THESIS

CHARACTERIZING STOOPED POSTURE OF AGRICUTURAL TASKS

Submitted By

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ABSTRACT

CHARACTERIZING STOOPED POSTURE OF AGRICUTURAL TASKS

Agricultural field workers worldwide are often required to work in stooped postures during their working tasks. Stooped postures constitute a significant risk factor for the development of musculoskeletal disorders, specifically low back pathologies that cause pain. Chronic low back pain is a devastating disorder that can lead to depression, decreased mobility, lower quality of life, absenteeism from work, and decreased work productivity. Unfortunately, few studies have quantified stooped postures among agricultural workers, which makes it difficult to develop targeted work design improvements. The present study aimed to characterize stooped postures among workers engaged in several common agricultural tasks.

Agricultural workers (N=43) were recruited from multiple Colorado farms and represented eight distinct work tasks. Participants wore a biomodule that contained a tri-axial accelerometer (Zephyr BioHarness) on their chests to record and log trunk postures in degrees for approximately two hours during specific work tasks. Data recorded on the sensor module were downloaded and analyzed in a customized RStudio program by participant and task to determine task cycle time, percentage of time spent in three posture categories (<0° to 30°, >30° to <60°, ≥60°), and mean trunk flexion. Stooped posture was defined as a trunk flexion equal to or greater than 60 degrees.

The data indicated differences in task cycle time, percentage of time spent in posture categories, and mean trunk flexion across agricultural tasks. The results of the current study provide quantitative data that can help inform the development of targeted interventions aimed at

reducing stooped postures in agricultural workers. Additionally, the methods developed in the present study may assist the Colorado Department of Agriculture and farm owners with evaluating the policies established in the Colorado Senate Bill (SB 21-087), which limits stooped postures during agricultural tasks that involve thinning and weeding during crop production.

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1. INTRODUCTION

There is a shortage of quantitative ergonomic research on stooped postures among agricultural workers. Therefore, it is challenging to create appropriate ergonomic recommendations and regulations for workers exposed to stooped postures. In an attempt to reduce the risk of low back injuries related to stooped agricultural work in Colorado, the Colorado Senate passed Bill 21-087 in 2021 to restrict the number of hours that workers can perform weeding activities (CDLE, 2022). However, the Bill's requirements are vaguely defined, unjustified, and difficult to apply in the field. Additionally, the Bill's requirements do not protect most workers from stooping during the workday. The only activity restricted in the Bill is weeding, which often requires less stooping than other agricultural tasks, such as harvesting produce. When weeding with a long-handled hoe, workers can stand fully upright.

Although studies have been conducted on stooped posture regarding agricultural workers, very few have attempted to quantify and log posture data in real-time. Most studies have relied on self-reported data such as employee surveys and questionnaires. While self-reported data is valuable, quantitative methods are essential to more thoroughly characterize and understand the ergonomic risks related to the various agricultural tasks that involve stooped postures. By quantitatively characterizing stooped postures during agricultural tasks, researchers can identify the tasks that involve the most stooping and have the shortest cycle times, indicating higher repetition rates. With data on the degree and severity of stoop relative to specific tasks, researchers, managers, and safety specialists can be fully informed in their endeavors to develop effective administrative and engineering workplace solutions.

The purpose of the present study was to characterize stooped postures among agricultural workers involved in vegetable production tasks. Three research objectives were accomplished to characterize stooped postures among agricultural workers.

Objective One: Define task cycle time for all cyclical agricultural tasks studied.

Objective Two: Determine the percentage of time workers spend in three posture categories (<0° to 30°, >30° to <60°, ≥60°).

Objective Three: Determine the mean trunk flexion postures for each agricultural task.

2. LITERATURE REVIEW

2.1 Worker Health in US Agriculture

Some 2.6 million US workers are employed in the agricultural sector, which is regarded as one of the most hazardous occupational sectors (Davis, 2007; NCFH, 2018). Agricultural work is generally divided into two sectors, which include animal production and crop production. Crop production accounts for approximately 60% of the US agricultural industry (USDOL, 2005). Agriculture is a physically demanding field, with about 80% of the US agricultural workforce being classified as manual laborers (USDOL, 2005). The physical demands on manual laborers may include performing repetitive motions, lifting heavy objects, performing highly paced tasks, lifting and turning, expending high cardiovascular and muscular effort, and maintaining awkward postures. Because of the highly manual nature of the work, agricultural workers are at high risk for developing musculoskeletal disorders (USDA, 2022).

Musculoskeletal disorders (MSDs) are highly prevalent in the agricultural industry, accounting for 43% of all agriculture-related injuries, but there is generally less research on MSDs than acute injuries in agriculture (Davis, 2007; Meyers et al., 1997). An important consideration while evaluating the prevalence of MSDs in the agricultural industry is that there are limitations in the collection of these data. One limitation is that small farms (under 11 employees) are not required to report injuries to OSHA (OSHA, 2023). As a result, only 4-10% of farms are required to report recordable injuries. Individuals working on farms with less than 11 people are also usually uninsured, and therefore have little incentive to report injuries (Chapman et al., 2001). Any injuries that occur on these small farms are, therefore, not recorded in statistics provided by OSHA or the Department of Labor (Chapman et al., 2001).

Another limitation is that not all agricultural workers feel "safe" reporting their injuries to managers because they fear repercussions based on their migrant or undocumented worker status (Earle-Richardson et al., 2003). With migrant workers composing 42% of the US agricultural workforce, MSDs may be underreported, and any estimates of prevalence are conservative (USDA, 2022). Even with limitations in data collection that lead to underreporting, the national cost of agriculture-related MSDs was approximately 4.5 billion dollars, including medical expenses, lost earnings, and lost benefits (Leigh et al., 2001).

