Accelerations of Trunk and Limb Assessment System (ALTAS): A Monte-Carlo simulation approach to dynamic work evaluation for the agricultural sector

by

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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this dissertation. The Graduate College will ensure this dissertation is globally accessible and will not permit alterations after a degree is conferred.

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DEDICATION

I dedicate this dissertation to my parents and brother for their unwavering and universal support. The lessons given about hard work through agriculture formed the basis of motivation for this dissertation. The work done here is done for them and will be the foundation for improve ergonomics in agriculture.

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NOMENCLATURE

ATLAS	Accelerations of Trunk and Limb Assessment System
ACRES	Agriculture Cumulative Risk Evaluation System
NLE	NIOSH Lifting Equation
RWL	Recommended Weight Limit
REBA	Rapid Entire Body Assessment
OSHA	Occupational Safety and Health Administration

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This dissertation would not have been possible without the support of my family and friends. First, I want to thank Dr. Stone for providing me with an environment that provided support and opportunity for growth when appropriate. Your willingness to approach any field of science without wavering from strong engineering principles is a characteristic I will never stop emulating.

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ABSTRACT

This dissertation begins with a deep dive into the demographics of different work groups. Work takes many forms; in the early 1900's we see a significant from an agrarian society shift to industrialization and assembly line work often described as blue collar work. More recently, Industry 4.0 has automated many of the manufacturing processes previously done by skilled laborers. Many jobs are growing to fit more of the definition of white-collar jobs. It was found that the current landscape of agricultural work does not fit the mold of either blue-collar or white-collar work.

The dissertation goes on to uncover systematic neglect for agricultural work. There are little to no ergonomic assessment tools designed to evaluate agrarian work through either government policy, industrial needs, or some combination of the two. The work done in fulfillment of this Doctorate of Philosophy developed and validated two separate ergonomic analysis tools, the Agriculture Cumulative Risk Evaluation System (ACRES) and Accelerations of Trunk and Limb Assessment System (ATLAS).

ACRES was developed to fit the immediate need of the farmer or rancher. Through brute force simulation, thousands of lifts were generated and evaluated. The recommended weight limits generated by the simulation served as the basis for the lifting portion of this novel ergonomic assessment tool. The second part of the work that ACRES addresses is the postural nature of some tasks. It simplifies the output down to a recommended exposure time (RET). In both cases, ACRES performed at the same level or better than more commonly used tools of the NIOSH Lifting Equation and Rapid Entire Body Assessment.

This dissertation highlights that the next significant contribution is a lifting model that internalizes the mathematics of dynamic movement inside a package as it is being lifted, ATLAS. This is a particularly relevant issue in manual material handling tasks in the agriculture setting. This contribution is realized in a novel risk assessment tool named ATLAS. While ATLAS externally appears very similar to ACRES inside of the model uses Monte-Carlo simulation to generate random anthropometries, to perform lifts with probabilistic shifts to the center of mass beyond what any other lifting model is capable of. The contribution here is ATLAS and the approach of using probabilistic simulation to path out the new recommended weight limits for a variety of lifting factors.

CHAPTER 1: GENERAL INTRODUCTION

This dissertation emphasizes differences between work sectors ranging from white-collar to blue-collar work with special consideration given to the agricultural work as a particular group within blue-collar work. It includes elements of biomechanics, advanced mathematical modeling, and usability to achieve its research goal.

The primary goal of this dissertation is to develop an effective and easy-to-use tool to evaluate the musculoskeletal risk of work that goes beyond the constraints of current work tools to address the needs of agricultural work. This tool is designed to be used by operators who may have limited resources (i.e., time and money) to reduce the risk of musculoskeletal injury without sacrificing productivity.

Research Motivation

As this dissertation progresses, it will become clear that the agricultural sector workers need a custom ergonomic analysis tool to aid them in their work structure. My background and experience in this industry have made it all too clear that the standard work week and all the assumptions used in common ergonomic analysis tools are limited. As it will be alluded to later, the agricultural worker is unique and needs protection as a workforce. Ergonomic interventions need to be developed to use in their custom operations at the grassroots level to improve their work design and reduce the risk of musculoskeletal disorders.

