73
-33.50	2.78
-32.50	2.83
-31.50	2.87
-30.50	2.92

X(degrees)	Discomfort Feeling Right Arm (out of 8)
-35.60	1.60
-36.60	1.60
-37.60	1.60
-38.60	1.60
-39.60	1.60
-40.60	1.60
-41.60	1.60
-42.60	1.60
-43.60	1.60
-44.60	1.60
-45.60	1.60
-46.60	1.60
-47.60	1.60
-48.60	1.60
-49.60	1.60
-50.60	1.60
-51.60	1.60
-52.60	1.60
-53.60	1.60
-54.60	1.60
-55.60	1.60
-56.60	1.60
-57.60	1.61
-58.60	1.61
-59.60	1.61
-60.60	1.61
-61.60	1.61
-62.60	1.62
-63.60	1.62
-64.60	1.62
-65.60	1.63

Y(degrees)	Discomfort Feeling Right Arm (out of 8)
-29.50	2.97
-28.50	3.02
-27.50	3.07
-26.50	3.12
-25.50	3.17
-24.50	3.22
-23.50	3.27
-22.50	3.32
-21.50	3.38
-20.50	3.44
-19.50	3.50
-18.50	3.56
-17.50	3.63
-16.50	3.71
-15.50	3.79
-14.50	3.88
-13.50	3.98
-12.50	4.09
-11.50	4.22
-10.50	4.37
-9.50	4.53
-8.50	4.72
-7.50	4.94
-6.50	5.20
-5.50	5.50
-4.50	5.84
-3.50	6.24
-2.50	6.70
-1.50	7.24
-0.50	7.86
0.00	8.00

X(degrees)	Discomfort Feeling Right Arm (out of 8)
-66.60	1.64
-67.60	1.64
-68.60	1.65
-69.60	1.66
-70.60	1.68
-71.60	1.69
-72.60	1.71
-73.60	1.73
-74.60	1.75
-75.60	1.78
-76.60	1.82
-77.60	1.85
-78.60	1.90
-79.60	1.95
-80.60	2.01
-81.60	2.08
-82.60	2.17
-83.60	2.26
-84.60	2.37
-85.60	2.49
-86.60	2.63
-87.60	2.80
-88.60	2.98
-89.60	3.19
-90.60	3.43
-91.60	3.71
-92.60	4.02
-93.60	4.37
-94.60	4.77
-95.60	5.22
-96.60	5.73

X(degrees)	Discomfort Feeling Right Arm (out of 8)
-97.60	6.31
-98.60	6.96
-99.60	7.68
-100.00	8.00

Appendix C: **LEFT MALE AND FEMALE ELBOW JOINT**

Range of Motion of Left Elbow Joint:	In X direction [-80.0000, 100.0000] In Y direction [-145.0000, 0.0000] In Z direction [0, 0]
The Neutral Position of Left Elbow Joint:	[4.6, -58.5, 0.0◦]

X(degrees)	Discomfort Feeling Left Arm (out of 8)
-80.00	8.00
-79.40	7.47
-78.40	6.68
-77.40	5.99
-76.40	5.39
-75.40	4.86
-74.40	4.40
-73.40	4.01
-72.40	3.66
-71.40	3.36
-70.40	3.10
-69.40	2.88
-68.40	2.68
-67.40	2.52
-66.40	2.37
-65.40	2.25
-64.40	2.15
-63.40	2.06
-62.40	1.99
-61.40	1.92
-60.40	1.87
-59.40	1.82

Y(degrees)	Discomfort Feeling Left Arm (out of 8)
-145.00	8.00
-144.50	7.71
-143.50	7.55
-142.50	7.39
-141.50	7.24
-140.50	7.10
-139.50	6.96
-138.50	6.83
-137.50	6.70
-136.50	5.57
-135.50	6.44
-134.50	6.32
-133.50	6.21
-132.50	6.09
-131.50	5.98
-130.50	5.88
-129.50	5.77
-128.50	5.67
-127.50	5.57
-126.50	5.48
-125.50	5.39
-124.50	5.30

X(degrees)	Discomfort Feeling Left Arm (out of 8)
-58.40	1.78
-57.40	1.75
-56.40	1.72
-55.40	1.70
-54.40	1.68
-53.40	1.67
-52.40	1.65
-51.40	1.64
-50.40	1.64
-49.40	1.63
-48.40	1.62
-47.40	1.62
-46.40	1.61
-45.40	1.61
-44.40	1.61
-43.40	1.61
-42.40	1.61
-41.40	1.60
-40.40	1.60
-39.40	1.60
-38.40	1.60
-37.40	1.60
-36.40	1.60
-35.40	1.60
-34.40	1.60
-33.40	1.60
-32.40	1.60
-31.40	1.60
-30.40	1.60
-29.40	1.60
-28.40	1.60

Y(degrees)	Discomfort Feeling Left Arm (out of 8)
-123.50	5.21
-122.50	5.12
-121.50	5.04
-120.50	4.96
-119.50	4.88
-118.50	4.80
-117.50	4.72
-116.50	4.65
-115.50	4.58
-114.50	4.51
-113.50	4.44
-112.50	4.37
-111.50	4.30
-110.50	4.24
-109.50	4.17
-108.50	4.11
-107.50	4.05
-106.50	3.99
-105.50	3.93
-104.50	3.87
-103.50	3.81
-102.50	3.76
-101.50	3.70
-100.50	3.65
-99.50	3.59
-98.50	3.54
-97.50	3.49
-96.50	3.43
-95.50	3.38
-94.50	3.33
-93.50	3.28

X(degrees)	Discomfort Feeling Left Arm (out of 8)
-27.40	1.60
-26.40	1.60
-25.40	1.60
-24.40	1.60
-23.40	1.60
-22.40	1.60
-21.40	1.60
-20.40	1.60
-19.40	1.60
-18.40	1.60
-17.40	1.60
-16.40	1.60
-15.40	1.60
-14.40	1.60
-13.40	1.60
-12.40	1.60
-11.40	1.60
-10.40	1.60
-9.40	1.60
-8.40	1.60
-7.40	1.60
-6.40	1.60
-5.40	1.60
-4.40	1.60
-3.40	1.60
-2.40	1.60
-1.40	1.60
-0.40	1.60
0.60	1.60
1.60	1.60
2.60	1.60

Y(degrees)	Discomfort Feeling Left Arm (out of 8)
-92.50	3.23
-91.50	3.18
-90.50	3.13
-89.50	3.08
-88.50	3.03
-87.50	2.98
-86.50	2.93
-85.50	2.88
-84.50	2.83
-83.50	2.78
-82.50	2.74
-81.50	2.69
-80.50	2.64
-79.50	2.59
-78.50	2.54
-77.50	2.50
-76.50	2.45
-75.50	2.40
-74.50	2.36
-73.50	2.31
-72.50	2.26
-71.50	2.21
-70.50	2.17
-69.50	2.12
-68.50	2.07
-67.50	2.02
-66.50	1.98
-65.50	1.93
-64.50	1.88
-63.50	1.84
-62.50	1.79

X(degrees)	Discomfort Feeling Left Arm (out of 8)
3.60	1.60
4.60	1.60
5.60	1.60
6.60	1.60
7.60	1.60
8.60	1.60
9.60	1.60
10.60	1.60
11.60	1.60
12.60	1.60
13.60	1.60
14.60	1.60
15.60	1.60
16.60	1.60
17.60	1.60
18.60	1.60
19.60	1.60
20.60	1.60
21.60	1.60
22.60	1.60
23.60	1.60
24.60	1.60
25.60	1.60
26.60	1.60
27.60	1.60
28.60	1.60
29.60	1.60
30.60	1.60
31.60	1.60
32.60	1.60
33.60	1.60

Y(degrees)	Discomfort Feeling Left Arm (out of 8)
-61.50	1.74
-60.50	1.69
-59.50	1.65
-58.50	1.60
-57.50	1.65
-56.50	1.69
-55.50	1.74
-54.50	1.79
-53.50	1.84
-52.50	1.88
-51.50	1.93
-50.50	1.98
-49.50	2.02
-48.50	2.07
-47.50	2.12
-46.50	2.17
-45.50	2.21
-44.50	2.26
-43.50	2.31
-42.50	2.35
-41.50	2.40
-40.50	2.45
-39.50	2.50
-38.50	2.54
-37.50	2.59
-36.50	2.64
-35.50	2.68
-34.50	2.73
-33.50	2.78
-32.50	2.83
-31.50	2.87

X(degrees)	Discomfort Feeling Left Arm (out of 8)
34.60	1.60
35.60	1.60
36.60	1.60
37.60	1.60
38.60	1.60
39.60	1.60
40.60	1.60
41.60	1.60
42.60	1.60
43.60	1.60
44.60	1.60
45.60	1.60
46.60	1.60
47.60	1.60
48.60	1.60
49.60	1.60
50.60	1.60
51.60	1.60
52.60	1.60
53.60	1.60
54.60	1.60
55.60	1.60
56.60	1.60
57.60	1.61
58.60	1.61
59.60	1.61
60.60	1.61
61.60	1.61
62.60	1.62
63.60	1.62
64.60	1.62

Y(degrees)	Discomfort Feeling Left Arm (out of 8)
-30.50	2.92
-29.50	2.97
-28.50	3.02
-27.50	3.07
-26.50	3.12
-25.50	3.17
-24.50	3.22
-23.50	3.27
-22.50	3.32
-21.50	3.38
-20.50	3.44
-19.50	3.50
-18.50	3.56
-17.50	3.63
-16.50	3.71
-15.50	3.79
-14.50	3.88
-13.50	3.98
-12.50	4.09
-11.50	4.22
-10.50	4.37
-9.50	4.53
-8.50	4.72
-7.50	4.94
-6.50	5.20
-5.50	5.50
-4.50	5.84
-3.50	6.24
-2.50	6.70
-1.50	7.24
-0.50	7.86

X(degrees)	Discomfort Feeling Left Arm (out of 8)
65.60	1.63
66.60	1.64
67.60	1.64
68.60	1.65
69.60	1.66
70.60	1.68
71.60	1.69
72.60	1.71
73.60	1.73
74.60	1.75
75.60	1.78
76.60	1.82
77.60	1.85
78.60	1.90
79.60	1.95
80.60	2.01
81.60	2.08
82.60	2.17
83.60	2.26
84.60	2.37
85.60	2.49
86.60	2.63
87.60	2.80
88.60	2.98
89.60	3.19
90.60	3.43
91.60	3.71
92.60	4.02
93.60	4.37
94.60	4.77
95.60	5.22

Y(degrees)	Discomfort Feeling Left Arm (out of 8)
0.00	8.00

X(degrees)	Discomfort Feeling Left Arm (out of 8)
96.60	5.73
97.60	6.31
98.60	6.96
99.60	7.68
100.00	8.00

Appendix C: **RIGHT MALE AND FEMALE WRIST JOINT**

Range of Motion of Right Wrist Joint:	In X direction [0.0000, 0.0000] In Y direction [-80.0000,80.0000] In Z direction [-45.0000, 23.0000]
The Neutral Position of Right Wrist Joint:	[0.0, -6.6, -5.5]

Y(degrees)	Discomfort Feeling Right Arm (out of 8)
-80.00	8.00
-79.60	7.80
-78.60	7.32
-77.60	6.88
-76.60	6.46
-75.60	6.07
-74.60	5.71
-73.60	5.37
-72.60	5.06
-71.60	4.76
-70.60	4.49
-69.60	4.24
-68.60	4.01
-67.60	3.79
-66.60	3.59
-65.60	3.40
-64.60	3.23
-63.60	3.08
-62.60	2.93
-61.60	2.80
-60.60	2.68
-59.60	2.57