2.2. Stooped Posture Research

Studies have been conducted on stooped posture and lower back pain (LBP) regarding agriculture (Rosecrance et al., 2022; Faucett et al., 2007; Sarig, 2000; Meyer & Radwin, 2007; NORA, 2018), but very few of them have attempted to log posture data in real-time. The majority of studies on stooped posture have relied on self-reported data such as employee surveys and questionnaires (USDA; Wong et al., 2009; Faucett et al., 2007; Meyer & Radwin, 2007). In 1998, NIOSH organized a conference for researchers to convene and discuss questions related to ergonomics, agriculture, and worker safety (Estill et al., 2002). Included in this conference were professors, private sector workers, migrant worker organization representatives, government employees, and other experts. When these individuals were asked to answer, "What should the research priorities be to adequately address the gaps in current information?" they recommended collecting more crop-specific data (Estill et al., 2002). Another conference hosted by the Western Center for Agricultural Health and Safety also included a call for more surveillance work on stooped posture, specifically listing the need for:

1. Conducting surveys in high-risk industries (agriculture, construction, mining)
2. Determining the number of workers exposed and what jobs they are doing

3. Recording the exposure in identified jobs and sorting posture into zones of mild, moderate, and severe positions
4. Identifying the specific job or task elements requiring stooped postures, and why (Meyers et al., 2004)

Despite these conferences taking place over twenty years ago, crop-specific ergonomic work exposure assessment data is still sparse, and government and scientific agencies are still calling for more. Currently, The CDC's NORA Council over agriculture (AgFF Sector Council) has identified four national agricultural research goals to focus on from 2016-2026. The second goal focuses on conducting research that describes and characterizes hazardous ergonomic exposures (NORA, 2018). The goal advises that "Basic research should continue over the next decade to better describe and characterize hazardous exposures including chemical (e.g. pesticides), respiratory, physical, biological, ergonomic, and animal exposures. Basic research should also focus on associated adverse health outcomes including acute and chronic respiratory diseases, reproductive health, cancers, musculoskeletal disorders, noise induced hearing loss and zoonotic infections" (NORA, 2018). Crop-specific data allows ergonomists to craft specific and informed ergonomic solutions and protocols for agricultural workers performing different tasks. While self-reported data is valuable, more quantitative data that precisely characterizes individual tasks must be collected to better understand the ergonomic risks associated with each task.

2.3 Agricultural Harvesting Tasks

As technology has progressed, many agricultural practices have changed to match modern innovation. Even though agricultural science has advanced, many individual harvesting tasks have remained the same since the 1800s, with crops harvested by hand or with simple tools

(McIntosh, 2020). Approximately 25% of US-grown vegetables and 45% of fruits rely on hand-harvesting (Yoav, 2000). Potential reasons for reliance on human labor include hesitation from farm owners to invest large amounts of money in robotics. Investing in expensive ergonomic solutions can be a net gain over time, but initial investment is still perceived as carrying a large amount of financial risk by many owners (McIntosh, 2020). Additionally, the relatively recent development of many new automative advances means there is not a wealth of data on how some of these machines work in the “real world”. Calibration and repairs can also often be expensive. In the eyes of most farm owners, human labor is still the most productive and cost-effective way to complete many harvesting tasks (McIntosh, 2020). Human labor will likely remain a large part of agricultural work for the foreseeable future.

2.4 Musculoskeletal Disorders and Lower Back Pain

MSDs are the most common occupational injuries within the US farm worker population (Fathallah et al., 2008). The lifetime prevalence of experiencing an MSD for an agricultural worker is 90.6%, and the one-year prevalence of MSDs for agricultural workers is 76.9% (Fathallah et al., 2008). These figures starkly contrast with the lifetime prevalence of MSDs in the general population, which is approximately 47% (Vos et al., 2021).

LBP is agricultural workers’ most prevalent and costly MSD (Fathallah et al., 2008). LBP is a multifactorial disease that can cause decreased mobility, lower quality of life, and work absenteeism (Treede et al., 2015). It is defined as pain that persists for more than three to six months (Treede et al., 2015). Some individuals with chronic lower back pain have reported starting to avoid all movement due to anxiety that any movement will cause pain. Movement avoidance can worsen lower back pain, creating a vicious cycle (Grabovac, 2019). LBP can also lead to depression, anxiety disorders, chronic stress disorders, sleep troubles, and other psychological ailments (Grabovac, 2019).

A cross-sectional epidemiological study from France collected data on the prevalence and predictors of LBP and investigated the difference in quality-of-life measures between those suffering from LBP and those who did not (Husky et al., 2018). The researchers interviewed 17,249 adults over the phone and asked in-depth questions about their experiences with LBP. Participants were asked to answer multiple surveys, including the CIDI Chronic Conditions Model and the SF-36 Health Survey (Husky et al., 2018). The SF-36 Health Survey was designed to measure physical and psychological well-being aspects for those suffering from any disease or injury. The researchers found statistically significant differences between LBP sufferers versus controls on every aspect of the SF-36 survey, which includes categories such as "physical functioning", "emotional well-being", and "social functioning". Additionally, the researchers found a statistically significant difference between LBP in the "farmer" occupation versus all other occupational categories included in the study, where farmers had the highest incidence of LBP (Husky et al., 2018). Even though the study was conducted in France, the prevalence of LBP amongst agricultural workers in the US is approximately 50%, which mirrors the researcher's finding that about one-half of all farmers surveyed reported LBP (Davis et al., 2007; Husky et al., 2018).

2.5 Stooped Posture as a Risk Factor for Lower Back Pain

Stooped posture has been demonstrated to be a major risk factor for developing chronic LBP. A cross-sectional study of workers in a school for severely disabled people examined two groups: one of eighteen workers who reported experiencing LBP for one to seven days in the last year, and another of fifteen workers who were asymptomatic for LBP (Wong et al., 2009). Both groups of workers were asked upon recruitment how many lifts they performed each week to ensure all employees were exposed to approximately the same workload. There were no statistically significant demographic differences within the study group besides sex because there were more females involved in the study. The researchers attached a bi-axial accelerometer to each study participant's lower back using a soft Velcro strap that wrapped around the body and calibrated the devices using each participant's baseline neutral upright posture. The accelerometer data indicated that the group of workers who reported LBP spent significantly longer in stooped postures when compared to coworkers who did not report LBP (Wong et al., 2009).

In another study, researchers recruited fifteen young men with no previous history of LBP from the University of Wisconsin (Meyer & Radwin, 2007). Subjects were randomly assigned to complete a simulated fifteen-minute farming task, either standing up or prone, lying on a foam-covered workstation. The standing task required participants to reach down to below knee level. Each task was split into two 15-minute sections, with electromyography (EMG) measurements taken for five minutes between each session. The standing task was performed in a work-rest ratio, with two minutes of work and 30 sections of rest cycled over each session, while the prone task was performed continuously (Meyer & Radwin, 2007). The researchers found that their subjects were unable to perform the standing task without taking breaks due to the required stooped posture. Each subject performed both tasks over two days in order to avoid residual fatigue. Subjects self-reported discomfort levels after the first 15 minutes of work and the last 15 minutes of work. Subjects reported significantly less back fatigue and discomfort after working in a prone posture (Meyer & Radwin, 2007). Heart rates and EMG results also indicated that the task completed on the prone workstation led to significantly less muscle activity and a lower heart rate than the standing task. The three areas where the most significant fatigue differences were observed between the standing and prone tasks include the hamstring, lower back, and back of the knee, in that order (Meyer & Radwin, 2007).

