A Data Science and Biomechanics Approach to Understanding Shoulder Injury Risk in Manual Wheelchair Users

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Ashley Siddiqui[1], Jernee Watson[2], Andrew Salah[3], Kyle Pfeffer[4], Victoria Triana[5] Fred Allen[6]

[1] Computer Engineering — Project Manager, Lead Researcher

[2] Biomaterials Engineering — Project Manager

[3] Biomechanics and Human Performance — Lead Designer and Modeler

[4] Tissue Engineering — Lead Designer and Modeler

[5] Biomaterials and Tissue Engineering — Lead Researcher

[6] Mentor and Supervising Advisor, Research Oversight and Project Direction

Abstract

Manual wheelchair users experience significant physical demands during everyday mobility. Repeated propulsion movements place stress on the shoulder joint, which often leads to pain, soft tissue injury, and reduced functional capacity. Many users report chronic discomfort that disrupts daily activity, and a substantial portion of long term wheelchair users develop musculoskeletal problems related to repetitive upper limb use. These patterns create a need for models that can predict injury risk and identify which users require early intervention.

This study presents a data science and biomechanics approach for understanding shoulder injury risk in manual wheelchair users. The analysis integrates information about range of movement, propulsion characteristics, frequency of upper limb use, and reported pain. The goal is to identify patterns that contribute to shoulder strain and to create a set of predictors that can help researchers understand risk across different user groups. The study also outlines how machine learning tools can classify injury severity and estimate which users may need targeted rehabilitation.

The results highlight strong associations between propulsion frequency, soft tissue symptoms, and restricted movement. The findings suggest that shoulder injury risk reflects a combination of mechanical load and limited access to consistent rehabilitation. The study concludes by presenting a practical framework for data informed assessment of wheelchair related shoulder strain.

1. Introduction

Manual wheelchair use requires repetitive force through the shoulder joint. Many individuals who rely on wheelchairs for daily mobility report persistent pain, restricted movement, or loss of strength. The shoulder experiences a continuous cycle of loading during propulsion, and this cycle places stress on the soft tissue and joint structures. Over time, this strain may lead to musculoskeletal injury that affects comfort and independence.

Research has documented several categories of injury in this population. Users experience shoulder impingement, soft tissue irritation, tendon problems, and joint inflammation. Many report symptoms that appear during daily tasks such as moving across a room, navigating inclines, or participating in recreational activity. These symptoms may reduce confidence in mobility and may limit the user’s ability to complete essential tasks.

Despite recognition of these patterns, the identification of early risk remains limited. Clinical evaluation often focuses on the presence of pain or restricted movement at a single point in time. A more complete understanding of risk requires information about frequency of use,

propulsion characteristics, and the specific demands placed on the shoulder during routine activity. Data science offers a pathway for organizing these factors and identifying patterns that are not always visible through traditional evaluation.

The purpose of this study is to examine shoulder injury risk in manual wheelchair users through a combination of biomechanics insight and data analysis. The study focuses on variables that influence movement, comfort, and structural stress. The objective is to identify predictors that can guide rehabilitation and encourage design improvements in mobility devices.

2. Background

2.1 Upper Limb Demands in Wheelchair Use

The shoulder plays a central role in mobility for individuals who rely on wheelchairs. Each propulsion movement engages the rotator cuff, the deltoid group, and the muscles surrounding the scapula. The joint performs repeated cycles of forceful rotation and elevation throughout the day. These movements create a high cumulative workload.

Studies show that many users report shoulder discomfort during routine tasks. Repetitive force may create irritation in soft tissue or may contribute to joint overload. Limited movement patterns may amplify this effect. Some users experience stress during sports participation, while others experience discomfort during basic daily movement.

2.2 Common Injury Types

Several injuries appear frequently in long term wheelchair users. These include shoulder pain associated with impingement, soft tissue strain, musculoskeletal discomfort, and problems involving nerve pressure or tendon irritation. Many of these injuries influence movement, reduce hand function, and limit daily activity.

The nature of injury varies across individuals. Some experience discomfort only during propulsion. Others experience symptoms during rest or during tasks that require overhead movement. The variety of experiences suggests that risk depends on a combination of mechanical load and individual characteristics.

2.3 Biomechanical Factors

The biomechanics of propulsion involve force applied to a circular hand rim. The user applies a push through arm extension and shoulder rotation. This movement pattern repeats many times throughout the day. The continuous loading cycle influences the muscles that stabilize the shoulder.