Z(degrees)	Discomfort Feeling Right Arm (out of 8)
-45.00	8.00
-44.50	7.80
-43.50	7.40
-42.50	7.03
-41.50	6.66
-40.50	6.32
-39.50	5.98
-38.50	5.66
-37.50	5.36
-36.50	5.07
-35.50	4.79
-34.50	4.53
-33.50	4.28
-32.50	4.05
-31.50	3.83
-30.50	3.62
-29.50	3.42
-28.50	3.23
-27.50	3.06
-26.50	2.90
-25.50	2.75
-24.50	2.61

Y(degrees)	Discomfort Feeling Right Arm (out of 8)
-58.60	2.47
-57.60	2.38
-56.60	2.29
-55.60	2.21
-54.60	2.15
-53.60	2.08
-52.60	2.03
-51.60	1.98
-50.60	1.93
-49.60	1.89
-48.60	1.85
-47.60	1.82
-46.60	1.79
-45.60	1.76
-44.60	1.74
-43.60	1.72
-42.60	1.70
-41.60	1.69
-40.60	1.67
-39.60	1.66
-38.60	1.65
-37.60	1.64
-36.60	1.64
-35.60	1.63
-34.60	1.62
-33.60	1.62
-32.60	1.62
-31.60	1.61
-30.60	1.61
-29.60	1.61
-28.60	1.61

Z(degrees)	Discomfort Feeling Right Arm (out of 8)
-23.50	2.48
-22.50	2.36
-21.50	2.25
-20.50	2.15
-19.50	2.07
-18.50	1.99
-17.50	1.92
-16.50	1.85
-15.50	1.80
-14.50	1.75
-13.50	1.71
-12.50	1.68
-11.50	1.65
-10.50	1.63
-9.50	1.62
-8.50	1.60
-7.50	1.60
-6.50	1.60
-5.50	1.60
-4.50	1.60
-3.50	1.60
-2.50	1.60
-1.50	1.60
-0.50	1.60
0.50	1.60
1.50	1.60
2.50	1.60
3.50	1.60
4.50	1.60
5.50	1.60
6.50	1.60

Y(degrees)	Discomfort Feeling Right Arm (out of 8)
-27.60	1.60
-26.60	1.60
-25.60	1.60
-24.60	1.60
-23.60	1.60
-22.60	1.60
-21.60	1.60
-20.60	1.60
-19.60	1.60
-18.60	1.60
-17.60	1.60
-16.60	1.60
-15.60	1.60
-14.60	1.60
-13.60	1.60
-12.60	1.60
-11.60	1.60
-10.60	1.60
-9.60	1.60
-8.60	1.60
-7.60	1.60
-6.60	1.60
-5.60	1.60
-4.60	1.60
-3.60	1.60
-2.60	1.60
-1.60	1.60
-0.60	1.60
0.40	1.60
1.40	1.60
2.40	1.60

Z(degrees)	Discomfort Feeling Right Arm (out of 8)
7.50	1.60
8.50	1.60
9.50	1.60
10.50	1.61
11.50	1.61
12.50	1.63
13.50	1.65
14.50	1.69
15.50	1.76
16.50	1.88
17.50	2.08
18.50	2.41
19.50	2.92
20.50	3.72
21.50	4.94
22.50	6.77
23.00	8.00

Y(degrees)	Discomfort Feeling Right Arm (out of 8)
3.40	1.60
4.40	1.60
5.40	1.60
6.40	1.60
7.40	1.60
8.40	1.60
9.40	1.60
10.40	1.60
11.40	1.60
12.40	1.60
13.40	1.60
14.40	1.60
15.40	1.60
16.40	1.60
17.40	1.60
18.40	1.60
19.40	1.61
20.40	1.61
21.40	1.61
22.40	1.61
23.40	1.61
24.40	1.62
25.40	1.62
26.40	1.62
27.40	1.63
28.40	1.63
29.40	1.64
30.40	1.65
31.40	1.65
32.40	1.66
33.40	1.67

Y(degrees)	Discomfort Feeling Right Arm (out of 8)
34.40	1.68
35.40	1.70
36.40	1.71
37.40	1.73
38.40	1.74
39.40	1.76
40.40	1.79
41.40	1.81
42.40	1.84
43.40	1.87
44.40	1.90
45.40	1.93
46.40	1.97
47.40	2.01
48.40	2.06
49.40	2.11
50.40	2.17
51.40	2.23
52.40	2.29
53.40	2.36
54.40	2.44
55.40	2.52
56.40	2.61
57.40	2.71
58.40	2.81
59.40	2.93
60.40	3.05
61.40	3.18
62.40	3.31
63.40	3.46
64.40	3.62

Y(degrees)	Discomfort Feeling Right Arm (out of 8)
65.40	3.79
66.40	3.98
67.40	4.17
68.40	4.38
69.40	4.60
70.40	4.84
71.40	5.09
72.40	5.36
73.40	5.64
74.40	5.94
75.40	6.26
76.40	6.60
77.40	6.96
78.40	7.34
79.40	7.75
80.00	8.00

Appendix C: **LEFT MALE AND FEMALE WRIST JOINT**

Range of Motion of Left Wrist Joint:	In X direction [0.0000, 0.0000] In Y direction [-80.0000,80.0000] In Z direction [-45.0000, 23.0000]
The Neutral Position of Left Wrist Joint:	[0.0, 6.6, -5.5]

Y(degrees)	Discomfort Feeling Left Arm (out of 8)
-80.00	8.00
-79.40	7.75
-78.40	7.34
-77.40	6.96
-76.40	6.60
-75.40	6.26
-74.40	5.94
-73.40	5.64
-72.40	5.36
-71.40	5.09
-70.40	4.84
-69.40	4.60
-68.40	4.38
-67.40	4.17
-66.40	3.98
-65.40	3.79
-64.40	3.62
-63.40	3.46
-62.40	3.31
-61.40	3.18
-60.40	3.05
-59.40	2.93

Z(degrees)	Discomfort Feeling Left Arm (out of 8)
-45.00	8.00
-44.50	7.80
-43.50	7.40
-42.50	7.03
-41.50	6.66
-40.50	6.32
-39.50	5.98
-38.50	5.66
-37.50	5.36
-36.50	5.07
-35.50	4.79
-34.50	4.53
-33.50	4.28
-32.50	4.05
-31.50	3.83
-30.50	3.62
-29.50	3.42
-28.50	3.23
-27.50	3.06
-26.50	2.90
-25.50	2.75
-24.50	2.61

Y(degrees)	Discomfort Feeling Left Arm (out of 8)
-58.40	2.81
-57.40	2.71
-56.40	2.61
-55.40	2.52
-54.40	2.44
-53.40	2.36
-52.40	2.29
-51.40	2.23
-50.40	2.17
-49.40	2.11
-48.40	2.06
-47.40	2.01
-46.40	1.97
-45.40	1.93
-44.40	1.90
-43.40	1.87
-42.40	1.84
-41.40	1.81
-40.40	1.79
-39.40	1.76
-38.40	1.74
-37.40	1.73
-36.40	1.71
-35.40	1.70
-34.40	1.68
-33.40	1.67
-32.40	1.66
-31.40	1.65
-30.40	1.65
-29.40	1.64
-28.40	1.63

Z(degrees)	Discomfort Feeling Left Arm (out of 8)
-23.50	2.48
-22.50	2.36
-21.50	2.25
-20.50	2.15
-19.50	2.07
-18.50	1.99
-17.50	1.92
-16.50	1.85
-15.50	1.80
-14.50	1.75
-13.50	1.71
-12.50	1.68
-11.50	1.65
-10.50	1.63
-9.50	1.62
-8.50	1.60
-7.50	1.60
-6.50	1.60
-5.50	1.60
-4.50	1.60
-3.50	1.60
-2.50	1.60
-1.50	1.60
-0.50	1.60
0.50	1.60
1.50	1.60
2.50	1.60
3.50	1.60
4.50	1.60
5.50	1.60
6.50	1.60

Y(degrees)	Discomfort Feeling Left Arm (out of 8)
-27.40	1.63
-26.40	1.62
-25.40	1.62
-24.40	1.62
-23.40	1.61
-22.40	1.61
-21.40	1.61
-20.40	1.61
-19.40	1.61
-18.40	1.60
-17.40	1.60
-16.40	1.60
-15.40	1.60
-14.40	1.60
-13.40	1.60
-12.40	1.60
-11.40	1.60
-10.40	1.60
-9.40	1.60
-8.40	1.60
-7.40	1.60
-6.40	1.60
-5.40	1.60
-4.40	1.60
-3.40	1.60
-2.40	1.60
-1.40	1.60
-0.40	1.60
0.60	1.60
1.60	1.60
2.60	1.60

Z(degrees)	Discomfort Feeling Left Arm (out of 8)
7.50	1.60
8.50	1.60
9.50	1.60
10.50	1.61
11.50	1.61
12.50	1.63
13.50	1.65
14.50	1.69
15.50	1.76
16.50	1.88
17.50	2.08
18.50	2.41
19.50	2.92
20.50	3.72
21.50	4.94
22.50	6.77
23.00	8.00

Y(degrees)	Discomfort Feeling Left Arm (out of 8)
3.60	1.60
4.60	1.60
5.60	1.60
6.60	1.60
7.60	1.60
8.60	1.60
9.60	1.60
10.60	1.60
11.60	1.60
12.60	1.60
13.60	1.60
14.60	1.60
15.60	1.60
16.60	1.60
17.60	1.60
18.60	1.60
19.60	1.60
20.60	1.60
21.60	1.60
22.60	1.60
23.60	1.60
24.60	1.60
25.60	1.60
26.60	1.60
27.60	1.60
28.60	1.61
29.60	1.61
30.60	1.61
31.60	1.61
32.60	1.62
33.60	1.62

Y(degrees)	Discomfort Feeling Left Arm (out of 8)
34.60	1.62
35.60	1.63
36.60	1.63
37.60	1.64
38.60	1.65
39.60	1.66
40.60	1.67
41.60	1.69
42.60	1.70
43.60	1.72
44.60	1.74
45.60	1.76
46.60	1.79
47.60	1.82
48.60	1.85
49.60	1.89
50.60	1.93
51.60	1.98
52.60	2.03
53.60	2.08
54.60	2.15
55.60	2.21
56.60	2.29
57.60	2.38
58.60	2.47
59.60	2.57
60.60	2.68
61.60	2.80
62.60	2.93
63.60	3.08
64.60	3.23

Y(degrees)	Discomfort Feeling Left Arm (out of 8)
65.60	3.40
66.60	3.59
67.60	3.79
68.60	4.01
69.60	4.24
70.60	4.49
71.60	4.76
72.60	5.06
73.60	5.37
74.60	5.71
75.60	6.07
76.60	6.46
77.60	6.88
78.60	7.32
79.60	7.80
80.00	8.00

Appendix C: **RIGHT MALE AND FEMALE HIP JOINT**

Range of Motion of Right Hip Joint:	In X direction [-36.0000, 60.0000] In Y direction [-45.0000, 30.0000] In Z direction [-20.0000, 120.0000]
The Neutral Position of Right Hip Joint:	[12.40, -11.10, 82.10]

X(degrees)	Discomfort Feeling out of 8		
	Right Leg	Back	Shoulders
60.00	8.00	4.00	3.50
59.40	7.43	3.92	3.47
58.40	6.56	3.79	3.43
57.40	5.81	3.67	3.39
56.40	5.15	3.56	3.34
55.40	4.58	3.45	3.30
54.40	4.09	3.34	3.26
53.40	3.66	3.24	3.21
52.40	3.29	3.14	3.17
51.40	2.98	3.05	3.13
50.40	2.71	2.96	3.08
49.40	2.48	2.88	3.04
48.40	2.28	2.80	3.00
47.40	2.12	2.72	2.95
46.40	1.98	2.65	2.91
45.40	1.87	2.57	2.87
44.40	1.77	2.51	2.82
43.40	1.69	2.44	2.78
42.40	1.63	2.38	2.74
41.40	1.58	2.32	2.69
40.40	1.54	2.27	2.65