2.6 Prolonged Stooped Postures

Study results have indicated that cyclic stooping may not be less dangerous than prolonged stooping. Researchers from North Carolina State University in 2005 measured the EMG activity from the back muscles as well as sagittal plane range of motion before and after 10-minute periods of stooping (Shin et al., 2005). Participants were asked to stoop for 10 minutes and then stand for 10 minutes. The following day, these same participants were also asked to stoop for 10 minutes with a 30-second rest break in the middle of the stooping. Results from examining the sagittal plane's range of motion revealed that adding a thirty-second break in the middle of stooping helped to moderate viscoelastic responses. Viscoelastic responses indicate a stretching of the back muscles that can lead to back strain (Shin et al., 2005). However, because the EMG results were similar between the two rounds of study, the researchers surmised that the small thirty-second breaks did not provide a significant benefit overall (Shin et al., 2005).

A 2012 study aimed to assess the difference between prolonged stooped posture and cyclic stooped posture using EMG (Nou et al., 2012). The researchers recruited 19 subjects, 17 of whom were male, and asked each subject to complete both prolonged stooped posture tasks and cyclic stooped posture tasks. The prolonged stooped posture task consisted of 120 seconds of work with 30 seconds of rest, while the cyclic stooped posture task consisted of 10 seconds of work, then two seconds of rest. The EMG results indicated "no significant differences in muscle fatigue between cyclic and prolonged stooped conditions" (Nou et al., 2012). The researchers surmised that even with small breaks, stooping can still lead to back muscle fatigue. The researchers recommended that future stooping interventions consider what constitutes an effective work-rest period (Nou et al., 2012).

Although there may not be a significant difference in quantitatively measured muscle fatigue between prolonged stooping and stooping with small breaks, workers self-report less fatigue when offered breaks (Faucett et al., 2007). A study from 2007, conducted amongst strawberry harvesters and citrus-fruit harvesters, split each group of harvesters into either a control group or an experimental group. The control group was required to take a break from their tasks for 10 minutes every four hours, along with a 30-minute meal break, in accordance with California law. The experimental group was required to take a five-minute break for every hour of work, not including the hours they took their lunch break. The experimental group's work-rest regimen was informed by previous research conducted by a NIOSH research group. (Faucett et al., 2007). Workers in both groups were surveyed at the end of the workday for overall levels of fatigue as well as any musculoskeletal (MS) symptoms. The workers who received the breaks reported significantly fewer severe MS symptoms and less fatigue at the end of their shifts than their control-group coworkers (Faucett et al., 2007).

2.7 Past Definitions of Stooped Posture

Past research has defined stooped posture in a variety of ways. A conference on stooped and squatting postures in the workplace defined stooped posture as “work done below the knees over 40% of the time” (Janowitz et al., 2004). Work done below the knees generally requires a trunk flexion of 60º or greater. Conversely, a literature review analyzing the relationship between stooped posture and LBP defined stooped posture as “performing agricultural work where more than 5% of the time is spent with the trunk bent more than 45°, which may or may not involve a lifting task” (Fathallah, 2008). At a conference on stooped posture hosted by the Center for

Occupational and Environmental Health, Fadi Fathallah, James Meyers, and Ira Janowitz defined stooped posture as “bent forward and down from the waist and/or mid-back while maintaining relatively straight legs” (Meyers et al., 2004). Finally, a 3-year prospective cohort study where researchers investigated the relationship between stooping and low back pain defined stooped posture as working with “a minimum of 60° of flexion for more than 5% of the working time” (Hoogendoorn et al., 2000). There is no current consensus on the definition of stooped posture. These studies, literature reviews, and conferences that do define stooped posture sometimes include a temporal component (more than 5% of the time), while some choose not to include a posture degree measurement at all (bent forward). Many studies do not attempt to concretely define stooped posture, even if analyzing stooped posture is the main objective of their research (Wong et al., 2009; Meyer & Radwin, 2007).

2.8 Methods to Assess Stooped Postures

Researchers studying stooped postures have utilized both qualitative and quantitative methods of measurement. Quantitative methods that have proven effective include tri-axial accelerometer use and electromagnetic motion tracking systems (Rosecrance et al., 2022; Shin et al., 2005). A study performed in Italy sought to evaluate the effectiveness of tri-axial accelerometer use in the field. The researchers determined that tri-axial accelerometers work well in the field and successfully quantified stooped posture among fruit and vegetable pickers performing harvesting tasks (Rosecrance et al., 2022). There has also been success using electromagnetic motion tracking systems. To calculate trunk flexion angle, these systems require two nodes to be placed on the spine. Trunk flexion angle is calculated as the relative angle between the two nodes (Shin et al., 2005). EMG cannot track the degree or the severity of stoop, but is a helpful tool to quantify muscle fatigue before and after different stooping tasks. EMG has been successfully utilized in multiple stooping task experiments (Meyer & Radwin, 2007; Nou et al., 2012; Shin et al., 2005).

Qualitative evaluation methods are more commonly used and include post-work fatigue surveys and subject self-reporting of MS symptoms (USDA; Wong et al., 2009; Faucett et al., 2007; Meyer & Radwin, 2007). Self-reporting and survey data can be useful for characterizing post-task fatigue and pain but come with limitations. One major limitation is that some workers may not feel comfortable reporting pain post-shift for fear of retaliation or loss of work. Another is that pain is inherently subjective, and individuals may experience or express their discomfort in a variety of ways. Another limitation is that agricultural workers often do not speak English or speak English as a second language. Surveys need to be administered in a language that subjects can easily understand, which may require an on-site translator. In order to bypass some language and literacy considerations, the surveys conducted by Faucett et al. in 2007 had subjects color in parts of a human body drawing where they felt pain after a work shift. These limitations indicate a need for a combination of quantitative and qualitative data for future stooped posture studies.

2.9 Colorado Senate Bill (SB 21-087)

In an effort to reduce the risk of occupational low back disability among agricultural workers, the Colorado Senate passed Bill 21-087 in 2021. The Bill stipulates that Colorado's agricultural workers may not spend over twenty percent of their workweek hand-weeding. Additionally, workers may not use short-handled hoes (CDLE, 2022). This provision was intended to reduce the time spent in stooped postures. However, the Bill does define what a "stooped posture" is, does not indicate how to assess stooped postures among agricultural workers, and does not justify the 20% protective limit. Without firm definitions, it is not likely that farm managers will be able to comply with the provisions outlined in the Bill.