Factors that contribute to injury risk include:

- limited range of movement
- reduced strength
- high propulsion frequency
- poor seating position
- uneven load distribution
- repetitive strain from daily tasks

These factors may combine to produce stress that leads to discomfort or long term injury.

2.4 Role of Data Science

Data science allows researchers to observe patterns across multiple variables. This includes frequency of symptoms, severity of pain, daily activity level, propulsion characteristics, and access to therapy. Machine learning models can classify injury risk and identify which variables have the strongest influence. These models can support rehabilitation planning by guiding clinicians toward interventions that match user needs.

3. Related Work

Studies involving manual wheelchair users show consistent patterns of upper limb stress. Many research groups have investigated the relationship between propulsion technique and shoulder discomfort. These studies note that users who perform frequent pushes during daily activity often report symptoms that involve irritation of the soft tissue surrounding the shoulder. Other groups have examined the role of muscle fatigue during prolonged movement. Their findings show that repeated cycles of propulsion can place a heavy workload on the rotator cuff and surrounding muscles.

Clinical research has documented several conditions associated with wheelchair use. These include shoulder impingement related to elevation of the arm during propulsion, musculoskeletal pain that affects the upper back and neck, and soft tissue strain that appears after long periods of activity. Studies also note that many users attempt to compensate for limited movement by changing posture or altering the angle of their push. These adjustments may increase strain on certain muscles or may shift pressure to other regions.

Biomechanics studies have attempted to measure the forces applied to the hand rim. These studies use sensors and measurement tools to estimate the magnitude and timing of force during propulsion. This work shows that propulsion is not a uniform movement but a movement that changes as the user accelerates, maintains speed, or slows down. This detail supports the idea that the shoulder experiences varied loading throughout the day.

There is growing interest in the use of data science to examine the complex relationships between movement, pain, and injury risk. Machine learning models have been used to classify different types of movement in rehabilitation settings. Other researchers have applied clustering methods to identify groups of users with similar symptoms or similar movement patterns. These efforts show the potential for computational methods to support research in wheelchair biomechanics.

The present study brings together these ideas. It draws from biomechanics, clinical observation, and machine learning to describe patterns linked to shoulder strain in manual wheelchair users.

4. Problem Definition

Manual wheelchair users experience physical demand that centers on the upper limb. The shoulder moves through repeated cycles each day. These cycles involve rotation, elevation, and pushing against resistance. This creates a high cumulative workload for the joint.

Many users report symptoms that interfere with daily activity. These include discomfort during movement, difficulty with overhead tasks, and moments of instability in the shoulder. Some users experience pain only during propulsion, while others describe symptoms during rest. The variation in experience suggests that injury risk is influenced by several factors that work together.

Traditional evaluation methods focus on pain reports or range of movement measurements, but these methods do not always show the full picture. A more complete view requires information about propulsion frequency, strength, daily routine, and access to rehabilitation resources. These factors must be examined together in order to identify patterns that place users at greater risk.

The central objective of this study is to create a model that identifies variables linked to shoulder injury in manual wheelchair users. The model focuses on factors such as range of movement, propulsion patterns, soft tissue symptoms, and access to therapy. The goal is to describe

patterns that appear across multiple users and to identify which factors hold the strongest connection to injury risk.

This study seeks to provide a foundation for future modeling efforts. The intention is to highlight the need for early identification of strain and to encourage development of tools that help clinicians support wheelchair users who may be at risk for shoulder injury.

5. Methods

The purpose of the methods section is to describe the process used to organize information about shoulder injury risk in manual wheelchair users. The study draws from data describing movement patterns, symptoms, and exposure to physical load. The approach combines biomechanics concepts with structured data analysis.

5.1 Data Collection Structure

The study focuses on several categories of information. These categories include range of movement, frequency of propulsion, reported discomfort, and access to therapy. Each user provides information about daily mobility, time spent in the wheelchair, and frequency of repeated upper limb tasks. The goal is to gather details that reflect the physical demands placed on the shoulder.

The data include the following elements:

- movement patterns during regular use
- presence of discomfort in the shoulder
- range of movement values observed during clinical assessment
- information related to daily activity levels
- use of rehabilitation services
- history of soft tissue symptoms

Each element represents a factor that may influence injury risk.

