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Wearable Sensor Technology:
Quantifying Ergonomic Risk within the Hemp Industry

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Author Note: Julia Boyd has 23 years of experience working in health and safety. She is an assistant professor in the Occupational Safety and Health Department at Murray State University, where she has taught for the past eight years. Dr. Julia Boyd earned her PhD in Occupational Safety and Health from Capitol Technology in 2021, graduated with her Masters in Occupational Safety and Health with an IH emphasis from Murray State University in 2001. She is a Certified Industrial Hygienist (CIH-CP 12267). Her background includes EHS and continuous improvement within automotive and food manufacturing. Dr. Boyd possesses expanded knowledge in ergonomics. She utilized sensor technology to conduct ergonomic risk assessments in agricultural and manufacturing settings. Acknowledgements: Dr. Linda Martin and Dr. Angela Giotto for their encouragement and support throughout the dissertation process, Hempwood, BCSP for my doctoral grant, Liberty Mutual for my doctoral ASSP scholarship both provided financial funding for research equipment, and lastly, all my family, friends and colleagues who came alongside me during this journey.

Abstract: Upon the passage of the 2018 U.S. Farm Bill (Federal Register, 2019), legalizing commodity hemp, industrialized hemp's growth and production have shown significant growth across the nation. Addressing the need for an innovative approach to tackle growth challenges, this study aims to equip practitioners with tools to swiftly and objectively assess ergonomic risk and implement controls to prevent musculoskeletal diseases. Furthermore, technological advancements like sensor technology have made it possible to apply these tools to almost any workplace, revolutionizing the field of occupational safety.

The crux of this study is to evaluate the ergonomic risk from the hemp harvest to the finished product. The study helps bridge the gap between musculoskeletal symptoms and risk assessment for labor-intensive manual agricultural processes. To achieve this, the researcher adopted a cutting-edge approach using sensor technology. In this context, the role of Artificial Intelligence (AI) in OEHS environments is paramount, enhancing awareness and preventing safety and health injuries. This technology not only quantifies risks but also supports process improvements and validations. Moreover, it serves as a training tool for employees, enhancing their understanding of ergonomic risks.

The site chosen for this research, collects harvested hemp scraps from various hemp farmers, and processes them into hardwood products, mainly flooring. The population chosen for the researcher's study was an industrial hemp-processing site with a working population of 20 employees. The researcher's hypothesis: Does a significant association exists between proclaimed musculoskeletal symptoms and ergonomic hazard classification? The research question: Do the musculoskeletal symptoms listed during the employee interviews, correlate to the ergonomic hazard rating for their job classification? The study-involved participant surveys, the Nordic Questionnaire, RULA, and non-invasive, wireless sensor technology to provide real-time data directly to the data collector's smartphones. This ergonomic sensor technology can wirelessly measure and assess challenging postures, such as repetitive, sustained, and muscle activity.

Multinomial regression was utilized to predict if a positive relationship exists between musculoskeletal disease presence, worker fatigue, RULA score, and shoulder/back sensor scores. All three variables added statistical significance to the prediction, $p < .05$; overall p-value for the model selected was .02, which is less than .05; the null hypothesis was proven to be significant. The researcher's question was answered, and the hypothesis proven. A significant association does exist between proclaimed musculoskeletal symptoms and ergonomic hazard classification from task analysis. The strongest associations were noted with the back and shoulder sensor data, followed by worker fatigue.

Keywords: Ergonomics, Sensor Technology, Agriculture, Hemp, Artificial Intelligence, Harvest, Risk Assessment

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1. Wearable Sensor Technology: Quantifying Ergonomic Risk within the Hemp Industry

U.S. Bureau of Labor Statistics data shows that agriculture continues to be the highest risk industry for injury and fatalities, coming in with 574 fatalities in 2018, or an equivalent of 23.4 deaths per 100,000 workers (Center for Disease Control, 2021). Improving worker safety in manual agricultural processes is a paradigm. Scholarly research studying the risk for musculoskeletal disorders in select manual agricultural processes has increased, however the research on the manual industrial hemp processes is scarce.