While weeding can be physically strenuous and involve stooping, it often requires less stooping compared to harvesting fruits or vegetables. Therefore, in some cases, weeding can provide a break from stooping. Even though the senators sponsoring the Bill intended for it to reduce stooping throughout a workday, the laws they set forth may end up limiting a task that is less harmful than routine harvesting.

Studies have proven that many agricultural workers worldwide work in stooped posture every day and that stooped posture can lead to LBP. However, there is a shortage of specific and quantitative data on measures of stooped posture according to individual agricultural tasks. The lack of data and scientific merit related to stooped postures in agriculture has led to state rules and regulations that are not based on empirical evidence. The present research study provides new information on the definition of stooped posture, evidence that supports the claim that stooped postures can be quantitatively measured among agricultural workers, and data that indicates that duration and magnitude of stooped posture varied according to the agricultural task.

3. METHODS

3.1 Sample Collection

Agricultural workers (N=43) from six farms in Colorado were recruited for the present study with help from the High Plains Intermountain Center for Agricultural Health and Safety. Approval for research methodology and conduct of the present research was granted by Colorado State University's Institutional Review Board. Farm workers who volunteered to participate in the study were informed about expectations in their primary language, either Spanish or English, and informed consent was received. A Spanish-speaking translator was on site to collect data and help facilitate conversations with workers who did not speak English. Demographic questionnaires were administered by the Spanish-speaking translator that collected each subject's name, age, weight, experience with LBP, and work history.

Participants wore a tri-axial accelerometer-based trunk motion logging system called the Zephyr BioHarness for approximately two hours per agricultural task. Accelerometers measure posture using acceleration data to mathematically calculate velocity, position, change of position, and finally, change of position in degrees. The BioHarness system did not interfere with the movements of each worker's daily tasks. Seventy-three sets of task data, representing eight separate agricultural tasks, were collected from forty-three participants. From the seventy-three sets of task data, fifty-five sets of data were analyzed after download due to data analysis limitations. The tasks sampled included weeding, harvesting cilantro, harvesting lettuce, harvesting spinach, corn picking, harvesting zucchini, corn sorting, and corn loading. Two tasks, "weeding" and "harvesting cilantro", had samples collected at multiple farms. In the results section, farm abbreviations are used for those two tasks to indicated a difference in location.

With two tasks separated by farm, there are a total of ten sets of distinct data, as illustrated in Table 1.

Table 1. Data Distribution

Data Distribution		
Task	**Location**	
Weeding	Farm FC (n=2)	Farm M (n=5)
Harvesting cilantro	Farm P (n=8)	Farm FC (n=6)
Harvesting lettuce	Farm P (n=8)	
Harvesting spinach	Farm FC (n=5)	
Corn picking	Farm T (n=6)	
Harvesting zucchini	Farm M (n=5)	
Corn sorting	Farm T (n=6)	
Corn loading	Farm T (n=4)	

The BioHarnesses were attached around the chests of each participant, with the modules on the left side of the chest, as illustrated in Figure 1. After attaching the BioHarness modules to each participant, the modules were calibrated to a neutral upright posture by asking each participant to touch their toes slowly three times, stand up straight for thirty seconds, and then touch their toes slowly three times again. These normalization data provided an individual baseline for upright neutral back posture. An example of a worker's baseline neutral posture data can be observed in Figure 2, from time points 7:26:54 to time point 7:27:34. The average degree of the baseline posture for each participant was recorded and used to adjust the remainder of the posture data. The application and setup of each BioHarness module took approximately five minutes per participant.

Figure 1. Placement of the Zephyr BioHarness (modules are placed over the left ribs)

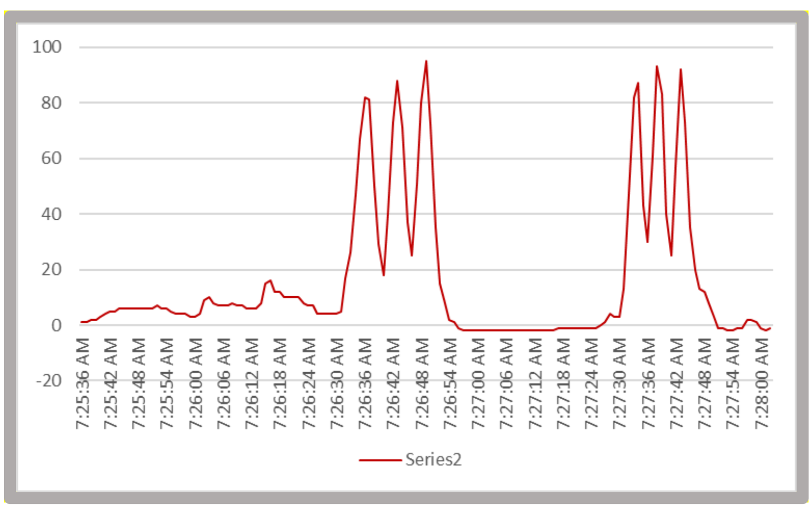


Figure 2. Calibration readout on Zephyr Program

Throughout data collection periods, detailed notes were recorded on each participant's actions, movements, and breaks, and subsequently marked with timestamps in the data timeline. The notes allowed for breaks in the work shift to be removed from the final data analysis. The notes also helped to explain any abnormalities in the downloaded data.

3.2 Data Analysis

The trunk posture data from each BioHarness were downloaded to an Excel file (Version 2406), adjusted for each subject's neutral baseline posture, and cleaned to remove breaks (using the restroom, changing fields, resting, and lunches). The adjusted data were then analyzed in a custom RStudio script (Version 2023.09.1 +494) and visualized with Tableau models (Version 2023.3). Tableau is a data visualization program that allows large amounts of quantitative data to be synthesized into customizable visuals, such as bar and pie graphs.

To fulfill research Objective One, determining the task cycle time and frequency of cycles (defined as trunk flexion and extension cycles per hour), cycle times were estimated for all tasks considered cyclical. The estimation focused on one individual from each task representative of the task group whose mean posture was closest to the task group average. Cycles were estimated by recording 10 cycle times for each individual and then calculating the mean. A cycle was defined as the time between standing in a neutral posture (<0° to 30°), stooping (≥60°), and then standing in neutral posture again. In the current study, cycles were not task dependent but posture dependent. Some tasks with a low percentage of time spent in 60-degree or greater postures did not have definable cycles. Cycles found visually in the posture data were compared to videos of the individual working to check for accuracy.