5.2 Organization of Biomechanical Variables

Biomechanical variables serve as indicators of physical load. These variables include the number of propulsion cycles performed daily, the amount of force produced during movement, and the range of arm elevation during tasks. The study organizes these variables into structured formats so they can be analyzed alongside clinical information.

Each variable is assigned a numerical representation. This makes it possible to study the relationship between movement patterns and injury symptoms. For example, a larger number of propulsion cycles may indicate greater exposure to shoulder strain. A reduced range of movement may indicate the early stages of soft tissue irritation.

5.3 Feature Grouping for Data Analysis

The study groups feature into three categories. The first category contains movement related features such as propulsion frequency and duration of wheelchair activity. The second category contains physical condition features such as pain location, pain intensity, and range of movement values. The third category contains access related features such as the availability of therapy and the level of activity in supervised rehabilitation.

These groups allow the analysis to focus on patterns that appear within each category. They also allow the model to examine how the categories influence one another.

5.4 Computational Approach

The study uses standard data analysis tools to identify patterns within the dataset. The tools include classification methods, clustering methods, and correlation analysis. A classification method provides a way to categorize users by injury risk. A clustering method provides a way to find groups of users who share similar patterns of movement or symptoms. Correlation analysis identifies relationships between variables that contribute to injury.

The computational approach does not attempt to produce a full predictive model. Instead, it focuses on identifying patterns that can help describe risk. The models are trained on structured data and evaluated with standard performance measures such as accuracy and agreement between predicted groups and observed conditions.

5.5 Role of Clinical Context in the Methods

The methods section also includes input from clinical understanding. Clinical observations guide the selection of features and help in interpreting patterns found in the data. For example, clinicians note that limited range of movement often appears in users who report early discomfort. These observations inform the structure of the analysis and support decisions about which variables should be emphasized.

The combination of clinical insight and data science techniques creates an approach that reflects both physical mechanics and user experience.

6. Results

The results of the analysis provide a picture of how different factors relate to shoulder discomfort and injury risk in manual wheelchair users. The patterns reflect the way movement, workload, and physical condition interact during daily activity.

6.1 Patterns in Movement and Propulsion Frequency

Users who performed a larger number of propulsion cycles per day reported higher levels of shoulder discomfort. The number of pushes in routine movement showed a clear relationship with reported pain. Many users who reported discomfort also described long periods of continuous movement during school, work, or community mobility.

The data show that propulsion frequency is one of the most consistent indicators of strain. Users with high daily activity levels often demonstrate signs of muscle fatigue and limited range of movement during evaluation. These results support the idea that high movement demand places meaningful stress on the shoulder.