The United States' 2018 Farm Bill was instrumental to agricultural farmers because it removed industrial hemp from a controlled substance (Federal Register, 2019). This bill initiated industrial hemp growth, predominantly for Cannabidiol (CBD) oil products, but more recently, fiber hemp has taken off for its use in sustainable building materials. The fast growth of the industrial hemp industry has created a need for research to determine the short and long-term exposure risks. Current technology and equipment engineering to improve this process has only just begun. Every step involved from cutting, collecting, and processing involves very labor-intensive methods, adding to the risk for worker's risk for future musculoskeletal disease (Hopkins, 2015).

An ergonomic risk assessment had not been conducted on the industrial hemp process at the time this research was conducted. The researcher evaluated those tasks to identify any ergonomic risk that could lead to the agricultural worker being prone for developing musculoskeletal disorders.

This research study systematically reviewed each component in the process to evaluate the ergonomic risk and quantify the severity. Evaluation is necessary to recognize risk factors and determine the effectiveness of an implemented procedure (Castaneda; et al., 2020). Additionally, duration of each task was to address worker fatigue, leading to an increased risk for musculoskeletal disorders.

The study used a combination of qualitative, semi-quantitative, and quantitative research methods to analyze the ergonomic risk involved with each task. The human ergonomic exposure in each task involved with processing must be thoroughly assessed in detail. The study results will provide needed data that can be used to improve the industrial hemp process.

2. Methodology Selected

Agriculture is one of the most hazardous industries (Widyanti, 2018), and presents more tasks involving stooped posture and repetitive manual tasks (Jain et al., 2018). A common complaint among agricultural workers is musculoskeletal disorders (Widyanti, 2018). The proper ergonomic tools must be chosen to adequately and fully capture the risk encountered in agriculture. A variety of techniques have been developed to predict and assess these risk factors (Sadeghi Yarandi et al., 2019).

After an extensive review of related research methods, the author chose to apply three ergonomic methods. The methods chosen were the following: Rapid Upper Limb Assessment (RULA), Sensor Technology, and the Nordic Questionnaire.

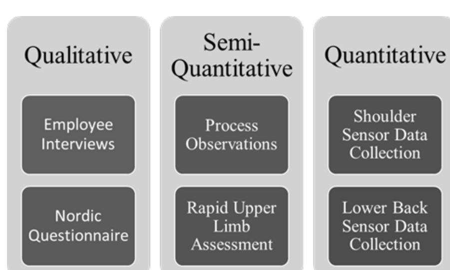

Figure 1. Methods

2.1 RULA

The semi-quantitative method chosen by the researcher is the RULA assessment (Middleworth, 2021). The researcher selected this method because scholarly research shows this method is preferred when evaluating upper extremity postures and provides consistent results. The researcher must complete the score sheet for both the right and left sides of the individual. The researcher will go by the worst-case scenario posture when evaluating a task because it uses static postures. Figure 2 above illustrates the posture scales utilized for the study.

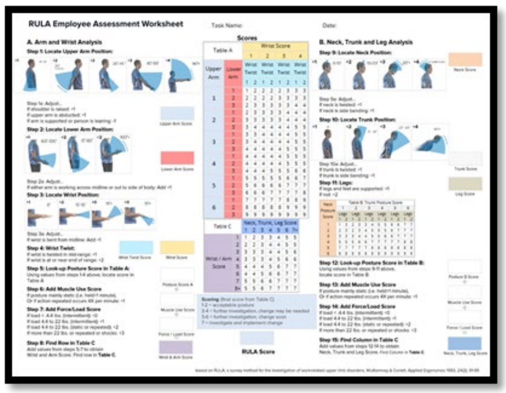

Figure 2. Rapid Upper Limb Assessment

The RULA method provides a cumulative score that considers loading on the entire body give more focus to the neck, trunk, shoulders, arms, and wrists regions and while accounting for force and repetition (Vazquez-Cabrera, 2016). This method was chosen because agricultural tasks are considered high risk when it relates to musculoskeletal disorders.

2.2 Sensor Technology

Technological advancements allow a combination effect to produce more reliable results (Gómez-Galán et al., 2020). Technology allows for sensors to address the gaps noted in previous research regarding the RULA method. Poitras et al. (2019) conducted a literature review study on the validity of sensor-worn technologies. The study revealed shoulder studies were limited due to a limited amount of literature available, but the back studies showed moderate validity.