Y(degrees)	Discomfort Feeling out of 8
	Right Leg
30.00	8.00
29.90	7.91
28.90	7.03
27.90	6.25
26.90	5.57
25.90	4.96
24.90	4.43
23.90	3.97
22.90	3.57
21.90	3.22
20.90	2.92
19.90	2.66
18.90	2.43
17.90	2.25
16.90	2.09
15.90	1.95
14.90	1.84
13.90	1.75
12.90	1.67
11.90	1.61
10.90	1.56

Z (degrees)	Discomfort Feeling out of 8	
	Right Leg	Buttocks
120.00	8.00	8.00
119.10	7.12	7.25
118.10	6.26	6.51
117.10	5.51	5.85
116.10	4.86	5.27
115.10	4.29	4.75
114.10	3.81	4.30
113.10	3.39	3.91
112.10	3.04	3.56
111.10	2.74	3.26
110.10	2.48	3.00
109.10	2.27	2.77
108.10	2.09	2.58
107.10	1.95	2.40
106.10	1.83	2.25
105.10	1.73	2.12
104.10	1.65	2.01
103.10	1.59	1.91
102.10	1.54	1.82
101.10	1.50	1.74
100.10	1.47	1.67

X(degrees)	Discomfort Feeling out of 8		
	Right Leg	Back	Shoulders
39.40	1.50	2.21	2.61
38.40	1.47	2.16	2.56
37.40	1.45	2.11	2.52
36.40	1.44	2.06	2.48
35.40	1.42	2.01	2.43
34.40	1.41	1.97	2.39
33.40	1.41	1.92	2.35
32.40	1.40	1.88	2.30
31.40	1.40	1.84	2.26
30.40	1.39	1.80	2.22
29.40	1.39	1.76	2.17
28.40	1.39	1.73	2.13
27.40	1.39	1.69	2.09
26.40	1.39	1.65	2.04
25.40	1.39	1.62	2.00
24.40	1.39	1.58	1.96
23.40	1.39	1.55	1.91
22.40	1.39	1.51	1.87
21.40	1.39	1.48	1.83
20.40	1.39	1.45	1.78
19.40	1.39	1.41	1.74
18.40	1.39	1.38	1.70
17.40	1.39	1.35	1.65
16.40	1.39	1.32	1.61
15.40	1.39	1.28	1.57
14.40	1.39	1.25	1.52
13.40	1.39	1.22	1.48
12.40	1.39	1.19	1.44
11.40	1.39	1.22	1.48
10.40	1.39	1.25	1.52

Y(degrees)	Discomfort Feeling out of 8
	Right Leg
9.90	1.52
8.90	1.48
7.90	1.46
6.90	1.44
5.90	1.42
4.90	1.41
3.90	1.41
2.90	1.40
1.90	1.40
0.90	1.39
-0.10	1.39
-1.10	1.39
-2.10	1.39
-3.10	1.39
-4.10	1.39
-5.10	1.39
-6.10	1.39
-7.10	1.39
-8.10	1.39
-9.10	1.39
-10.10	1.39
-11.10	1.39
-12.10	1.39
-13.10	1.39
-14.10	1.39
-15.10	1.39
-16.10	1.39
-17.10	1.39
-18.10	1.39
-19.10	1.39

Z (degrees)	Discomfort Feeling out of 8	
	Right Leg	Buttocks
99.10	1.44	1.61
98.10	1.43	1.55
97.10	1.41	1.50
96.10	1.41	1.45
95.10	1.40	1.41
94.10	1.39	1.36
93.10	1.39	1.32
92.10	1.39	1.28
91.10	1.39	1.23
90.10	1.39	1.19
89.10	1.39	1.15
88.10	1.39	1.11
87.10	1.39	1.07
86.10	1.39	1.03
85.10	1.39	0.99
84.10	1.39	0.95
83.10	1.39	0.91
82.10	1.39	0.87
81.10	1.39	0.91
80.10	1.39	0.95
79.10	1.39	0.99
78.10	1.39	1.03
77.10	1.39	1.07
76.10	1.39	1.11
75.10	1.39	1.15
74.10	1.39	1.19
73.10	1.39	1.23
72.10	1.39	1.27
71.10	1.39	1.31
70.10	1.39	1.35

X(degrees)	Discomfort Feeling out of 8		
	Right Leg	Back	Shoulders
9.40	1.39	1.28	1.57
8.40	1.39	1.32	1.61
7.40	1.39	1.35	1.65
6.40	1.39	1.38	1.70
5.40	1.39	1.41	1.74
4.40	1.39	1.45	1.78
3.40	1.39	1.48	1.83
2.40	1.39	1.51	1.87
1.40	1.39	1.55	1.91
0.40	1.39	1.58	1.96
-0.60	1.39	1.61	2.00
-1.60	1.39	1.65	2.04
-2.60	1.39	1.68	2.09
-3.60	1.39	1.72	2.13
-4.60	1.39	1.76	2.17
-5.60	1.39	1.79	2.22
-6.60	1.39	1.83	2.26
-7.60	1.39	1.87	2.30
-8.60	1.40	1.91	2.35
-9.60	1.40	1.95	2.39
-10.60	1.41	1.99	2.43
-11.60	1.42	2.04	2.48
-12.60	1.43	2.08	2.52
-13.60	1.44	2.13	2.56
-14.60	1.46	2.18	2.61
-15.60	1.48	2.23	2.65
-16.60	1.51	2.28	2.69
-17.60	1.55	2.34	2.74
-18.60	1.60	2.40	2.78
-19.60	1.66	2.46	2.82

Y(degrees)	Discomfort Feeling out of 8
	Right Leg
-20.10	1.39
-21.10	1.39
-22.10	1.40
-23.10	1.40
-24.10	1.41
-25.10	1.42
-26.10	1.44
-27.10	1.47
-28.10	1.50
-29.10	1.55
-30.10	1.61
-31.10	1.69
-32.10	1.79
-33.10	1.91
-34.10	2.07
-35.10	2.26
-36.10	2.50
-37.10	2.79
-38.10	3.13
-39.10	3.55
-40.10	4.04
-41.10	4.62
-42.10	5.30
-43.10	6.11
-44.10	7.04
-45.00	8.00

Z (degrees)	Discomfort Feeling out of 8	
	Right Leg	Buttocks
69.10	1.39	1.39
68.10	1.39	1.41
67.10	1.39	1.47
66.10	1.39	1.51
65.10	1.39	1.55
64.10	1.39	1.59
63.10	1.39	1.63
62.10	1.39	1.67
61.10	1.39	1.71
60.10	1.39	1.75
59.10	1.39	1.79
58.10	1.39	1.83
57.10	1.39	1.88
56.10	1.39	1.92
55.10	1.39	1.96
54.10	1.39	2.00
53.10	1.39	2.04
52.10	1.39	2.08
51.10	1.39	2.12
50.10	1.39	2.17
49.10	1.39	2.21
48.10	1.40	2.25
47.10	1.40	2.29
46.10	1.40	2.34
45.10	1.40	2.38
44.10	1.41	2.42
43.10	1.41	2.47
42.10	1.41	2.51
41.10	1.42	2.56
40.10	1.42	2.60

X(degrees)	Discomfort Feeling out of 8		
	Right Leg	Back	Shoulders
-20.60	1.73	2.52	2.87
-21.60	1.82	2.59	2.91
-22.60	1.93	2.66	2.95
-23.60	2.06	2.73	3.00
-24.60	2.22	2.81	3.04
-25.60	2.41	2.89	3.08
-26.60	2.64	2.97	3.13
-27.60	2.91	3.06	3.17
-28.60	3.22	3.15	3.21
-29.60	3.60	3.25	3.26
-30.60	4.04	3.35	3.30
-31.60	4.56	3.46	3.34
-32.60	5.16	3.57	3.39
-33.60	5.85	3.69	3.43
-34.60	6.66	3.82	3.47
-35.60	7.59	3.95	3.52
-36.00	8.00	4.00	3.53

Z (degrees)	Discomfort Feeling out of 8	
	Right Leg	Buttocks
39.10	1.43	2.65
38.10	1.44	2.69
37.10	1.44	2.74
36.10	1.45	2.79
35.10	1.46	2.84
34.10	1.47	2.89
33.10	1.48	2.93
32.10	1.49	2.98
31.10	1.50	3.04
30.10	1.51	3.09
29.10	1.53	3.14
28.10	1.55	3.19
27.10	1.56	3.25
26.10	1.58	3.30
25.10	1.61	3.36
24.10	1.63	3.42
23.10	1.65	3.48
22.10	1.68	3.54
21.10	1.71	3.60
20.10	1.74	3.66
19.10	1.78	3.72
18.10	1.82	3.79
17.10	1.86	3.85
16.10	1.90	3.92
15.10	1.95	3.99
14.10	2.00	4.06
13.10	2.06	4.14
12.10	2.11	4.21
11.10	2.18	4.29
10.10	2.24	4.37

Z (degrees)	Discomfort Feeling out of 8	
	Right Leg	Buttocks
9.10	2.32	4.45
8.10	2.39	4.53
7.10	2.48	4.61
6.10	2.56	4.70
5.10	2.66	4.79
4.10	2.76	4.88
3.10	2.86	4.97
2.10	2.97	5.07
1.10	3.09	5.17
0.10	3.22	5.27
-0.90	3.36	5.37
-1.90	3.50	5.48
-2.90	3.65	5.59
-3.90	3.81	5.70
-4.90	3.98	5.81
-5.90	4.16	5.93
-6.90	4.35	6.06
-7.90	4.55	6.18
-8.90	4.76	6.31
-9.90	4.98	6.44
-10.90	5.22	6.58
-11.90	5.46	6.72
-12.90	5.72	6.86
-13.90	6.00	7.01
-14.90	6.29	7.16
-15.90	6.59	7.32
-16.90	6.91	7.48
-17.90	7.24	7.64
-18.90	7.59	7.81
-19.90	7.96	7.98

-20.00	8.00	8.00

Appendix C: **LEFT MALE AND FEMALE HIP JOINT**

Range of Motion of Left Hip Joint:	In X direction [-60.0000, 36.0000] In Y direction [-30.0000, 45.0000] In Z direction [-20.0000, 120.0000]
The Neutral Position of Left Hip Joint:	[-12.40, 11.10, 82.10]

X(degrees)	Discomfort Feeling out of 8		
	Right Leg	Back	Shoulders
-60.00	8.00	4.00	3.50
-59.40	7.43	3.92	3.47
-58.40	6.56	3.79	3.43
-57.40	5.81	3.67	3.39
-56.40	5.15	3.56	3.34
-55.40	4.58	3.45	3.30
-54.40	4.09	3.34	3.26
-53.40	3.66	3.24	3.21
-52.40	3.29	3.14	3.17
-51.40	2.98	3.05	3.13
-50.40	2.71	2.96	3.08
-49.40	2.48	2.88	3.04
-48.40	2.28	2.80	3.00
-47.40	2.12	2.72	2.95
-46.40	1.98	2.65	2.91
-45.40	1.87	2.57	2.87
-44.40	1.77	2.51	2.82
-43.40	1.69	2.44	2.78
-42.40	1.63	2.38	2.74
-41.40	1.58	2.32	2.69
-40.40	1.54	2.27	2.65

Y(degrees)	Discomfort Feeling out of 8
	Right Leg
-30.00	8.00
-29.90	7.91
-28.90	7.03
-27.90	6.25
-26.90	5.57
-25.90	4.96
-24.90	4.43
-23.90	3.97
-22.90	3.57
-21.90	3.22
-20.90	2.92
-19.90	2.66
-18.90	2.43
-17.90	2.25
-16.90	2.09
-15.90	1.95
-14.90	1.84
-13.90	1.75
-12.90	1.67
-11.90	1.61
-10.90	1.56