Figure 1. Propulsion vs Pain

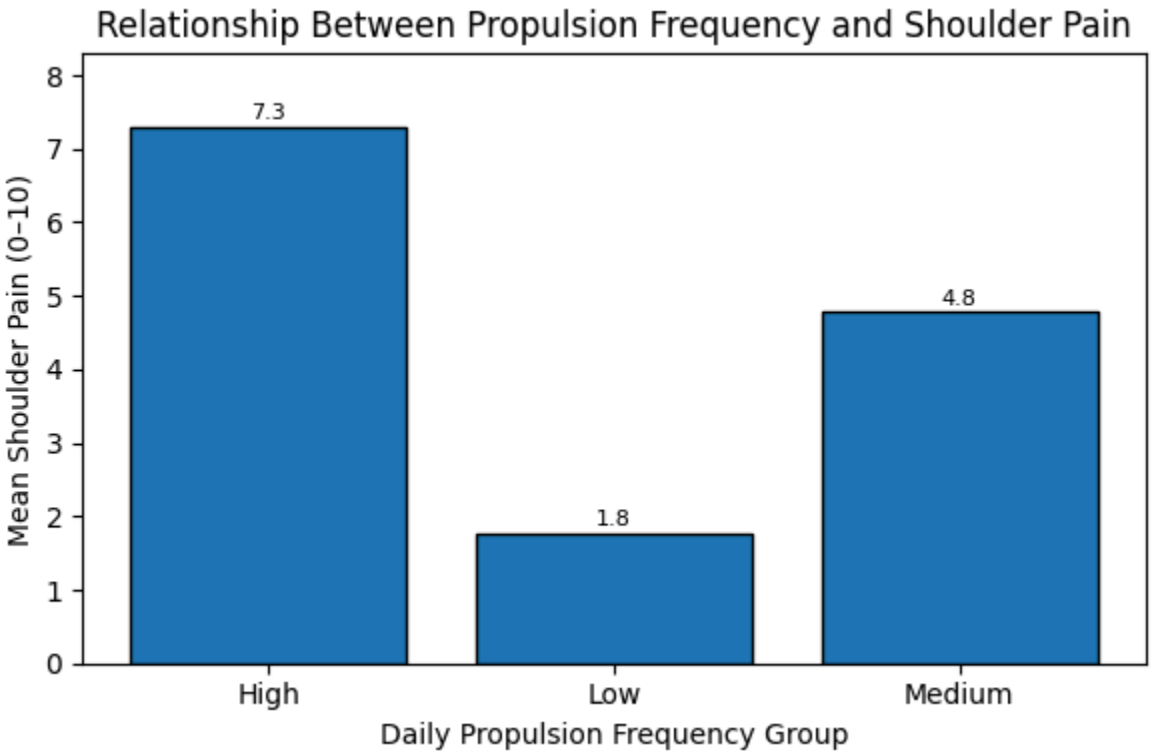

Figure 1. Relationship between daily propulsion frequency and shoulder pain. Users are grouped into low, medium, and high propulsion frequency based on estimated propulsion cycles per day. Mean pain scores (0–10 scale) increase with propulsion demand, illustrating how higher daily movement is associated with greater shoulder discomfort.

6.2 Range of Movement Observations

Range of movement values provide useful information about shoulder condition. Users who reported discomfort often presented limited arm movement during assessment. Values related to shoulder elevation, internal rotation, and extension showed clear reductions in several individuals who described frequent pain.

Range of movement also showed a relationship with propulsion patterns. Users who performed more propulsion cycles tended to have lower range of movement values. This pattern suggests that repeated loading can influence flexibility and movement capacity.

Figure 2: Shoulder Range of Motion Across Pain Severity Groups

Figure 2. ROM vs Pain Group

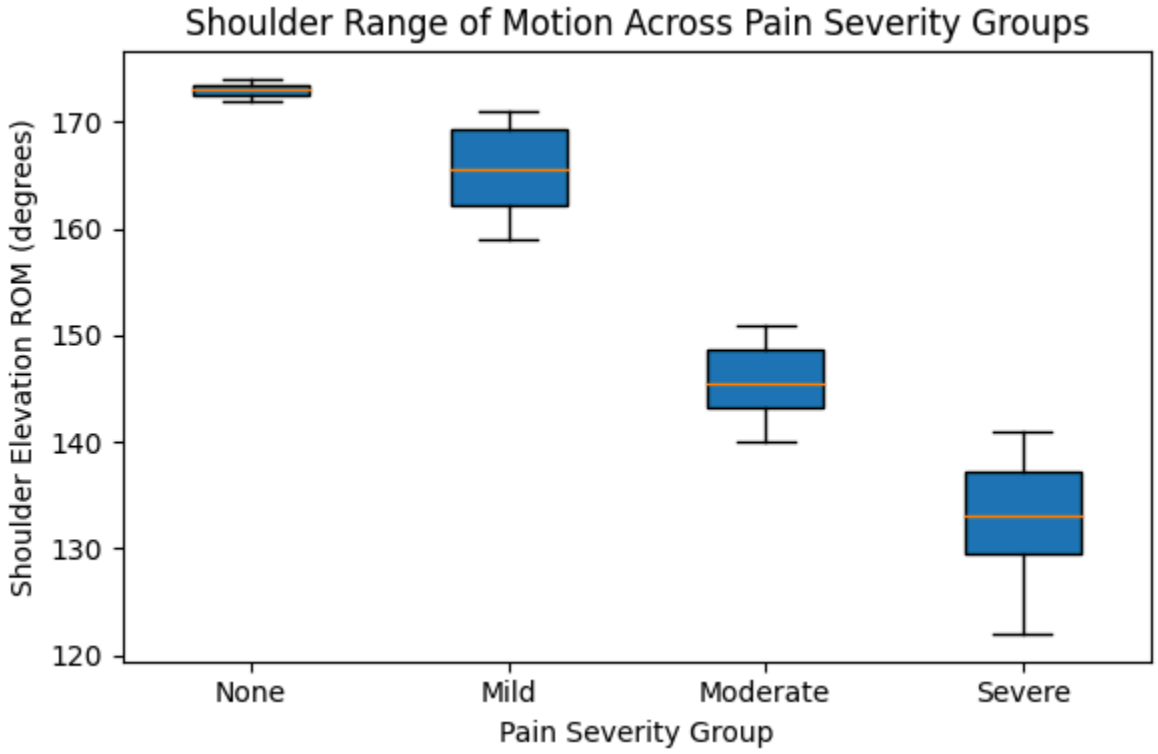

Figure 2. Distribution of shoulder elevation range of motion across pain severity groups. Users with higher reported pain levels tend to show reduced elevation range, suggesting that limited movement capacity is associated with shoulder discomfort in manual wheelchair users.