The quantitative method chosen by the researcher will be the sensor technology provided by DorsaVi, a biotechnology company based out of Australia. There is no funding or conflict of interest regarding the technology chosen by the researcher. DorsaVi's technology allows the observer to use sensors in combination with smartphone technology to measure the worker's postures accurately. This technology can assess challenging postures, repetition of movement, sustained movement, and muscle activity. Four mini-sensors and a desktop dashboard allows the researcher to view the participants range of motions while performing given work tasks. The sensors are worn on the back and shoulder, capturing real-time movement in the workplace.

Newer technology that uses smartphones connected to wireless sensors is rising in popularity. These methods have the advantages of being portable, which makes it possible to monitor workers' postures during their workday (Mjøsund et al., 2017). Mjøsund et al. (2017) research validated that sensor technology is acceptable compared to 3D modeling results.

2.3 Nordic Questionnaire

The researcher chose Nordic Questionnaire as a subjective survey that pinpoints musculoskeletal symptoms among industrial hemp workers. Employee interviews and job task observation is considered a qualitative method. Table 1 depicts how the Nordic Questionnaire is conducted.

The qualitative approach is to interview the workers about musculoskeletal symptoms in different body regions in a standardized method. The Nordic Questionnaire uses a series of questions that address nine regions of the interviewees' body. There are 28 multiple-choice ("yes" or "no") questions that ask about any pain in these regions during the last 12 months / 7days, and the second section addresses musculoskeletal symptoms that subjects experience during their working life (López-Aragón et al., 2017).

Reference Figure 3, listed below, allows for a better visual concept of the Nordic Questionnaire Survey. López-Aragón et al. (2017) noted that the Nordic Questionnaire could detect musculoskeletal disorders in industries that can be difficult to solve, such as agriculture. The Nordic Questionnaire will determine the prevalence of musculoskeletal disorders among tasks that are high risk in nature.

This method has the following advantages: quick, standardized, recognized worldwide, and utilized commonly in conjunction with RULA and REBA techniques (López-Aragón et al., 2017). The popularity of the Nordic Questionnaire has grown among researchers over the years. It is used in a variety of fields and, most importantly, frequently used with agricultural research.

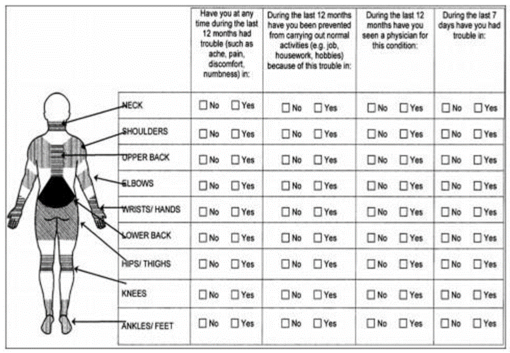

Figure 3. Nordic Questionnaire

3. Statistical Analysis

To answer the researcher's four research questions, this study aims to determine the association of the agricultural worker's demographic information, sensor technology data, and RULA data (independent variables). The researcher will collect data utilizing the Nordic Questionnaire to reveal specific regions of musculoskeletal discomfort (dependent variable).

3.1 Software

The IBM SPSS software was used for statistical analysis. The statistical investigations of the individual work-related risk factors identified in the Nordic Questionnaire will be compared to the RULA and Sensor data collected to evaluate if an association/correlation exists between the different data subsets. Table 1 shows the Nordic Questionnaire results collected from study participants.

4. Results

Table 1. Nordic Questionnaire

	Have you at any time during the past 12 months had trouble (such as ache, pain, discomfort, numbness) in:	
	Yes	No
Neck	35.3%	64.7%
Shoulders	17.6%	82.4%
Upper Back	23.5%	76.5%
Elbows	11.8%	88.2%
Wrists/Hands	11.8%	88.2%
Lower Back	58.8%	41.2%
Hips/Thighs	11.8%	88.2%
Knees	35.3%	64.7%
Ankles/Feet	23.5%	76.5%

4.1 RULA Results

The dataset contains 128 comprehensive observations. The researcher conducted a RULA observation on both sides of the employee's body. The researcher observed sixteen participants. The researcher removed 64 of the 128 comprehensive observations to focus on the side of the participant's body that showed the highest risk during the task being assessed.