Objective Two, determining the mean time spent in three posture categories, was fulfilled by quantifying the percentage of time spent in (<0° to 30°), (>30° to <60°), and (≥60°) according to task. The custom R Studio script provided the percentage of time in each posture category, and pie charts were created to aid in visualization.

Objective Three, determining each mean trunk flexion for each agricultural task, was fulfilled by quantifying and visualizing the mean trunk flexion postures for each agricultural task using a bar graph created on Tableau. Tableau coding provided the average mean posture for each task and subject and provided the standard deviation for each task's average.

4. RESULTS

4.1 Cycle Time and Frequency of Cycle Estimate

Cycle time estimates as well as estimated cycles per hour (frequency) are found in Table 2. Subjects that were “harvesting lettuce”, “working piece-rate to harvest cilantro”, and “weeding by hand” had the highest cycle times at 203 seconds, 89 seconds, and 92 seconds respectively. The lowest cycle time was observed in the task “harvesting spinach”, at 11 seconds. Cycle time can indicate how often workers take a break from stooping to stand up, with lower cycle times leading to higher estimated cycles per hour. Four tasks were found to have no discernable cycles due to minimal stooping, and were not included in this table.

Table 2. Estimated Cycle Time by Task and Subject Observed

Task	**Subject Observed**	**Mean Cycle Time (mean of 10 samples)**	**Estimated Cycles per Hour**
Weeding by hand and with long-handled hoe: farm FC	Subject 5	92 s	39
Harvesting cilantro: farm P	Subject 11	89 s	40
Harvesting cilantro: farm FC	Subject 22	40 s	90
Harvesting lettuce	Subject 7	203 s	18
Harvesting spinach	Subject 19	11 s	327
Harvesting zucchini	Subject 26	41 s	90

4.2 Percent of Time in Each Posture Category

The percentages of time spent in each posture category as well as the number of subjects per task are found in Table 3. The three tasks where individuals spent the most time in the 60º+ posture category included “weeding by hand and with long-handled hoe”, “harvesting cilantro at farm P”, and “harvesting lettuce”. The three tasks with the last percent of time in this category were “weeding with a long-handled hoe standing”, “corn picking”, “corn sorting”, and “corn loading”. Eight distinct tasks are included in this table, with two additionally divided by farm for a total of ten categories.

Table 3: Percent of Time in 60+ Posture Category

Task	**Percent of time in posture category (60+)**	**n**
Weeding by hand and with long-handled hoe: farm FC	41%	2
Weeding with long-handled hoe standing: farm M	7%	5
Harvesting cilantro: farm P	67%	8
Harvesting cilantro: farm FC	26%	6
Harvesting lettuce	77%	8
Harvesting spinach	29%	5
Corn picking	0%	6
Harvesting zucchini	33%	5
Corn sorting	2%	6
Corn loading	4%	4
		Total = 55

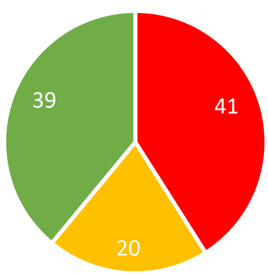
Percent of time in each posture category (<0° to 30°, >30° to <60°, and ≥60°) can be easily visualized in Figure 3, which displays pie charts for each task observed. Numbers on each pie chart “slice” indicate the percentage of time spent in that category. Red slices represent time spent in ≥60º, yellow slices represent time spent in >30° to <60°, and green slices represent time spent in <0° to 30°. Eight distinct tasks are included in this figure, with two additionally divided by farm for a total of ten charts.

Legend

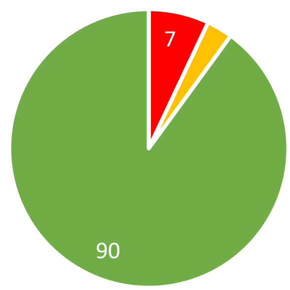
≥60º
>30° to <60°
<0° to 30°

Each pie chart segment represents the % of total time spent in each posture category

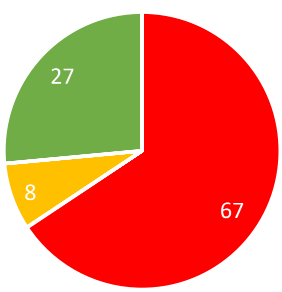
Weeding by hand and with long-handled hoe: farm FC



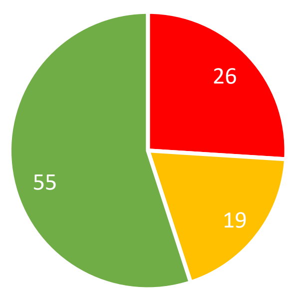
Weeding with long-handled hoe standing: farm M