Z (degrees)	Discomfort Feeling out of 8	
	Right Leg	Buttocks
120.00	8.00	8.00
119.10	7.12	7.25
118.10	6.26	6.51
117.10	5.51	5.85
116.10	4.86	5.27
115.10	4.29	4.75
114.10	3.81	4.30
113.10	3.39	3.91
112.10	3.04	3.56
111.10	2.74	3.26
110.10	2.48	3.00
109.10	2.27	2.77
108.10	2.09	2.58
107.10	1.95	2.40
106.10	1.83	2.25
105.10	1.73	2.12
104.10	1.65	2.01
103.10	1.59	1.91
102.10	1.54	1.82
101.10	1.50	1.74
100.10	1.47	1.67

X(degrees)	Discomfort Feeling out of 8		
	Right Leg	Back	Shoulders
-39.40	1.50	2.21	2.61
-38.40	1.47	2.16	2.56
-37.40	1.45	2.11	2.52
-36.40	1.44	2.06	2.48
-35.40	1.42	2.01	2.43
-34.40	1.41	1.97	2.39
-33.40	1.41	1.92	2.35
-32.40	1.40	1.88	2.30
-31.40	1.40	1.84	2.26
-30.40	1.39	1.80	2.22
-29.40	1.39	1.76	2.17
-28.40	1.39	1.73	2.13
-27.40	1.39	1.69	2.09
-26.40	1.39	1.65	2.04
-25.40	1.39	1.62	2.00
-24.40	1.39	1.58	1.96
-23.40	1.39	1.55	1.91
-22.40	1.39	1.51	1.87
-21.40	1.39	1.48	1.83
-20.40	1.39	1.45	1.78
-19.40	1.39	1.41	1.74
-18.40	1.39	1.38	1.70
-17.40	1.39	1.35	1.65
-16.40	1.39	1.32	1.61
-15.40	1.39	1.28	1.57
-14.40	1.39	1.25	1.52
-13.40	1.39	1.22	1.48
-12.40	1.39	1.19	1.44
-11.40	1.39	1.22	1.48

Y(degrees)	Discomfort Feeling out of 8
	Right Leg
-9.90	1.52
-8.90	1.48
-7.90	1.46
-6.90	1.44
-5.90	1.42
-4.90	1.41
-3.90	1.41
-2.90	1.40
-1.90	1.40
-0.90	1.39
0.10	1.39
1.10	1.39
2.10	1.39
3.10	1.39
4.10	1.39
5.10	1.39
6.10	1.39
7.10	1.39
8.10	1.39
9.10	1.39
10.10	1.39
11.10	1.39
12.10	1.39
13.10	1.39
14.10	1.39
15.10	1.39
16.10	1.39
17.10	1.39
18.10	1.39

Z (degrees)	Discomfort Feeling out of 8	
	Right Leg	Buttocks
99.10	1.44	1.61
98.10	1.43	1.55
97.10	1.41	1.50
96.10	1.41	1.45
95.10	1.40	1.41
94.10	1.39	1.36
93.10	1.39	1.32
92.10	1.39	1.28
91.10	1.39	1.23
90.10	1.39	1.19
89.10	1.39	1.15
88.10	1.39	1.11
87.10	1.39	1.07
86.10	1.39	1.03
85.10	1.39	0.99
84.10	1.39	0.95
83.10	1.39	0.91
82.10	1.39	0.87
81.10	1.39	0.91
80.10	1.39	0.95
79.10	1.39	0.99
78.10	1.39	1.03
77.10	1.39	1.07
76.10	1.39	1.11
75.10	1.39	1.15
74.10	1.39	1.19
73.10	1.39	1.23
72.10	1.39	1.27
71.10	1.39	1.31

X(degrees)	Discomfort Feeling out of 8		
	Right Leg	Back	Shoulders
-10.40	1.39	1.25	1.52
-9.40	1.39	1.28	1.57
-8.40	1.39	1.32	1.61
-7.40	1.39	1.35	1.65
-6.40	1.39	1.38	1.70
-5.40	1.39	1.41	1.74
-4.40	1.39	1.45	1.78
-3.40	1.39	1.48	1.83
-2.40	1.39	1.51	1.87
-1.40	1.39	1.55	1.91
-0.40	1.39	1.58	1.96
0.60	1.39	1.61	2.00
1.60	1.39	1.65	2.04
2.60	1.39	1.68	2.09
3.60	1.39	1.72	2.13
4.60	1.39	1.76	2.17
5.60	1.39	1.79	2.22
6.60	1.39	1.83	2.26
7.60	1.39	1.87	2.30
8.60	1.40	1.91	2.35
9.60	1.40	1.95	2.39
10.60	1.41	1.99	2.43
11.60	1.42	2.04	2.48
12.60	1.43	2.08	2.52
13.60	1.44	2.13	2.56
14.60	1.46	2.18	2.61
15.60	1.48	2.23	2.65
16.60	1.51	2.28	2.69
17.60	1.55	2.34	2.74

Y(degrees)	Discomfort Feeling out of 8
	Right Leg
19.10	1.39
20.10	1.39
21.10	1.39
22.10	1.40
23.10	1.40
24.10	1.41
25.10	1.42
26.10	1.44
27.10	1.47
28.10	1.50
29.10	1.55
30.10	1.61
31.10	1.69
32.10	1.79
33.10	1.91
34.10	2.07
35.10	2.26
36.10	2.50
37.10	2.79
38.10	3.13
39.10	3.55
40.10	4.04
41.10	4.62
42.10	5.30
43.10	6.11
44.10	7.04
45.00	8.00

Z (degrees)	Discomfort Feeling out of 8	
	Right Leg	Buttocks
70.10	1.39	1.35
69.10	1.39	1.39
68.10	1.39	1.41
67.10	1.39	1.47
66.10	1.39	1.51
65.10	1.39	1.55
64.10	1.39	1.59
63.10	1.39	1.63
62.10	1.39	1.67
61.10	1.39	1.71
60.10	1.39	1.75
59.10	1.39	1.79
58.10	1.39	1.83
57.10	1.39	1.88
56.10	1.39	1.92
55.10	1.39	1.96
54.10	1.39	2.00
53.10	1.39	2.04
52.10	1.39	2.08
51.10	1.39	2.12
50.10	1.39	2.17
49.10	1.39	2.21
48.10	1.40	2.25
47.10	1.40	2.29
46.10	1.40	2.34
45.10	1.40	2.38
44.10	1.41	2.42
43.10	1.41	2.47
42.10	1.41	2.51

X(degrees)	Discomfort Feeling out of 8		
	Right Leg	Back	Shoulders
18.60	1.60	2.40	2.78
19.60	1.66	2.46	2.82
20.60	1.73	2.52	2.87
21.60	1.82	2.59	2.91
22.60	1.93	2.66	2.95
23.60	2.06	2.73	3.00
24.60	2.22	2.81	3.04
25.60	2.41	2.89	3.08
26.60	2.64	2.97	3.13
27.60	2.91	3.06	3.17
28.60	3.22	3.15	3.21
29.60	3.60	3.25	3.26
30.60	4.04	3.35	3.30
31.60	4.56	3.46	3.34
32.60	5.16	3.57	3.39
33.60	5.85	3.69	3.43
34.60	6.66	3.82	3.47
35.60	7.59	3.95	3.52
36.00	8.00	4.00	3.53

Z (degrees)	Discomfort Feeling out of 8	
	Right Leg	Buttocks
41.10	1.42	2.56
40.10	1.42	2.60
39.10	1.43	2.65
38.10	1.44	2.69
37.10	1.44	2.74
36.10	1.45	2.79
35.10	1.46	2.84
34.10	1.47	2.89
33.10	1.48	2.93
32.10	1.49	2.98
31.10	1.50	3.04
30.10	1.51	3.09
29.10	1.53	3.14
28.10	1.55	3.19
27.10	1.56	3.25
26.10	1.58	3.30
25.10	1.61	3.36
24.10	1.63	3.42
23.10	1.65	3.48
22.10	1.68	3.54
21.10	1.71	3.60
20.10	1.74	3.66
19.10	1.78	3.72
18.10	1.82	3.79
17.10	1.86	3.85
16.10	1.90	3.92
15.10	1.95	3.99
14.10	2.00	4.06
13.10	2.06	4.14

Z (degrees)	Discomfort Feeling out of 8	
	Right Leg	Buttocks
12.10	2.11	4.21
11.10	2.18	4.29
10.10	2.24	4.37
9.10	2.32	4.45
8.10	2.39	4.53
7.10	2.48	4.61
6.10	2.56	4.70
5.10	2.66	4.79
4.10	2.76	4.88
3.10	2.86	4.97
2.10	2.97	5.07
1.10	3.09	5.17
0.10	3.22	5.27
-0.90	3.36	5.37
-1.90	3.50	5.48
-2.90	3.65	5.59
-3.90	3.81	5.70
-4.90	3.98	5.81
-5.90	4.16	5.93
-6.90	4.35	6.06
-7.90	4.55	6.18
-8.90	4.76	6.31
-9.90	4.98	6.44
-10.90	5.22	6.58
-11.90	5.46	6.72
-12.90	5.72	6.86
-13.90	6.00	7.01
-14.90	6.29	7.16
-15.90	6.59	7.32

Z (degrees)	Discomfort Feeling out of 8	
	Right Leg	Buttocks
-16.90	6.91	7.48
-17.90	7.24	7.64
-18.90	7.59	7.81
-19.90	7.96	7.98
-20.00	8.00	8.00

Appendix C: **RIGHT MALE AND FEMALE KNEE JOINT**

Range of Motion of Right Knee Joint:	In X direction [-20.0000, 40.0000] In Y direction [0.0000, 140.0000] In Z direction [0.0000, 0.0000]
The Neutral Position of Right Knee Joint:	[0.0, 63.10, 0.0]

X(degrees)	Discomfort Feeling Right Leg (out of 8)
40.00	8.00
39.00	7.09
38.00	6.29
37.00	5.58
36.00	4.96
35.00	4.41
34.00	3.94
33.00	3.53
32.00	3.18
31.00	2.88
30.00	2.62
29.00	2.39
28.00	2.21
27.00	2.05
26.00	1.92
25.00	1.81
24.00	1.72
23.00	1.65
22.00	1.59
21.00	1.54
20.00	1.50
19.00	1.47

Y(degrees)	Discomfort Feeling Right Leg (out of 8)
140.00	8.00
139.10	7.39
138.10	6.76
137.10	6.17
136.10	5.63
135.10	5.12
134.10	4.66
133.10	4.23
132.10	3.83
131.10	3.47
130.10	3.13
129.10	2.83
128.10	2.55
127.10	2.29
126.10	2.06
125.10	1.85
124.10	1.65
123.10	1.48
122.10	1.32
121.10	1.18
120.10	1.06
119.10	0.95

X(degrees)	Discomfort Feeling Right Leg (out of 8)
18.00	1.45
17.00	1.43
16.00	1.42
15.00	1.41
14.00	1.40
13.00	1.40
12.00	1.39
11.00	1.39
10.00	1.39
9.00	1.39
8.00	1.39
7.00	1.39
6.00	1.39
5.00	1.39
4.00	1.39
3.00	1.39
2.00	1.39
1.00	1.39
0.00	1.39
-1.00	1.39
-2.00	1.39
-3.00	1.39
-4.00	1.39
-5.00	1.39
-6.00	1.39
-7.00	1.39
-8.00	1.40
-9.00	1.42
-10.00	1.45
-11.00	1.50
-12.00	1.60