The data was collected using a systematic approach to evaluate body posture, force, and repetition involved with each job classification. The researcher took each job classification and sectioned it into steps. Those steps were then assessed for postures involving the participants arm & wrist postures and the neck, trunk, and leg support. Figure 4 and Table 2 show the RULA scoring system utilized by the researcher.

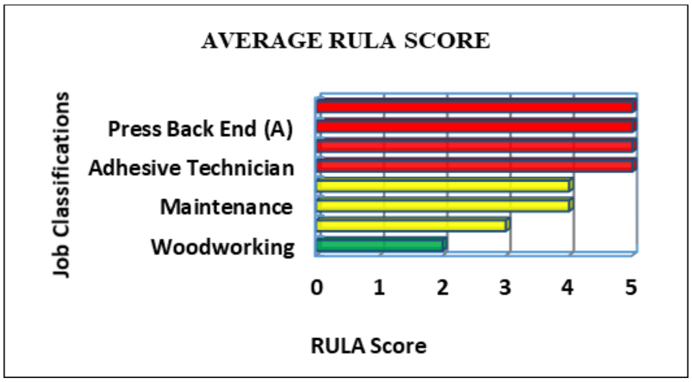

Figure 4. RULA Scores

Table 2. RULA Score Rubric

RULA Score	Recommendations
1-2	acceptable posture
3-4	further investigation, change may be needed
5-6	further investigation, change soon
7+	investigate implement change

4.2 Sensor Technology Results

Figure 5 shows how the sensors utilize heat mapping to measure the shoulder range of motion risk.

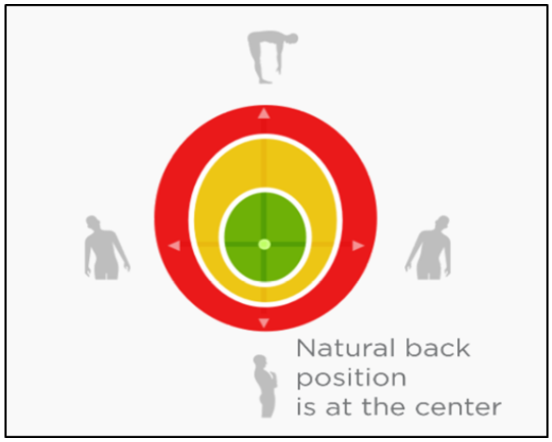

Figure 5. Heat map showing shoulder range of motion risk

Figures 6 & 7 show the sensor data for the Material Handling job classification. Figure 6 shows participant ergonomic shoulder risk to be high; the participant spent more than 10% (Left-33%; Right-36%) of the time in the high-risk shoulder range. Figure 7 shows the research participants' ergonomic back risk to be high; the participant spent 29% in the high-risk back range.