Harvesting Cilantro: farm P



Harvesting Cilantro: farm FC



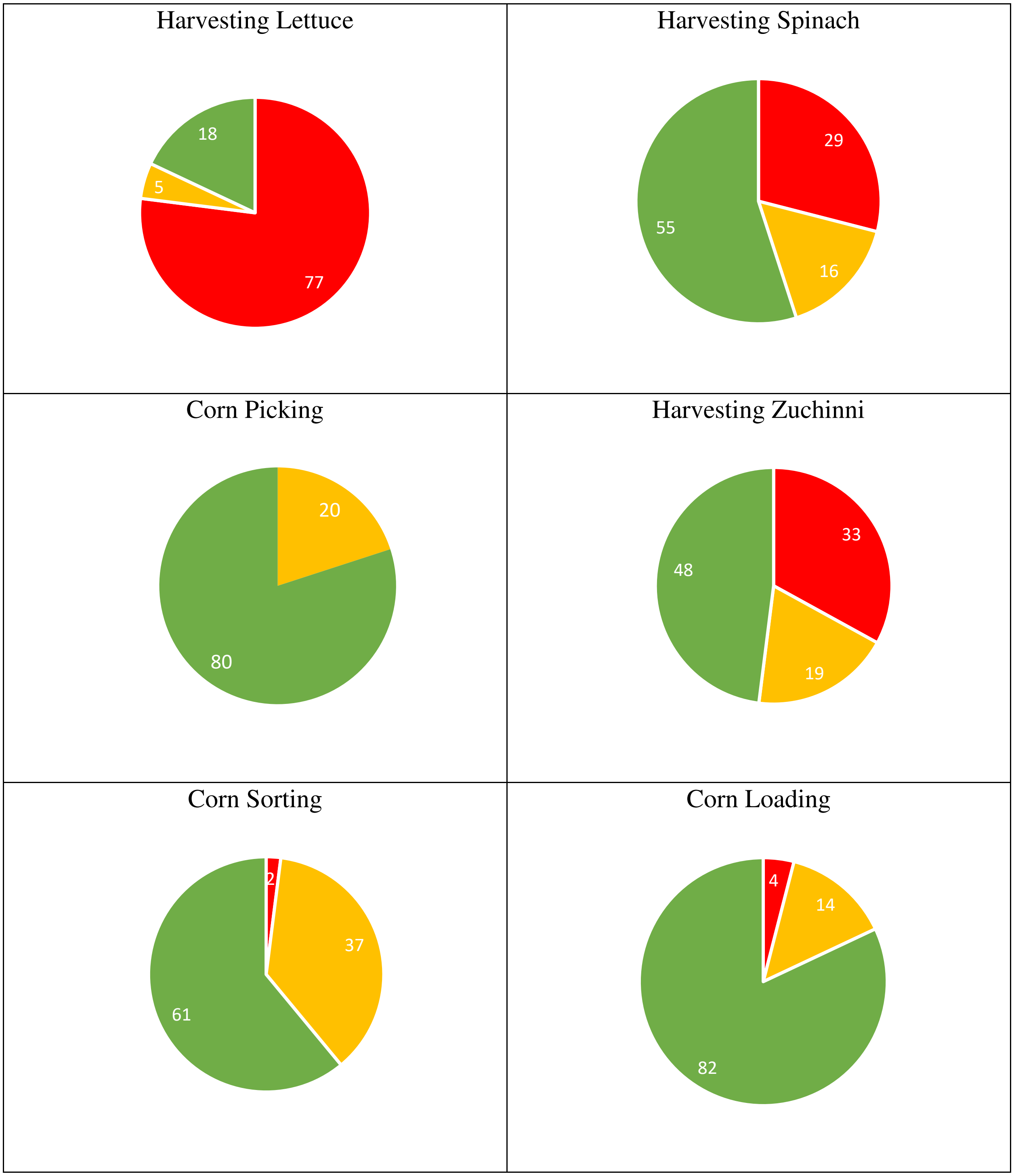


Figure 3. Percent of Time in Each Posture Category, Pie Charts

4.3 Mean Trunk Flexion Postures for Each Agricultural Task

Mean trunk flexion postures categorized by task are found in Table 4. The tasks where mean posture exceeded 60 degrees included "harvesting cilantro at farm P" and "harvesting lettuce", while "weeding with a long-handled hoe standing", "corn picking", "corn sorting", and "corn loading" had mean postures under 30º. Eight distinct tasks are included in this table, with two additionally divided by farm for a total of ten categories.

Table 4. Mean Trunk Posture by Task

Task	**Mean (SD) Trunk Posture (degrees)**	**n**
Weeding by hand and with long-handled hoe: farm FC	44 (2)	2
Weeding with long-handled hoe standing: farm M	13 (15)	5
Harvesting cilantro: farm P	68 (5)	8
Harvesting cilantro: farm FC	34 (11)	6
Harvesting lettuce	80 (6)	8
Harvesting spinach	34 (10)	5
Corn picking	19 (3)	6
Harvesting zucchini	38 (8)	5
Corn sorting	23 (5)	6
Corn loading	14 (6)	4
		Total = 55

Mean posture per subject is visualized in Figure 4, a bar graph that divides mean posture by task and subject. Eight distinct tasks are included in this table, which does not differentiate by farm.

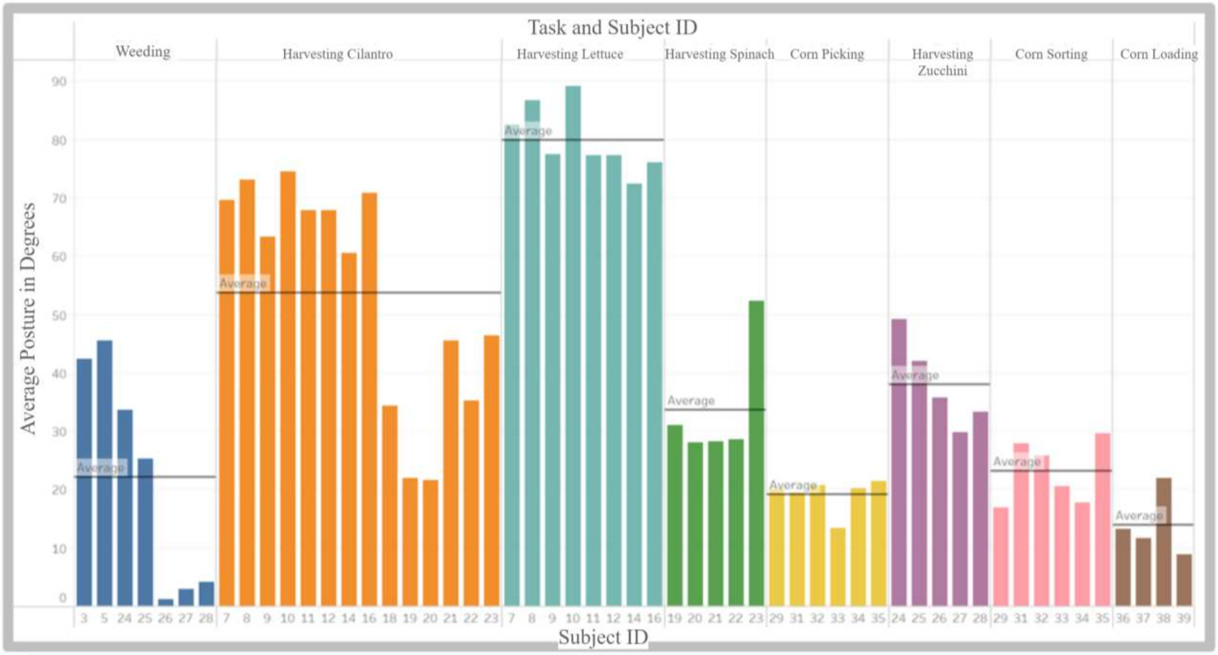


Figure 4. Mean Posture (in degrees) by Task and Subject ID

5. DISCUSSION

5.1 Data Findings

Stooped postures among agricultural workers were characterized by analyzing task cycle time, percent of time in posture category 60+, and mean trunk flexion postures for each task. These metrics were each found to be highly task-dependent. Variability between individuals performing the same task was also observed. Agricultural harvesting tasks are not homogeneous, with significant differences in all metrics found between workers harvesting the same crop but at different farms.