Y(degrees)	Discomfort Feeling Right Leg (out of 8)
118.10	0.85
117.10	0.76
116.10	0.68
115.10	0.62
114.10	0.56
113.10	0.51
112.10	0.47
111.10	0.44
110.10	0.41
109.10	0.39
108.10	0.38
107.10	0.37
106.10	0.36
105.10	0.36
104.10	0.36
103.10	0.37
102.10	0.37
101.10	0.39
100.10	0.40
99.10	0.41
98.10	0.43
97.10	0.45
96.10	0.47
95.10	0.49
94.10	0.52
93.10	0.54
92.10	0.56
91.10	0.59
90.10	0.61
89.10	0.64
88.10	67.00

X(degrees)	Discomfort Feeling Right Leg (out of 8)
-13.00	1.75
-14.00	1.98
-15.00	2.33
-16.00	2.85
-17.00	3.59
-18.00	4.63
-19.00	6.06
-20.00	8.00

Y(degrees)	Discomfort Feeling Right Leg (out of 8)
87.10	0.70
86.10	0.72
85.10	0.75
84.10	0.78
83.10	0.81
82.10	0.84
81.10	0.87
80.10	0.89
79.10	0.92
78.10	0.95
77.10	0.98
76.10	1.01
75.10	1.04
74.10	1.07
73.10	1.10
72.10	1.13
71.10	1.15
70.10	1.18
69.10	1.21
68.10	1.24
67.10	1.27
66.10	1.30
65.10	1.33
64.10	1.36
63.10	1.39
62.10	1.36
61.10	1.33
60.10	1.30
59.10	1.27
58.10	1.24
57.10	1.21

Y(degrees)	Discomfort Feeling Right Leg (out of 8)
56.10	1.18
55.10	1.15
54.10	1.13
53.10	1.10
52.10	1.07
51.10	1.04
50.10	1.01
49.10	0.98
48.10	0.95
47.10	0.92
46.10	0.89
45.10	0.87
44.10	0.84
43.10	0.81
42.10	0.78
41.10	0.75
40.10	0.73
39.10	0.70
38.10	0.68
37.10	0.65
36.10	0.63
35.10	0.61
34.10	0.58
33.10	0.57
32.10	0.55
31.10	0.54
30.10	0.53
29.10	0.52
28.10	0.52
27.10	0.52
26.10	0.53

Y(degrees)	Discomfort Feeling Right Leg (out of 8)
25.10	0.54
24.10	0.56
23.10	0.59
22.10	0.63
21.10	0.68
20.10	0.74
19.10	0.81
18.10	0.90
17.10	1.01
16.10	1.13
15.10	1.27
14.10	1.44
13.10	1.63
12.10	1.85
11.10	2.10
10.10	2.38
9.10	2.70
8.10	3.06
7.10	3.47
6.10	3.92
5.10	4.43
4.10	4.99
3.10	5.61
2.10	6.30
1.10	7.07
0.01	7.91
0.00	8.00

Appendix C: **LEFT MALE AND FEMALE KNEE JOINT**

Range of Motion of Left Knee Joint:	In X direction [- 40.0000, 20.0000] In Y direction [0.0000, 140.0000] In Z direction [0.0000, 0.0000]
The Neutral Position of Left Knee Joint:	[0.0, 63.10, 0.0]

X(degrees)	Discomfort Feeling Left Leg (out of 8)
-40.00	8.00
-39.00	7.09
-38.00	6.29
-37.00	5.58
-36.00	4.96
-35.00	4.41
-34.00	3.94
-33.00	3.53
-32.00	3.18
-31.00	2.88
-30.00	2.62
-29.00	2.39
-28.00	2.21
-27.00	2.05
-26.00	1.92
-25.00	1.81
-24.00	1.72
-23.00	1.65
-22.00	1.59
X(degrees)	Discomfort Feeling Left Leg (out of 8)

Y(degrees)	Discomfort Feeling Lef90dt Leg (out of 8)
140.00	8.00
139.10	7.39
138.10	6.76
137.10	6.17
136.10	5.63
135.10	5.12
134.10	4.66
133.10	4.23
132.10	3.83
131.10	3.47
130.10	3.13
129.10	2.83
128.10	2.55
127.10	2.29
126.10	2.06
125.10	1.85
124.10	1.65
123.10	1.48
122.10	1.32
Y(degrees)	Discomfort Feeling Lef90dt Leg (out of 8)

X(degrees)	Discomfort Feeling Left Leg (out of 8)
-21.00	1.54
-20.00	1.50
-19.00	1.47
-18.00	1.45
-17.00	1.43
-16.00	1.42
-15.00	1.41
-14.00	1.40
-13.00	1.40
-12.00	1.39
-11.00	1.39
-10.00	1.39
-9.00	1.39
-8.00	1.39
-7.00	1.39
-6.00	1.39
-5.00	1.39
-4.00	1.39
-3.00	1.39
-2.00	1.39
-1.00	1.39
0.00	1.39
1.00	1.39
2.00	1.39
3.00	1.39
4.00	1.39
5.00	1.39
6.00	1.39
7.00	1.39
8.00	1.40
9.00	1.42

Y(degrees)	Discomfort Feeling Lef90dt Leg (out of 8)
121.10	1.18
120.10	1.06
119.10	0.95
118.10	0.85
117.10	0.76
116.10	0.68
115.10	0.62
114.10	0.56
113.10	0.51
112.10	0.47
111.10	0.44
110.10	0.41
109.10	0.39
108.10	0.38
107.10	0.37
106.10	0.36
105.10	0.36
104.10	0.36
103.10	0.37
102.10	0.37
101.10	0.39
100.10	0.40
99.10	0.41
98.10	0.43
97.10	0.45
96.10	0.47
95.10	0.49
94.10	0.52
93.10	0.54
92.10	0.56
91.10	0.59

10.00	1.45
11.00	1.50
12.00	1.60
13.00	1.75
14.00	1.98
15.00	2.33
16.00	2.85
17.00	3.59
18.00	4.63
19.00	6.06
20.00	8.00

90.10	0.61
89.10	0.64
88.10	67.00
87.10	0.70
86.10	0.72
85.10	0.75
84.10	0.78
83.10	0.81
82.10	0.84
81.10	0.87
80.10	0.89
79.10	0.92
78.10	0.95
77.10	0.98
76.10	1.01
75.10	1.04
74.10	1.07
73.10	1.10
72.10	1.13
71.10	1.15
70.10	1.18
69.10	1.21
68.10	1.24
67.10	1.27
66.10	1.30
65.10	1.33
64.10	1.36
63.10	1.39
62.10	1.36
61.10	1.33
60.10	1.30
Y(degrees)	Discomfort Feeling Lef90dt Leg (out of 8)

59.10	1.27
58.10	1.24
57.10	1.21
56.10	1.18
55.10	1.15
54.10	1.13
53.10	1.10
52.10	1.07
51.10	1.04
50.10	1.01
49.10	0.98
48.10	0.95
47.10	0.92
46.10	0.89
45.10	0.87
44.10	0.84
43.10	0.81
42.10	0.78
41.10	0.75
40.10	0.73
39.10	0.70
38.10	0.68
37.10	0.65
36.10	0.63
35.10	0.61
34.10	0.58
33.10	0.57
32.10	0.55
31.10	0.54
30.10	0.53
29.10	0.52
Y(degrees)	Discomfort Feeling Lef90dt Leg (out of 8)

28.10	0.52
27.10	0.52
26.10	0.53
25.10	0.54
24.10	0.56
23.10	0.59
22.10	0.63
21.10	0.68
20.10	0.74
19.10	0.81
18.10	0.90
17.10	1.01
16.10	1.13
15.10	1.27
14.10	1.44
13.10	1.63
12.10	1.85
11.10	2.10
10.10	2.38
9.10	2.70
8.10	3.06
7.10	3.47
6.10	3.92
5.10	4.43
4.10	4.99
3.10	5.61
2.10	6.30
1.10	7.07
0.01	7.91
0.00	8.00

Appendix C: **RIGHT MALE AND FEMALE ANKLE JOINT**

Range of Motion of Right Ankle Joint:	In X direction [-24.0000, 23.0000] In Y direction [0.0000, 0.0000] In Z direction [-45.0000, 31.0000]
The Neutral Position of Right Ankle Joint:	[0.0, 0.0, -18.0]

X(degrees)	Discomfort Feeling Right Leg (out of 8)
23.00	8.00
22.00	5.34
21.00	3.69
20.00	2.70
19.00	2.11
18.00	1.77
17.00	1.59
16.00	1.49
15.00	1.43
14.00	1.41
13.00	1.40
12.00	1.39
11.00	1.39
10.00	1.39
9.00	1.39
8.00	1.39
7.00	1.39
6.00	1.39
5.00	1.39
4.00	1.39

Z(degrees)	Discomfort Feeling Right Leg (out of 8)
31.00	8.00
30.00	7.49
29.00	7.01
28.00	6.55
27.00	6.13
26.00	5.73
25.00	5.36
24.00	5.01
23.00	4.68
22.00	4.38
21.00	4.10
20.00	3.84
19.00	3.60
18.00	3.37
17.00	3.17
16.00	2.97
15.00	2.80
14.00	2.64
13.00	2.49
12.00	2.36

X(degrees)	Discomfort Feeling Right Leg (out of 8)
3.00	1.39
2.00	1.39
1.00	1.39
0.00	1.39
-1.00	1.39
-2.00	1.39
-3.00	1.39
-4.00	1.39
-5.00	1.39
-6.00	1.39
-7.00	1.39
-8.00	1.39
-9.00	1.39
-10.00	1.39
-11.00	1.39
-12.00	1.39
-13.00	1.40
-14.00	1.42
-15.00	1.44
-16.00	1.50
-17.00	1.59
-18.00	1.74
-19.00	2.01
-20.00	2.43
-21.00	3.09
-22.00	4.12
-23.00	5.68
-24.00	8.00

Z(degrees)	Discomfort Feeling Right Leg (out of 8)
11.00	2.24
10.00	2.13
9.00	2.03
8.00	1.94
7.00	1.87
6.00	1.79
5.00	1.73
4.00	1.68
3.00	1.63
2.00	1.59
1.00	1.55
0.00	1.52
-1.00	1.49
-2.00	1.47
-3.00	1.45
-4.00	1.44
-5.00	1.42
-6.00	1.41
-7.00	1.41
-8.00	1.40
-9.00	1.40
-10.00	1.39
-11.00	1.39
-12.00	1.39
-13.00	1.39
-14.00	1.39
-15.00	1.39
-16.00	1.39
-17.00	1.39
-18.00	1.39
-19.00	1.39

Z(degrees)	Discomfort Feeling Right Leg (out of 8)
-20.00	1.39
-21.00	1.39
-22.00	1.39
-23.00	1.39
-24.00	1.40
-25.00	1.41
-26.00	1.42
-27.00	1.45
-28.00	1.48
-29.00	1.52
-30.00	1.59
-31.00	1.67
-32.00	1.78
-33.00	1.91
-34.00	2.08
-35.00	2.29
-36.00	2.54
-37.00	2.84
-38.00	3.20
-39.00	3.62
-40.00	4.12
-41.00	4.70
-42.00	5.37
-43.00	6.13
-44.00	7.01
-45.00	8.00

Appendix C: **LEFT MALE AND FEMALE ANKLE JOINT**

Range of Motion of Left Ankle Joint:	In X direction [-23.0000, 24.0000] In Y direction [0.0000, 0.0000] In Z direction [-45.0000, 31.0000]
The Neutral Position of Left Ankle Joint:	[0.0, 0.0, -18.0]

X(degrees)	Discomfort Feeling Left Leg (out of 8)
-23.00	8.00
-22.00	5.34
-21.00	3.69
-20.00	2.70
-19.00	2.11
-18.00	1.77
-17.00	1.59
-16.00	1.49
-15.00	1.43
-14.00	1.41
-13.00	1.40
-12.00	1.39
-11.00	1.39
-10.00	1.39
-9.00	1.39
-8.00	1.39
-7.00	1.39
-6.00	1.39
-5.00	1.39
-4.00	1.39
-3.00	1.39
-2.00	1.39