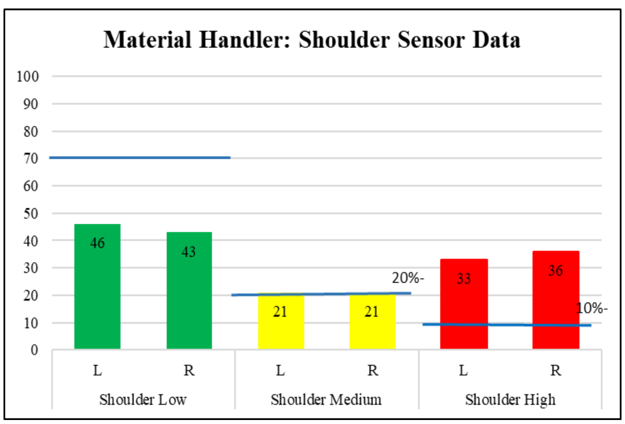

Figure 6. Shoulder sensor data

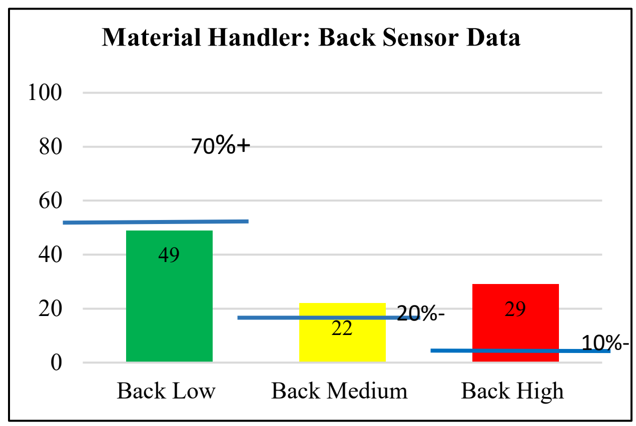

Figure 7. Back sensor data

4.3 Multinomial Regression Analysis

Multinomial regression analysis was used to address this question or address this hypothesis:
Q1: If musculoskeletal symptoms are listed during the employee interviews, do they correlate to the ergonomic hazard rating for their job classification?
H1: A significant association exists between proclaimed musculoskeletal symptoms and ergonomic hazard classification from task analysis.

Figure 8 shows the residuals of the regression model are normally distributed between the independent variables (perceived worker fatigue, RULA scores, shoulder & back sensor data) and dependent variable (presence of musculoskeletal disease). Figure 9 shows regression plot and histogram. A graphical representation of normal distributed data; no outliers were noted.

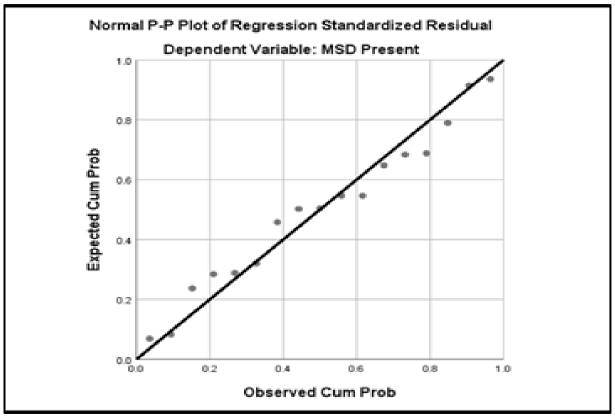

Figure 8. P-P plot

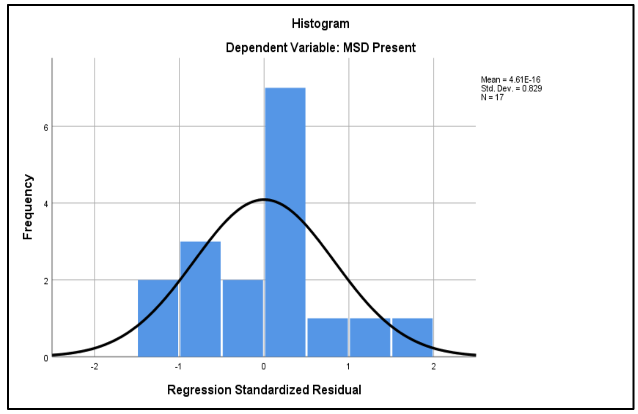

Figure 9. Regression plot and histogram

The adjusted R-squared value was moderately high at 40.2%, which signifies a good level of prediction. The model chosen by the researcher was a good fit for the dataset. The Durbin Watson score can suggest if there is a significant problem in analyzing historical data. The Durbin Watson has a value of 0.00-4.00. A value of 0.00-2.00 indicates a positive autocorrelation, while values 2.00-4.00 would negatively affect autocorrelation. The value for the multinomial regression ran by the researcher is valued at 1.925, indicating a positive autocorrelation.
All three variables added statistically significantly to the prediction, $p < .05$; overall p-value for the model selected was .02, which is less than .05; the null hypothesis was proven to be significant. The researcher's last question was answered, and the previous hypothesis proven. A significant association does exist between proclaimed musculoskeletal symptoms and ergonomic hazard classification from task analysis. The strongest associations were noted with the back and shoulder sensor data, followed by worker fatigue.

5. Conclusion

This study's outcome could benefit the industrial hemp industry by shining a light on areas that could benefit from technological advancements. The results could benefit the safety community a better idea of those risk factors involved in ergonomics for the industrial hemp industry. This study showed sensor technology could be used as a validated measurement tool. Sensor use with qualitative and semi-qualitative methods adds to the results' reliability. The data collection methods could be applied to the expanding cannabis industry to identify risks during harvest, processing, grinding, and packaging processes.

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