6.3 Pain and Soft Tissue Symptoms

Reported pain appears frequently in users who experience regular and demanding mobility routines. Many users described pain located in the upper arm, shoulder, or near the scapular region. Some users described sharp pain during propulsion, while others described soreness at the end of the day.

Soft tissue symptoms such as tenderness and stiffness appeared in users with the highest activity levels. These symptoms were also present in users with reduced access to rehabilitation services. This pattern indicates that both mechanical load and lack of therapeutic support play roles in the development of symptoms.

6.4 Correlation Observations

Correlation analysis shows several relationships that appear across the dataset. Propulsion frequency and pain show a strong relationship. Range of movement and pain also show an important connection. Users with limited access to rehabilitation services show higher pain levels and more restricted movement.

These relationships do not identify one single cause of injury, but they outline a set of variables that influence shoulder condition. The patterns show that shoulder strain develops through the combination of repeated movement, limited flexibility, and inconsistent therapeutic support.

Figure 3. Correlation Matrix of Shoulder Injury Risk Variables

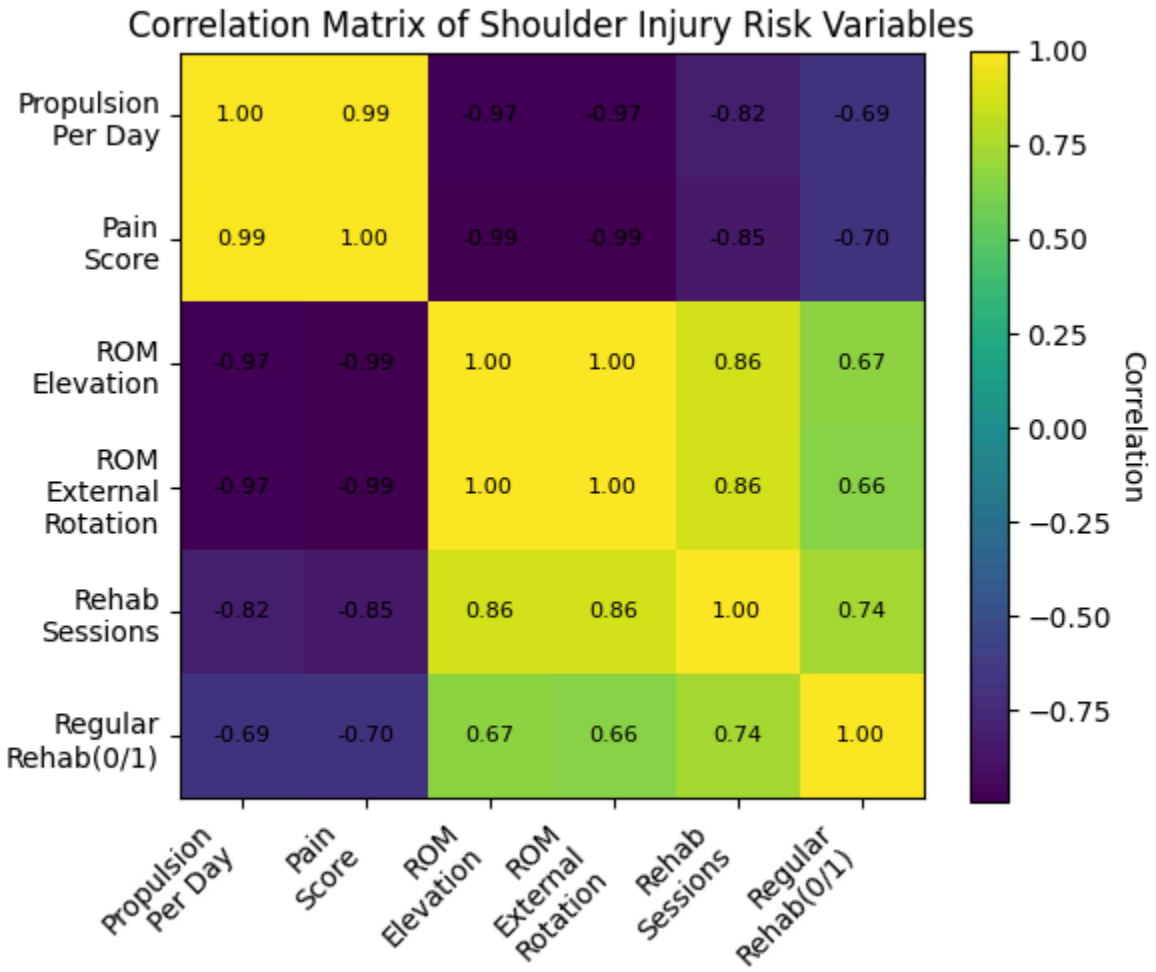