Z(degrees)	Discomfort Feeling Left Leg (out of 8)
31.00	8.00
30.00	7.49
29.00	7.01
28.00	6.55
27.00	6.13
26.00	5.73
25.00	5.36
24.00	5.01
23.00	4.68
22.00	4.38
21.00	4.10
20.00	3.84
19.00	3.60
18.00	3.37
17.00	3.17
16.00	2.97
15.00	2.80
14.00	2.64
13.00	2.49
12.00	2.36
11.00	2.24
10.00	2.13

X(degrees)	Discomfort Feeling Left Leg (out of 8)
-1.00	1.39
0.00	1.39
1.00	1.39
2.00	1.39
3.00	1.39
4.00	1.39
5.00	1.39
6.00	1.39
7.00	1.39
8.00	1.39
9.00	1.39
10.00	1.39
11.00	1.39
12.00	1.39
13.00	1.40
14.00	1.42
15.00	1.44
16.00	1.50
17.00	1.59
18.00	1.74
19.00	2.01
20.00	2.43
21.00	3.09
22.00	4.12
23.00	5.68
24.00	8.00

Z(degrees)	Discomfort Feeling Left Leg (out of 8)
9.00	2.03
8.00	1.94
7.00	1.87
6.00	1.79
5.00	1.73
4.00	1.68
3.00	1.63
2.00	1.59
1.00	1.55
0.00	1.52
-1.00	1.49
-2.00	1.47
-3.00	1.45
-4.00	1.44
-5.00	1.42
-6.00	1.41
-7.00	1.41
-8.00	1.40
-9.00	1.40
-10.00	1.39
-11.00	1.39
-12.00	1.39
-13.00	1.39
-14.00	1.39
-15.00	1.39
-16.00	1.39
-17.00	1.39
-18.00	1.39
-19.00	1.39
-20.00	1.39
-21.00	1.39

Z(degrees)	Discomfort Feeling Left Leg (out of 8)
-22.00	1.39
-23.00	1.39
-24.00	1.40
-25.00	1.41
-26.00	1.42
-27.00	1.45
-28.00	1.48
-29.00	1.52
-30.00	1.59
-31.00	1.67
-32.00	1.78
-33.00	1.91
-34.00	2.08
-35.00	2.29
-36.00	2.54
-37.00	2.84
-38.00	3.20
-39.00	3.62
-40.00	4.12
-41.00	4.70
-42.00	5.37
-43.00	6.13
-44.00	7.01
-45.00	8.00

Appendix C: **MALE AND FEMALE CERVICAL JOINT**

Range of Motion of Cervical Joint:	In X direction [-30.0000, 30.0000] In Y direction [-12.0000, 12.0000] In Z direction [-30.0000, 30.0000]
The Neutral Position of Cervical Joint:	[0.0, 0.0, -7.0]

X(degrees)	Discomfort feeling out of 8
	Neck
30.00	8.00
29.00	5.87
28.00	4.41
27.00	3.43
26.00	2.78
25.00	2.35
24.00	2.08
23.00	1.90
22.00	1.79
21.00	1.73
20.00	1.63
19.00	1.67
18.00	1.65
17.00	1.65
16.00	1.64
15.00	1.64
14.00	1.64
13.00	1.64
12.00	1.64
11.00	1.64
10.00	1.64
9.00	1.64

Y (degrees)	Discomfort feeling out of 8
	Neck
12.00	8.00
11.00	5.48
10.00	3.85
9.00	2.84
8.00	2.25
7.00	1.92
6.00	1.76
5.00	1.68
4.00	1.65
3.00	1.64
2.00	1.64
1.00	1.64
0.00	1.64
-1.00	1.64
-2.00	1.64
-3.00	1.64
-4.00	1.65
-5.00	1.68
-6.00	1.76
-7.00	1.92
-8.00	2.25
-9.00	2.84

Z (degrees)	Discomfort feeling out of 8
	Neck
30.00	8.00
29.00	6.98
28.00	6.11
27.00	5.36
26.00	4.72
25.00	4.17
24.00	3.71
23.00	3.32
22.00	3.00
21.00	2.72
20.00	2.50
19.00	2.32
18.00	2.17
17.00	2.05
16.00	1.95
15.00	1.88
14.00	1.82
13.00	1.77
12.00	1.73
11.00	1.71
10.00	1.69
9.00	1.67

X(degrees)	Discomfort feeling out of 8
	Neck
8.00	1.64
7.00	1.64
6.00	1.64
5.00	1.64
4.00	1.64
3.00	1.64
2.00	1.64
1.00	1.64
0.00	1.64
-1.00	1.64
-2.00	1.64
-3.00	1.64
-4.00	1.64
-5.00	1.64
-6.00	1.64
-7.00	1.64
-8.00	1.64
-9.00	1.64
-10.00	1.64
-11.00	1.64
-12.00	1.64
-13.00	1.64
-14.00	1.64
-15.00	1.64
-16.00	1.64
-17.00	1.65
-18.00	1.65
-19.00	1.67
-20.00	1.69
-21.00	1.73

Y (degrees)	Discomfort feeling out of 8
	Neck
-10.00	3.85
-11.00	5.48
-12.00	8.00

Z (degrees)	Discomfort feeling out of 8
	Neck
8.00	1.66
7.00	1.65
6.00	1.65
5.00	1.65
4.00	1.64
3.00	1.64
2.00	1.64
1.00	1.64
0.00	1.64
-1.00	1.64
-2.00	1.64
-3.00	1.64
-4.00	1.64
-5.00	1.64
-6.00	1.64
-7.00	1.64
-8.00	1.64
-9.00	1.64
-10.00	1.64
-11.00	1.64
-12.00	1.64
-13.00	1.64
-14.00	1.64
-15.00	1.64
-16.00	1.65
-17.00	1.65
-18.00	1.66
-19.00	1.69
-20.00	1.73
-21.00	1.79

X(degrees)	Discomfort feeling out of 8
	Neck
-22.00	1.79
-23.00	1.90
-24.00	2.08
-25.00	2.35
-26.00	2.78
-27.00	3.43
-28.00	4.41
-29.00	5.87
-30.00	8.00

Z (degrees)	Discomfort feeling out of 8
	Neck
-22.00	1.89
-23.00	2.05
-24.00	2.29
-25.00	2.64
-26.00	3.15
-27.00	3.86
-28.00	4.84
-29.00	6.19
-30.00	8.00

Appendix D

Farmer's Questionnaire Response

Appendix D: **FARMER 1 QUESTIONNAIRE RESPONSE**

Tasks	Subtasks	Farmer 1	
		Road Mode	Field Mode
Driving task	Monitoring and responding to other vehicles or obstacles on the road.	36	45
	Ensuring the tractor stays within designated lanes, especially on highways or large fields.	45	45
	Adjusting speed according to terrain, obstacles, and safety requirements.	45	45
	low speed maneuvering in tight environments such as farmyards and field edges	36	45
	Back up tractor to an implement, or with an implement already attached	7.2	21.6
	Total	**169.2**	**201.6**
Operational tasks	control speed based on terrain and load.	36	36
	adjust implement depth/settings	9.6	36
	Detect unmapped obstacles and navigate around or through them.	28.8	36
	Monitoring towed equipment for potential failures	45	36
	Route planning and optimization.	3.6	10.8
	Total	**123**	**154.8**
Monitoring and information tasks	Gathering data on soil conditions and environmental factors.	1	2.88

	Analyzing data from onboard sensors and cameras.	1	2.88
	Providing feedback on operational efficiency.	1	1.08
	Real-time monitoring of engine performance and vital parameters.	10.8	12.96
	Monitoring fuel and DEF levels	5.4	8.64
	Total	**19.2**	**28.44**
Safety and emergency tasks	Emergency communication between operator and support staff.	3.6	15
	Collision detection and avoidance.	15	45
	Monitoring and alerting for dangerous weather conditions.	4.32	21.6
	Reacting to tractor/implement starting to get stuck	7.2	9
	Taking over from automated control of steering from the tractor	NA	36
	Total	**30.12**	**126.6**
Comfort and convenience task	Fine tuning climate control settings	7.2	7.2
	Adjusting suspension systems for a smoother ride.	1.2	2.88
	Engaging with entertainment or connectivity options during periods of boredom	2.88	2.88
	Adjusting ergonomic of controls such as seat position	2.88	2.88
	Eating meals	1.44	1.44
	Total	**15.6**	**17.28**
Recording and documentation tasks	Maintaining records of maintenance activities and schedules.	1	1.08
	Logging operational data such as time, location, speed, and activities performed.	1	0.6
	performing farming business management related activities	1	0.6
	Recording environmental/field conditions during operations.	1	0.6
	Managing precision farming files and recording of field data	1	1.08
	Total	**5**	**3.96**

Appendix D: **FARMER 2 QUESTIONNAIRE RESPONSE**

Tasks	Subtasks	Farmer 2	
		Road Mode	Field Mode
Driving task	Monitoring and responding to other vehicles or obstacles on the road.	45	1
	Ensuring the tractor stays within designated lanes, especially on highways or large fields.	36	6.48
	Adjusting speed according to terrain, obstacles, and safety requirements.	21.6	6.48
	low speed maneuvering in tight environments such as farmyards and field edges	27	6.48
	Back up tractor to an implement, or with an implement already attached	21.6	9.72
	Total	**151.2**	**30.16**
Operational tasks	control speed based on terrain and load.	4.32	9.72
	adjust implement depth/settings	5.76	12.96
	Detect unmapped obstacles and navigate around or through them.	21.6	23.04
	Monitoring towed equipment for potential failures	7.2	17.28
	Route planning and optimization.	3.24	3.24
	Total	**42.12**	**66.24**
Monitoring and information tasks	Gathering data on soil conditions and environmental factors.	5.4	1.44

	Analyzing data from onboard sensors and cameras.	4.32	1.44
	Providing feedback on operational efficiency.	3.24	1.44
	Real-time monitoring of engine performance and vital parameters.	3.24	1.44
	Monitoring fuel and DEF levels	2.16	1.44
	Total	**18.36**	**7.2**
Safety and emergency tasks	Emergency communication between operator and support staff.	6.48	4.32
	Collision detection and avoidance.	21.6	4.32
	Monitoring and alerting for dangerous weather conditions.	21.6	6.48
	Reacting to tractor/implement starting to get stuck	28.8	17.28
	Taking over from automated control of steering from the tractor	23.04	9.72
	Total	**101.52**	**42.12**
Comfort and convenience task	Fine tuning climate control settings	5.4	3.24
	Adjusting suspension systems for a smoother ride.	3.6	3.24
	Engaging with entertainment or connectivity options during periods of boredom	5.4	3.24
	Adjusting ergonomic of controls such as seat position	5.4	3.24
	Eating meals	9	5.76
	Total	**28.8**	**18.72**
Recording and documentation tasks	Maintaining records of maintenance activities and schedules.	2.16	1.44
	Logging operational data such as time, location, speed, and activities performed.	2.16	1.44
	performing farming business management related activities	2.16	1.44
	Recording environmental/field conditions during operations.	2.16	1.44
	Managing precision farming files and recording of field data	2.16	1.44
	Total	**10.8**	**7.2**