“Harvesting lettuce, “harvesting cilantro at farm P”, and “weeding by hand and with a long-handled hoe” had the longest cycle times, the highest percentages of time in the 60+ posture category, and the highest mean trunk flexion of the tasks. Having a longer cycle time means these workers took fewer posture breaks and spent more time in a stooped posture before returning to a neutral one. Even though micro-breaks may not significantly influence back recovery after stooping, they have been shown to decrease perceived overall fatigue and end-of-workday MSD complaints (Nou et al., 2012). Cilantro, lettuce, and weeds are all similar in that they are located at ground level. Workers had to bend over 60 degrees to reach these crops or weeds. Additionally, cilantro and lettuce are light crops that are relatively easy to carry and handle. Workers stayed down in a stooped posture for a long time and held their harvest in their hands until bundles became too large to carry, upon which they would stand to deposit their harvest into cardboard boxes. This likely contributed to the longer cycle times for these three tasks. Figure 5 depicts subjects stooping to harvest a ground-level crop.

Figure 5. Workers harvesting lettuce

"Corn picking," "corn sorting," "corn loading," and "weeding with a long-handled hoe standing" had the lowest percentages of time in the 60+ posture category and the lowest mean trunk flexion out of all observed tasks. The corn tasks were all performed around waist level or higher, and subjects performing one of these four tasks rarely experienced trunk flexion equal to or greater than 60 degrees over their entire work shift. No cycle times were determined for these tasks, as trunk flexions equal to or greater than 60 degrees were either absent or rare for all participants. In addition to corn harvesting tasks being performed at waist level rather than ground level, ears of corn are also heavier and bulkier than lettuce or cilantro. Workers could not hold many ears of corn in their arms at once and, therefore, needed to deposit them more often into bins, which were located around head level on a moving harvesting truck. Figure 6 depicts workers harvesting corn.

Figure 6. Workers harvesting corn

Concretely defining stooped posture as a trunk flexion equal to or greater than 60 degrees proved useful in determining which jobs require the most stooping. Without a clear definition of stooped posture, it would be impossible to quantify what percentage of time was spent in a stooped posture for each task. The definition of stooping as "a trunk flexion equal to or greater than 60 degrees" was chosen because multiple past definitions of stooped posture have agreed that stooped posture definitely occurs when the back is bent more than 60º (Hoogendoorn et al., 2000; Janowitz et al., 2004; Meyers et al., 2004). Additionally, with some past studies defining stooped posture as any work done below 45º, choosing a larger angle for the present study ensured that estimates of stoop were conservative rather than potentially exaggerated (Fathallah, 2008).

5.2 Current Findings and Past Research

Results of the present study point to a correlation between the proximity of each crop to the ground and the worker's average degree of stooped posture. This correlation mirrors findings from the 2022 study "Quantification of Trunk Postures Among Fruit and Vegetable Pickers in

Sardinia" (Rosecrance et al., 2022). The trunk posture study researchers recruited 16 workers, including nine eggplant pickers and seven strawberry pickers. A tri-axial accelerometer (Zephyr BioHarness) was used to record trunk postures. The data were then analyzed to determine the magnitude, frequency, and time spent in four posture categories. The Sardinian study researchers found that strawberry pickers had a higher mean degree of stoop than eggplant pickers (93º, 82º) and surmised a main explanation was that strawberries were grown on the ground while eggplants were dangling off of a higher vining plant (Rosecrance et al., 2022). Additionally, researchers found that strawberry pickers had longer cycle times than eggplant pickers (27 seconds vs. 49 seconds). The researchers concluded that fruit or vegetable size often impacts cycle time, as smaller fruits or vegetables fill bins more slowly. When fruits or vegetables are small, workers can collect more in one bin or basket before standing up to grab a new receptacle (Rosecrance et al., 2022).

A second important finding indicated by mean trunk flexions is that there was often significant variability between workers, even between workers performing the same task in the same location. Differences in worker's harvesting speed, technique, and tool use were observed in the field. For example, in both weeding tasks observed (weeding at farm FC and weeding at farm M), workers were provided with long-handled hoes, as outlined in Colorado law (CDLE, 2022). However, most workers at farm FC either hung onto the hoe with one hand, stooped, and picked weeds with their other hand, or stooped while holding the long-handled hoe to better see the ground, as illustrated in Figure 7.

Figure 7. Workers weeding at farm FC

Workers at farm M used the long-handled hoe with both hands to weed the soil and very rarely stooped, keeping close to a neutral upright posture throughout their weeding task. Figure 8 shows workers at farm M using the long-handled hoe to weed. The differences between weeding practices led to a mean trunk flexion angle of 43º for workers at farm FC and a mean trunk flexion angle of 13º for workers at farm M.

Figure 8. Worker weeding at farm M

5.3 Ergonomic Solutions

The data from the present study can be used to develop effective and specific ergonomic solutions. These solutions can include enforcing the use of a long-handled hoe or short-handled hoe while weeding, using weeding and picking waist-level crops as protective breaks from constant stooping, and educating workers on different harvesting stances. It is not recommended to provide tools to employees without also providing proper training. As seen in workers weeding at farm FC, tools like long-handled hoes can be used incorrectly and not act as a protective measure against stooping. It is also important to listen to workers and ask them what tools they would prefer. Some workers, used to using a short-handled hoe, would rather hand-weed than properly use a long-handled hoe. Therefore, in some cases, opting for a tool that offers less protection yields better outcomes than opting for a protective tool that workers are unwilling to adopt. When advocating for the use of different harvesting postures, it is crucial to remember that telling workers to kneel or squat rather than stoop is not a long-term solution to stopping the development of MSDs. Workers were observed using kneeling or squatting stances while harvesting, as shown in Figure 9. Even though kneeling and squatting allow workers to reduce the bend in their back when working at ground level, these stances have been shown to cause knee disorders (Meyers et al., 2004). It is vital to prioritize work design fixes that focus on removing awkward postures altogether.

Figure 9. Worker using squatting stances while harvesting

Frequent standing breaks, which translate to a shorter task cycle time, can lower the risk of worker end-of-day discomfort (Faucett et al., 2007). Administrative and engineering fixes focused on shortening cycle time can help to lower reported end-of-day fatigue for workers. Examples of simple controls could include placing cardboard boxes for packing vegetables or fruit at the end of harvesting rows, which forces workers to stand up from their harvesting and walk to the end of a row and back. Another solution could be building raised rows or beds, requiring a lower degree of stoop for workers, and enforcing frequent short breaks from harvesting (Faucett et al., 2007).