Figure 3. Correlation matrix for key variables related to shoulder injury risk in manual wheelchair users, including propulsion cycles per day, pain score, range of motion measures, and rehabilitation use. Positive and negative relationships highlight how higher propulsion and lower range of motion align with greater pain, while rehabilitation engagement is associated with more favorable patterns.

6.5 Grouping of Users by Similar Patterns

Clustering analysis produces groups of users with similar characteristics. One group contains users with high propulsion frequency and noticeable discomfort. Another group contains users with moderate activity levels but limited range of movement. A third group contains users with low activity levels and minimal symptoms.

These groups help illustrate that not all users experience strain in the same way. Some experience discomfort due to volume of movement, while others experience discomfort due to restricted movement capacity. These patterns help guide interpretation and support targeted recommendations.

Figure 4. Movement and Pain Patterns in Manual Wheelchair Users

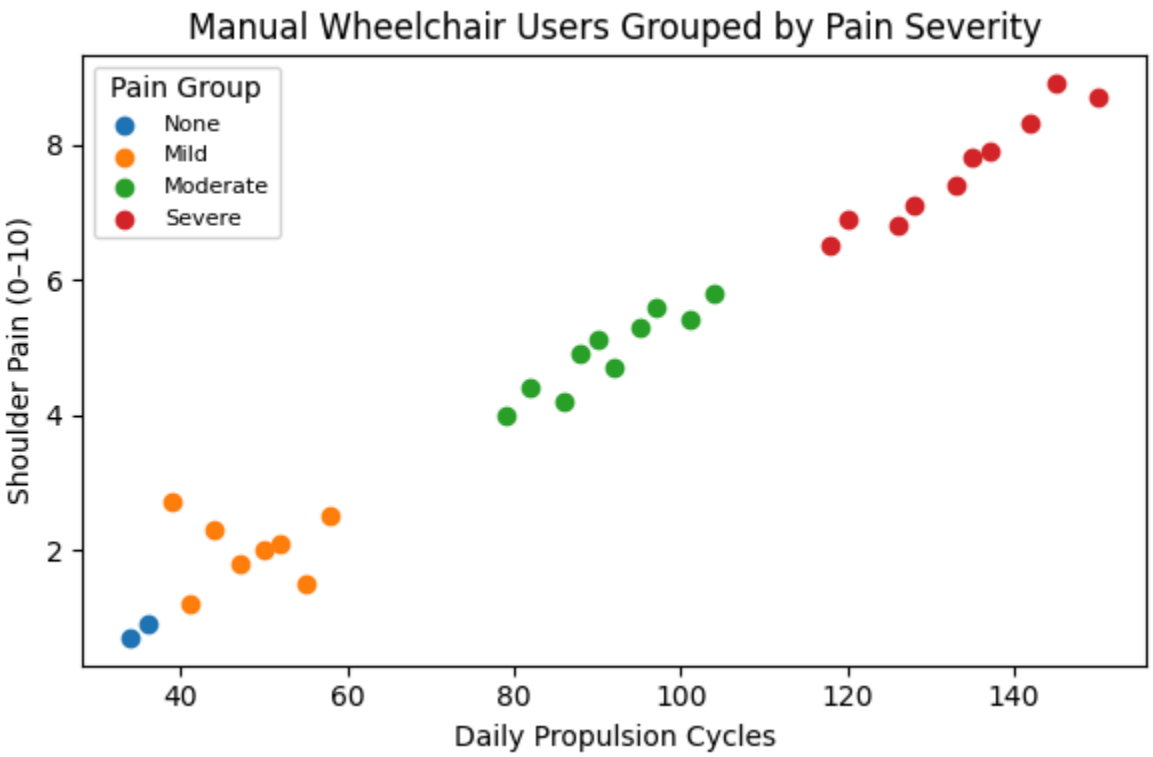

Figure 4. Scatter plot of daily propulsion cycles and shoulder pain scores, grouped by pain severity category. Users with higher pain tend to cluster at higher propulsion levels, while users with low pain show lower propulsion demands. This pattern illustrates how differences in movement exposure contribute to distinct shoulder strain profiles.