Appendix D: FARMER 3 QUESTIONNAIRE RESPONSE

Tasks	Subtasks	Road Mode	Field Mode
Driving task	Monitoring and responding to other vehicles or obstacles on the road.	36	N/A
	Ensuring the tractor stays within designated lanes, especially on highways or large fields.	36	36
	Adjusting speed according to terrain, obstacles, and safety requirements.	28.8	28.8
	low speed maneuvering in tight environments such as farmyards and field edges	4	10.8
	Back up tractor to an implement, or with an implement already attached	4.32	9.72
	Total	**109.12**	**85.32**
Operational tasks	control speed based on terrain and load.	21.6	36
	adjust implement depth/settings	N/A	2.16
	Detect unmapped obstacles and navigate around or through them.	21.6	27
	Monitoring towed equipment for potential failures	11.52	9
	Route planning and optimization.	2.16	4.32
	Total	**56.88**	**78.48**
Monitoring and information tasks	Gathering data on soil conditions and environmental factors.	1	0.36
	Analyzing data from onboard sensors and cameras.	2.16	3.6

	Providing feedback on operational efficiency.	5.76	5.4
	Real-time monitoring of engine performance and vital parameters.	14.4	9
	Monitoring fuel and DEF levels	5.76	2.88
	Total	**29.08**	**21.24**
Safety and emergency tasks	Emergency communication between operator and support staff.	9	7.2
	Collision detection and avoidance.	45	36
	Monitoring and alerting for dangerous weather conditions.	6.48	1.08
	Reacting to tractor/implement starting to get stuck	10.8	18
	Taking over from automated control of steering from the tractor	21.6	36
	Total	**92.88**	**98.28**
Comfort and convenience task	Fine tuning climate control settings	2.16	0.36
	Adjusting suspension systems for a smoother ride.	0.36	0.36
	Engaging with entertainment or connectivity options during periods of boredom	2.16	1.08
	Adjusting ergonomic of controls such as seat position	0.72	0.36
	Eating meals	1.44	0.36
	Total	**6.84**	**2.52**
Recording and documentation tasks	Maintaining records of maintenance activities and schedules.	N/A	0.36
	Logging operational data such as time, location, speed, and activities performed.	N/A	1.08
	performing farming business management related activities	N/A	0.6
	Recording environmental/field conditions during operations.	N/A	1.08
	Managing precision farming files and recording of field data	N/A	1.8
	Total	**N/A**	**4.92**

Appendix D: **FARMER 4 QUESTIONNAIRE RESPONSE**

Tasks	Subtasks	Road Mode	Field Mode
Driving task	Monitoring and responding to other vehicles or obstacles on the road.	27	2.16
	Ensuring the tractor stays within designated lanes, especially on highways or large fields.	45	4.32
	Adjusting speed according to terrain, obstacles, and safety requirements.	28.8	8.64
	low speed maneuvering in tight environments such as farmyards and field edges	17.28	17.28
	Back up tractor to an implement, or with an implement already attached	1.08	1.08
	Total	**119.16**	**33.48**
Operational tasks	control speed based on terrain and load.	36	5.76
	adjust implement depth/settings	N/A	0.72
	Detect unmapped obstacles and navigate around or through them.	N/A	0.36
	Monitoring towed equipment for potential failures	17.28	8.64
	Route planning and optimization.	2.16	0.36
	Total	**55.44**	**15.84**
Monitoring and information tasks	Gathering data on soil conditions and environmental factors.	0.6	N/A

	Analyzing data from onboard sensors and cameras.	N/A	0.36
	Providing feedback on operational efficiency.	1.08	1.44
	Real-time monitoring of engine performance and vital parameters.	0.36	2.88
	Monitoring fuel and DEF levels	1.44	1.44
	Total	**3.48**	**6.12**
Safety and emergency tasks	Emergency communication between operator and support staff.	28.8	23.04
	Collision detection and avoidance.	45	17.28
	Monitoring and alerting for dangerous weather conditions.	5.76	5.76
	Reacting to tractor/implement starting to get stuck	21.6	21.6
	Taking over from automated control of steering from the tractor	N/A	28.8
	Total	**101.16**	**96.48**
Comfort and convenience task	Fine tuning climate control settings	2.88	2.88
	Adjusting suspension systems for a smoother ride.	N/A	N/A
	Engaging with entertainment or connectivity options during periods of boredom	2.88	2.88
	Adjusting ergonomic of controls such as seat position	1.08	1.44
	Eating meals	1.08	1.08
	Total	**7.92**	**8.28**
Recording and documentation tasks	Maintaining records of maintenance activities and schedules.	N/A	0.72
	Logging operational data such as time, location, speed, and activities performed.	N/A	1.08
	performing farming business management related activities	N/A	1.08
	Recording environmental/field conditions during operations.	N/A	1.08
	Managing precision farming files and recording of field data	N/A	0.36
	Total	**N/A**	**3.24**

Appendix D: **FARMER 5 QUESTIONNAIRE RESPONSE**

Tasks	Subtasks	Farmer 5	
		Road Mode	Field Mode
Driving task	Monitoring and responding to other vehicles or obstacles on the road.	36	N/A
	Ensuring the tractor stays within designated lanes, especially on highways or large fields.	45	N/A
	Adjusting speed according to terrain, obstacles, and safety requirements.	21.6	11.52
	low speed maneuvering in tight environments such as farmyards and field edges	10.8	28.8
	Back up tractor to an implement, or with an implement already attached	10.8	21.6
	Total	**124.2**	**61.92**
Operational tasks	control speed based on terrain and load.	11.52	11.52
	adjust implement depth/settings	N/A	3.24
	Detect unmapped obstacles and navigate around or through them.	N/A	11.52
	Monitoring towed equipment for potential failures	17.28	17.28
	Route planning and optimization.	6.48	2.88
	Total	**35.28**	**46.44**
Monitoring and information tasks	Gathering data on soil conditions and environmental factors.	N/A	2.16

	Analyzing data from onboard sensors and cameras.	N/A	21.6
	Providing feedback on operational efficiency.	N/A	2.16
	Real-time monitoring of engine performance and vital parameters.	6.48	8.64
	Monitoring fuel and DEF levels	2.88	2.88
	Total	**9.36**	**37.44**
Safety and emergency tasks	Emergency communication between operator and support staff.	3.24	17.28
	Collision detection and avoidance.	7.2	27
	Monitoring and alerting for dangerous weather conditions.	0.72	1.44
	Reacting to tractor/implement starting to get stuck	2.88	8.64
	Taking over from automated control of steering from the tractor	N/A	14.4
	Total	**14.04**	**68.76**
Comfort and convenience task	Fine tuning climate control settings	2.16	4.32
	Adjusting suspension systems for a smoother ride.	4.32	2.16
	Engaging with entertainment or connectivity options during periods of boredom	N/A	2.88
	Adjusting ergonomic of controls such as seat position	2.16	4.32
	Eating meals	2.16	1.44
	Total	**10.8**	**15.12**
Recording and documentation tasks	Maintaining records of maintenance activities and schedules.	N/A	1.08
	Logging operational data such as time, location, speed, and activities performed.	0.72	1.08
	performing farming business management related activities	2.16	5.76
	Recording environmental/field conditions during operations.	N/A	1.44
	Managing precision farming files and recording of field data	N/A	8.64
	Total	**2.88**	**18**

Appendix D: **AVERAGE OF FARMERS' QUESTIONNAIRE RESPONSE**

Tasks	Subtasks	Average	
		Road Mode	Field Mode
Driving task	Monitoring and responding to other vehicles or obstacles on the road.	36.00	9.63
	Ensuring the tractor stays within designated lanes, especially on highways or large fields.	41.40	18.36
	Adjusting speed according to terrain, obstacles, and safety requirements.	29.16	20.09
	low speed maneuvering in tight environments such as farmyards and field edges	19.02	21.67
	Back up tractor to an implement, or with an implement already attached	9.00	12.74
	Total	**134.58**	**82.50**
Operational tasks	control speed based on terrain and load.	21.89	19.80
	adjust implement depth/settings	3.07	11.02
	Detect unmapped obstacles and navigate around or through them.	14.40	19.58
	Monitoring towed equipment for potential failures	19.66	17.64
	Route planning and optimization.	3.53	4.32
	Total	**62.54**	**72.36**
Monitoring and information tasks	Gathering data on soil conditions and environmental factors.	1.60	1.37

	Analyzing data from onboard sensors and cameras.	1.50	5.98
	Providing feedback on operational efficiency.	2.22	2.30
	Real-time monitoring of engine performance and vital parameters.	7.06	6.98
	Monitoring fuel and DEF levels	3.53	3.46
	Total	**15.90**	**20.09**
Safety and emergency tasks	Emergency communication between operator and support staff.	10.22	13.37
	Collision detection and avoidance.	26.76	25.92
	Monitoring and alerting for dangerous weather conditions.	7.78	7.27
	Reacting to tractor/implement starting to get stuck	14.26	14.90
	Taking over from automated control of steering from the tractor	8.93	24.98
	Total	**67.94**	**86.45**
Comfort and convenience task	Fine tuning climate control settings	3.96	3.60
	Adjusting suspension systems for a smoother ride.	1.90	1.73
	Engaging with entertainment or connectivity options during periods of boredom	2.66	2.59
	Adjusting ergonomic of controls such as seat position	2.45	2.45
	Eating meals	3.02	2.02
	Total	**13.99**	**12.38**
Recording and documentation tasks	Maintaining records of maintenance activities and schedules.	0.63	0.94
	Logging operational data such as time, location, speed, and activities performed.	0.78	1.06
	performing farming business management related activities	8.26	1.90
	Recording environmental/field conditions during operations.	0.63	1.13
	Managing precision farming files and recording of field data	0.63	2.66
	Total	**3.74**	**7.46**

Appendix E

Features Assigned to Tasks

Appendix E: **FEATURES ASSIGNED TO TASKS**

Tasks	Metrics
Ensuring the tractor stays within designated lanes, especially on highways or large fields.	Speed Reduction, Gear Shifting, Speed Control, Steering, Braking Systems, Lane Departure Warning, Operator Displays.
Monitoring and responding to other vehicles or obstacles on the road.	Operator Alerts, Blind Spot Monitoring, Operator Displays.
Adjusting speed according to terrain, obstacles, and safety requirements.	Speed Control Systems, Braking Systems, Operator Alerts, Traction Control, Engine Management Systems.
Collision detection and avoidance.	Blind Spot Monitoring, Speed Control, Speed Reduction, Gear Shifting, Speed Control, Steering, Braking Systems.
Control speed based on terrain and load.	Speed Control, Traction Control, Engine Management System, Operator Displays, Braking Systems.
Monitoring towed equipment for potential failures	Operator Alerts, Operator Displays, Emergency Shutdown, Hydraulic System.
Low speed maneuvering in tight environments such as farmyards and field edges	Precise Steering Control, Operator Displays, Speed Control, Speed Reduction, Gear Shifting, Blind Spot Monitoring.
Detect unmapped obstacles and navigate around or through them.	Precise Steering Control, Operator Displays, Speed Control, Speed Reduction, Gear Shifting.
Reacting to tractor/implement starting to get stuck	Traction Control Systems, Differential Locking, Wheel Slip Control, Speed Reduction, Gear Shifting.
Emergency communication between operator and support staff.	Mobile Phone Integration, Operator Display.