Speakers at the 2004 conference "Stooped and Squatting Posture in the Workplace" suggested that managers hire more workers at peak harvesting times and introduce job rotation when possible (Janowitz et al., 2004). Job rotation practices help ensure that workers take turns performing tasks that require a high degree of stooped posture and that one group of workers is not overexposed. If farms are willing to invest in mechanical harvesting tools, some harvesters can cut leafy ground crops and elevate them to approximately waist height for sorting and packing (Janowitz at al., 2004). Other mechanical harvesting tools allow the workers to lay prone while they harvest, reducing overall fatigue and LBP (Meyer & Radwin, 2007).

While advancements in mechanics can sometimes help alleviate stooped postures, it is essential to consider the all of the work design implications of mechanical advancement. Researchers in a 2014 study investigated the impact of introducing robot assistants on stooped posture in strawberry harvesters (Khosro-Anjom et al., 2014). The robots were purchased in order to take full trays of strawberries from workers to an unloading station, effectively streamlining the harvesting process. These robots were intended to increase harvesting efficiency and allow human workers to dedicate their time to fruit picking. However, the walks to the unloading station actually provided regular breaks from the stooped posture required of strawberry pickers. The researchers re-implemented the breaks by programming the robots to only approach workers if the workers had not been stooping for a long consecutive period, defined in this study as over 5% of their workday (Khosro-Anjom et al., 2014). If the workers had been stooping too long, the robots would stop a few feet away, prompting them to stand to unload their berries and take a break from stooping. The innovative solution presented in the case study offered a balance between increased productivity and improved ergonomic practices. Even with the workers still required to stand to deposit their berries, the robots served as a more convenient unloading station (Khosro-Anjom et al., 2014).

Programmatic solutions such as occupational health and safety management systems (OHSMSs) effectively reduce stooped postures and educate managers and workers on the dangers of stooped postures. Ergonomic programs should be a subsection of OHSMSs and focus on education, risk assessment, risk communication, and work-design changes. These programs should be written and have methods to ensure continual improvement in workplace ergonomic practice. Ergonomic programs take a proactive approach to reducing the development of MSDs in the workplace (McSweeney et al., 2002).

5.4 Policy Implications

The data from the current study also has implications for state policy, such as Colorado Senate Bill 21-087. The Bill authors sought to limit stooped postures by limiting weeding and banning short-handled hoes (CDLE, 2022). However, in the field, some workers who were forced to use long-handled hoes held them in one hand unused and stooped to pick weeds with their free hand. These workers would have benefited from the use of a short-handled hoe. Other weeders correctly used long-handled hoes and barely left a neutral posture. Properly weeding with a long-handled hoe was the task with the lowest mean posture. Unfortunately, Senate Bill 21-087 is limited to regulating weeding activities.

The present study indicates that other agricultural tasks are likely more hazardous to the low back, but no other tasks are included in Bill 21-087. In the small sample taken of weeding tasks, they did not require significant amounts of the stooped postures classified as "hazardous" under the Bill. The Bill also regulates not only stooping, but also squatting and kneeling, which do not involve significant degrees of trunk flexion. Squatting and kneeling can be considered awkward postures but do not typically involve stooped postures specifically (Meyers et al., 2004). Squatting and kneeling can provide breaks in lower back strain caused by stooping, even though they may be harmful to the knees over time (Meyers et al., 2004). Bill 21-087 should have considered other agricultural tasks in the regulation of stooped posture, such as harvesting produce, while promoting weeding with a long-handled hoe as a protective break from stooping.

Authors drafting future bills on workplace ergonomics should carefully observe the tasks they intend to regulate and consult with career ergonomists before creating regulations.

Additionally, engaging directly with workers in the industries being regulated can ensure that proposed regulatory measures are well-received and may help shape future directions in regulation.

5.5 Study Limitations and Future Research

Some limitations of the present study include the relatively small sample size (n=53) and the fact that only six farms participated. The posture data collected from workers at those six farms may differ from the postures of workers at other Coloradan farms. Additionally, only posture data were measured. However, there are many other significant considerations in terms of ergonomic variables that affect LBP, such as weight of load, size of load, twisting or turning while lifting, and reach. Stooped posture is only one of the risk factors that can lead to low back pain.

Additional limitations include that Zephyr Bimodules can only measure the degree of stoop, not the lower back's bend. Consequently, workers who are kneeling or squatting might be incorrectly classified as having a stooped posture, even if their backs are straight and not curved. The Biomodule data cannot differentiate between stooping with a slumped back and kneeling with a straight back while leaning over to complete a task. Other work physiology variables collected during fieldwork but not analyzed in the present study are heart rate, worker body temperature, environmental temperature, worker body weight, and worker age.

Looking ahead, future studies could leverage the work physiology variables that were not analyzed in the present study. Analysis of other variables could reveal correlations between heart rate and average degree of stooped posture, or heart rate and environmental temperature. Demographic data could also be a valuable resource for heart rate studies. Additionally, future work could delve into the effects of piece-rate work on the percentage of time spent in a stooped posture. The present study's data indicated that workers harvesting cilantro while being paid a piece rate stooped longer than those who were paid by the hour. The correlation between piece-rate work and stooping presents an intriguing avenue for further exploration, offering the potential for deeper understanding and more targeted interventions.

6. CONCLUSION

It has been proven that stooped posture is a risk factor for the development of LBP. Therefore, it is vital to understand which occupational tasks involve stooped posture. However, there is very little quantitative data on the degree of stooped posture in specific work tasks. The author of the present study analyzed eight agricultural tasks for mean posture, task cycle time and frequency, and time spent in three posture categories. Posture data were recorded using a tri-axial accelerometer that was attached to each subject. Data analysis found that “weeding by hand and with a long-handled hoe,” “harvesting lettuce,” and “harvesting cilantro at Farm P” had the longest cycle times, the highest mean postures, and the largest percent of time spent in the 60º+ posture category. Conversely, “weeding with a long-handled hoe” and three other corn-harvesting tasks had the lowest mean postures and the lowest percentage of time spent in the 60º+ posture category. The data collected can inform future Colorado policy, create tailored ergonomic solutions to stooped posture, and help ergonomists and occupational health specialists create successful training. The data from the current study indicated that duration and magnitude of stooped posture varied according to agricultural task and demonstrated that stooped posture can be effectively measured in the field. The present research also provided new information on the definition of stooped posture, creating a basis for future field research on stooped posture.

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