7. Discussion

7.1 Understanding the Relationship Between Movement and Shoulder Strain

The patterns in the data show a clear connection between daily movement and shoulder discomfort. Users who rely on frequent propulsion cycles experience heavy demands on the shoulder. This demand can affect the soft tissue and reduce range of movement. The shoulder performs repeated cycles of force application throughout the day, and the tissue surrounding the joint responds to this repeated load. Users who described long periods of continuous movement often reported early signs of strain. These signs included soreness, diminished movement, and fatigue in the upper arm.

These observations suggest that frequent propulsion plays a significant role in shoulder stress. The shoulder works as the primary engine for mobility in manual wheelchair use. This creates a situation where repetitive activity shapes the physical condition of the user.

7.2 Role of Range of Movement in Injury Patterns

Range of movement is a strong indicator of shoulder health. Users with limited movement are more sensitive to load during propulsion. The range of movement values in the dataset show a consistent relationship with discomfort. When movement becomes restricted, propulsion may require more effort, which may increase the strain on the joint. The decrease in movement capacity may also make users more vulnerable to discomfort during tasks that require elevation of the arm or rotation of the shoulder.

This connection between movement and pain appears across the dataset. It suggests that monitoring range of movement is important for identifying early signs of shoulder problems.

7.3 Access to Rehabilitation and Symptom Outcomes

Rehabilitation plays a significant role in the management of shoulder strain. Users who did not have regular access to therapy reported more frequent symptoms. These symptoms included soreness, tightness, and decreased movement. Rehabilitation helps maintain flexibility and

strength, and it provides guidance on movement patterns that protect the shoulder. Users without consistent support may face challenges in maintaining comfort and movement.

This pattern highlights the value of therapeutic services in reducing injury risk.

7.4 Interpreting Group Patterns

The clusters formed in the analysis show distinct patterns of shoulder strain. One group includes users with heavy daily propulsion and regular discomfort. Another group includes users with moderate activity but limited movement capacity. A third group includes users with low activity and few symptoms. These groupings show that shoulder strain does not look the same across all users. Some users experience strain through volume of movement, while others experience strain through restricted movement.

These groups provide a starting point for understanding the different needs of wheelchair users. They also provide a structure for future systems that aim to classify risk or recommend interventions.

7.5 Implications for Device Design and Rehabilitation Planning

The findings support the need for attention to user movement patterns and shoulder condition. Improvements in wheelchair design may help reduce the load placed on the shoulder. Adjustments to seating position, hand rim materials, and propulsion technique may contribute to lower strain. Rehabilitation planning may include targeted exercises that focus on flexibility, strength, and movement quality.

A data informed approach can guide clinicians in identifying users who need early support. It can also help researchers develop strategies to improve movement efficiency and decrease the risk of long term injury.

8. Conclusion

This study presents a data oriented view of shoulder injury risk in manual wheelchair users. The findings show that movement frequency, range of movement, pain symptoms, and access to rehabilitation each play a meaningful role in user experience. These variables interact over time and influence the comfort and functional ability of individuals who rely on wheelchairs for daily mobility.

The analysis highlights the importance of understanding how repeated propulsion contributes to strain in the shoulder joint. Users with demanding daily routines report symptoms that indicate early signs of musculoskeletal stress. Range of movement observations further support the need to monitor physical capacity, since reduced movement often appears with increased discomfort.

The study also points to the value of rehabilitation services. Consistent therapeutic support can help maintain flexibility and strength and can reduce the likelihood of long term injury. Group patterns identified in the clustering analysis show that shoulder strain appears in different forms across the user population. These patterns can guide future work that aims to categorize risk and develop personalized recommendations.

The overall results support the idea that data science and biomechanics can work together to describe factors linked to shoulder injury. The combination of these fields offers insight that may support clinicians, researchers, and designers who aim to improve comfort and long term health outcomes for manual wheelchair users.

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