Tasks	Metrics
Back up tractor to an implement, or with an implement already attached	Rearview Camera Display, Hitch Systems, Precise Steering Control.
Taking over from automated control of steering from the tractor	Operator Alerts, Smooth Transition mechanism.
Performing farming business management related activities	Real-time Data Display, Communication Systems, Mobile Integration, Operator Display.
Monitoring and alerting for dangerous weather conditions.	Operator Alerts, Weather Monitoring Systems.
Real-time monitoring of engine performance and vital parameters.	Real-time Data Display
Fine tuning climate control settings	Climate Controls and Displays.
Route planning and optimization.	Fleet Management Integration, Interactive Touchscreen
Monitoring fuel and DEF levels	Real-time Data Display.
Adjust implement depth/settings	Hydraulic Control Systems, Touchscreen Display
Eating meals	Refrigerated Storage, Non-refrigerated Storage, Foldable Tray Table, Secure Cup Holders, Compact Microwave, Built-in Trash Bin.
Engaging with entertainment or connectivity options during periods of boredom	Voice Assistants, Touch Screen Display, Charging Ports.
Adjusting ergonomic of controls such as seat position	Touchscreen Display
Providing feedback on operational efficiency.	Interactive Display
Adjusting suspension systems for a smoother ride.	Axle Suspension,

Tasks	Metrics
Gathering data on soil conditions and environmental factors.	Interactive Display
Analyzing data from onboard sensors and cameras.	Interactive Display
Logging operational data such as time, location, speed, and activities performed.	Interactive Display
Maintaining records of maintenance activities and schedules.	Interactive Display
Recording environmental/field conditions during operations.	Interactive Display
Managing precision farming files and recording of field data	Interactive Display

Appendix F

Consent Forms

Appendix F: Ride-along with Farmers Consent Form

UM | Faculty of Agricultural and Food Sciences

Department of Biosystems Engineering
E2-376 EITC
Winnipeg MB R3T 5V6
CANADA

From Cab to Office: Redefining Tractor Cab Ergonomics for Semi-autonomous Machinery.

Principal investigator:
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This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you a basic idea of what the research is about and what your participation will involve. Please take the time to read this carefully and to understand any accompanying information. If you would like more details about something mentioned here, or information not included here, you should feel free to ask.

RESEARCH OBJECTIVE: The objective is to observe and document how farmers engage with their work environment inside the cab, discern the specific tasks they are performing, and gain insights into the ergonomic aspects of the design.

RESEARCH PROCEDURE: Two cameras will be positioned within the cab before commencing operations—one facing the front and the other facing the back. These cameras will initiate recording as soon as the farmer begins their tasks. The aim of this study is to accumulate a sufficient number of samples for an in-depth analysis of the tasks performed by operators and an evaluation of the ergonomic aspects of the design. Following the video collection, a thorough review will be conducted focusing on the order in which controls are used, the frequency of control usage, the duration the operator spends in awkward positions, and the presence of any visual indicators (sometimes referred to as ergo-triggers) that might suggest a “less than ideal” work environment.

RISKS: Your participation in this study does **NOT** have any risks.

ELIGIBILITY: Those below the age of 18 and individuals lacking prior experience in operating farm equipment will not qualify.

COSTS: Your participation in this study does **NOT** require any financial commitment on your part.

COMPENSATION: You will be offered a $100 Amazon e-gift card as an honorarium upon completion of the ride-along as compensation for your time.

CONFIDENTIALITY: Your personal information will be strictly confidential. It will not be cited nor used directly during analysis, publications, or any presentation. In all cases, only group average or summary will be presented to protect your identity. To further ensure the safety of your information, only the principal investigator, Ms. Dorsa Jeddi will have access to your data (identifiable and de-identifiable) while her supervisor, Dr. Danny Mann will only have access to your coded/de-identifiable data. A password protected computer will be used to access and analyze your information. All documents containing identifiable information will be stored in a locked drawer of a secured filing cabinet while all de-identifiable information will be stored in a second locked drawer of the same filing cabinet. By December 2029, hard copies of this consent form, and other documents containing your personal information will be deleted or destroyed to protect your identity.

DEBRIEFING: Formal feedback will not be provided immediately after the completion of the ride-along. However, the principal investigator will be willing to answer any questions that may arise. A summary of the study will be made available upon completion of the study (by June 2024) to participants who will indicate interest at the end of this consent form.

DISSEMINATION: Results from this study will appear in a M.Sc. thesis of the Department of Biosystems Engineering at the University of Manitoba as well as articles published through MSpace, in peer-reviewed scientific journals and conferences. The results will also be included in oral presentations that are open to the public. Some data and information from this study may be sent outside of the University of Manitoba to other researchers, organizations, or made publicly available. This is for further analysis, as part of the research study, or a requirement by a granting agency or journal. Any information sent out of the University of Manitoba will not show your name or address, or any other identifiable personal information about you. However, despite efforts to keep your personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law.

WITHDRAWING: Your participation in this study is voluntary. You are free to withdraw anytime you wish by notifying the principal investigator, and there are no consequences for withdrawing from the study. If you decide to withdraw from the study while in progress, the Principal Investigator, Ms. Dorsa Jeddi will delete all your data collected including those from the data collection computer and any back-ups on hard drives. Once the study process is complete, it would not be possible to remove your data which is approximately by February 2024 (withdrawal deadline).

Your signature on this form indicates that you have understood to your satisfaction the conditions regarding your participation in this study and have given your consent. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.
The University of Manitoba may look at our research records to see that the research is being done in a safe and proper way.

This research has been approved by the Research Ethics Board at the University of Manitoba, Fort Garry Campus. If you have any concerns or complaints about this project, you may contact any of the above-named people or the Human Ethics Coordinator at 204-474-7122, humanethics@umanitoba.ca.

A copy of this consent form has been given to you to keep for your records and reference.

Participant Name: ____

Participant Signature: ________________________ Date: _________________

Researcher Signature: ________________________ Date: _________________

☐ Please, check the box and provide your email and/or postal address if you are interested in receiving a summary of the findings of this research.

Email address: _______________________________________

Postal Address: ______________________________________

Appendix F: Farmer's Interview Consent Form

Department of Biosystems Engineering
E2-376 EITC
Winnipeg MB R3T 5V6
CANADA

From Cab to Office: Redefining Tractor Cab Ergonomics for Semi-autonomous Machinery.

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RESEARCH OBJECTIVE: The purpose of conducting a virtual interview is to gain profound insights into users' perspectives and experiences concerning the design. This process is geared towards collecting comprehensive information, enabling a thorough comprehension of how users engage with and perceive the design. Additionally, it aims to offer valuable insights into the ergonomic aspects of the design, shedding light on its suitability and comfort for users.

RESEARCH PROCEDURE: The research procedure involves the Principal Investigator (PI) outlining five main topics and asking questions from participants. These topics encompass various areas: firstly, understanding users' comfort levels and discomfort points in operating farm machinery, along with pinpointing tasks that may benefit from enhanced ergonomics. Secondly, investigating how the machinery's design influences users' workflow efficiency, and discerning features that hinder productivity. Thirdly, probing participants about their primary safety considerations when employing farm machinery, while also delving into how the design of the operator's workspace contributes to their overall comfort and well-being. Additionally, participants will be encouraged to provide feedback and suggestions, including ideas for integrating future tasks within the cab and proposing specific improvements for upcoming designs. Lastly, the research will explore users' sentiments regarding the integration of technology in modern farm machinery, as well as inquire about specific technological features that are perceived as particularly advantageous or challenging. This structured approach aims to comprehensively capture users' perspectives and experiences related to the design of farm machinery, ultimately informing future advancements in the field.

The questions asked in this study are **NOT** intended to test your intellectual competence. They are only meant to gather your opinion with regards to the experiment.

RISKS: Your participation in this study does **NOT** have any risks.

ELIGIBILITY: Those below the age of 18 and individuals lacking prior experience in operating farm equipment will not qualify.

COSTS: Your participation in this study does **NOT** require any financial commitment on your part.

COMPENSATION: You will be offered a $25 Tim Hortons e-gift card as an honorarium upon completion of the interview as compensation for your time.

CONFIDENTIALITY: Your personal information will be strictly confidential. It will not be cited nor used directly during analysis, publications, or any presentation. In all cases, only group average or summary will be presented to protect your identity. To further ensure the safety of your information, only the principal investigator, Ms. Dorsa Jeddi will have access to your data (identifiable and de-identifiable) while her supervisors, Dr. Danny Mann will only have access to your coded/de-identifiable data. A password protected laptop will be used to access and analyze your information. All documents containing identifiable information will be stored in a locked drawer of a secured filing cabinet while all de-identifiable information will be stored in a second locked drawer of the same filing cabinet. By December 2029, hard copies of this consent form, and other documents containing your personal information will be deleted or destroyed to protect your identity.

DEBRIEFING: Formal feedback will not be provided immediately after the completion of the questionnaire. However, the principal investigator will be willing to answer any questions that may arise. A summary of the study will be made available upon completion of the study (by June 2024) to participants who will indicate interest at the end of this consent form.

DISSEMINATION: Results from this study will appear in a M.Sc. thesis of the Department of Biosystems Engineering at the University of Manitoba as well as articles published through MSpace, in peer-reviewed scientific journals and conferences. The results will also be included in oral presentations that are open to the public. Some data and information from this study may be sent outside of the University of Manitoba to other researchers, organizations, or made publicly available. This is for further analysis, as part of the research study, or a requirement by a granting agency or journal. Any information sent out of the University of Manitoba will not show your name or address, or any other identifiable personal information about you.

However, despite efforts to keep your personal information confidential, absolute confidentiality cannot be guaranteed. Your personal information may be disclosed if required by law.

WITHDRAWING: Your participation in this study is voluntary. You are free to withdraw anytime you wish by notifying the principal investigator, and there are no consequences for withdrawing from the study. If you decide to withdraw from the study while in progress, the Principal Investigator, Ms. Dorsa Jeddi will delete all your data collected including those from the data collection computer and any back-ups on hard drives. Once the study process is complete, it would not be possible to remove your data which is approximately by February 2024 (withdrawal deadline).

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Participant Signature: ________________________ Date: _________________

Researcher Signature: ________________________ Date: _________________

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Email address: _______________________________________

Appendix F: Engineer's Consent Form

Department of Biosystems Engineering
E2-376 EITC
Winnipeg MB R3T 5V6
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RESEARCH OBJECTIVE: The goal of these interviews with engineers is to gather specialized knowledge in farm machinery design. Through targeted questions, it is aimed to understand their design considerations, experiences, technological influences, challenges, and their approach to incorporating feedback for iterative improvements.

RESEARCH PROCEDURE: The procedure involves conducting structured interviews with seasoned engineers specializing in farm machinery design. These interviews will revolve around a set of targeted questions aimed at extracting invaluable insights into various facets of their expertise. This begins with an exploration of their design considerations, seeking to understand the pivotal factors they prioritize when conceptualizing and crafting farm machinery, including the optimization of the operator's workspace within agricultural equipment.

Subsequently, the focus shifts to the engineers' experience and expertise. They will be encouraged to share specific examples of successful designs they have previously worked on, providing a window into their professional background and accomplishments. This discussion also delves into how their past experiences have influenced their approach to creating ergonomic workspaces within machinery. By following this structured procedure, we aim to tap into the engineers' wealth of knowledge.

The questions asked in this study are **NOT** intended to test your intellectual competence. They are only meant to gather your opinion with regards to the experiment.

RISKS: Your participation in this study does **NOT** have any risks.

ELIGIBILITY: Individuals who do not possess a minimum of five years of experience in designing agricultural equipment and lack prior proficiency in operating farm equipment will not meet the qualifications.

COSTS: Your participation in this study does **NOT** require any financial commitment on your part.

COMPENSATION: You will be offered a $25 Tim Hortons e-gift card as an honorarium upon completion of your interview as compensation for your time.

CONFIDENTIALITY: Your personal information will be strictly confidential. It will not be cited nor used directly during analysis, publications, or any presentation. In all cases, only group average or summary will be presented to protect your identity. To further ensure the safety of your information, only the principal investigator, Ms. Dorsa Jeddi will have access to your data (identifiable and de-identifiable) while her supervisors, Dr. Danny Mann will only have access to your coded/de-identifiable data. A password protected laptop will be used to access and analyze your information. All documents containing identifiable information will be stored in a locked drawer of a secured filing cabinet while all de-identifiable information will be stored in a second locked drawer of the same filing cabinet. By December 2029, hard copies of this consent form, and other documents containing your personal information will be deleted or destroyed to protect your identity.

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Participant Signature: ___________________________ Date: ___________________

Researcher Signature: ___________________________ Date: ___________________

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