The need for this tool is present and clear. The tool needs to be developed not to hinder work and evaluate a diverse number of tasks that require immense dynamic applications of force. The accelerations of the trunk, limbs, and load and their effect on the body need to be analyzed and produce interpretable results to a layperson. While there are ergonomic analysis tools that evaluate such work, they may not be approachable to novice users. Thus, we arrive at the hypotheses of this dissertation:

List of Hypotheses

H1. Agricultural workers will report more variability between seasons of work than blue- or white-collar jobs

H2. The distribution of recommended weight limits generated by the NIOSH lifting equation will be wider than Snook and Ciriello tables outputs when used by novice users.

H3. The recommended weight limit of the NIOSH lifting equation will be more restrictive than the Snook and Ciriello tables.

H4. Novice users will find the NIOSH lifting equation and Rapid Entire Body Assessment tools more appropriate than their traditional counterparts.

H5. Novice users will find the Snook and Ciriello tables easier to use/interpret than NIOSH lifting equation.

H6. Novice users will find the Quick Exposure Checklist analysis easier to interpret/use than Rapid Entire Body Assessment

H7. The distribution of the NIOSH lifting equation will be wider than the Agriculture Cumulative Risk Evaluation System outputs.

H8. The recommended weight limit of the NIOSH lifting equation will be more restrictive than the Agriculture Cumulative Risk Evaluation System.

H9. Users will find the NIOSH lifting equation and Rapid Entire Body Assessment analysis tools more appropriate than their novel counterparts.

H10. Novice users will find the Agriculture Cumulative Risk Evaluation System easier to use/interpret than NIOSH lifting equation.

H11. Novice users will find the Agriculture Cumulative Risk Evaluation System easier to interpret/use than Rapid Entire Body Assessment

H12 Agriculture Cumulative Risk Evaluation System will correlate more closely with spinal compression forces beyond the NIOSH lifting Equation

H13. Accelerations of Trunk and Limb Assessment System will correlate more closely with spinal compression forces beyond the NIOSH lifting Equation

Dissertation Organization

This dissertation begins by identifying agricultural work bounds through the Fair Labor and Standards Act, Bureau of Labor Statistics, Occupational Safety and Health Organization, and other government regulations. Just as the work meets a particular set of standards, this changes the characteristics of agriculture workers; a pillar of good human factors is to know the end-user and population for design.

The dissertation then continues with a summary of the many ergonomics tools and the areas where they excel. Summarizing tools ranging from qualitative methods such as checklists to intense quantitative methods such as biomechanical models and evaluating their appropriateness to the agricultural sector.

Once a fundamental understanding of both the users and tools has been developed, the first stage of this research was concluded. The next step was to fill the void of a tool appropriate for the type of work done by agricultural workers, which began developing and testing the Agricultural Cumulative Risk Evaluation System (ACRES).

After comparing ACRES and other analysis tools to evaluate their usability and appropriateness, ACRES was rebuilt to address its shortcomings. A new tool, ATLAS, was developed from this, and both models were validated with spinal compressive loads were evaluated and compared to the assessments of the NIOSH lifting equation for reference.

CHAPTER 2: INTRODUCTION TO TYPES OF WORKER

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Abstract

This chapter discusses certain fundamental differences between working populations from several different aspects such as educational, economics, demographical, and attitudes towards work.

Introduction

The current workforce can be viewed broadly to have two broad categories white-collar workers and blue-collar workers. White-collar is a common term used to describe workers with a college degree and manage businesses, institutions, and governmental entities. Activity levels in these occupations vary between sedentary and light (Church, 2011). Additionally, these jobs are typically described as having salaries with bonuses and incentives for high performance and usually have little physical demand associated with their day-to-day tasks compared to blue-collar workers.

The median age of all white-collar workers [i.e., accountants, bankers, and chief executive officers] is approximately 43.3 years old, according to the 2017 data released by the Bureau of Labor Statistics. This workforce employs 74.8% as full-time, with an additional 24.9% working beyond the standard 40-hour week (Bureau of Labor Statistics). While being salaried may not show a benefit when working overtime, any hourly white-collar employee still has the opportunity. Overtime pay earns the worker 1.5 times their standard rate as when they work more than 40 hours a week or more than 80 hours in two weeks; not all groups get this privilege, as will be discussed later.

Usually, the day-to-day tasks are conducted in climate-controlled environments, where the outside elements are a non-factor in a white collar's ability to perform their functions. Additionally, it is observed that the key source of injury for this group is from repetitive motion tasks such as typing or poor alignment of desk layout, as was the motivation for the Rapid Office

Strain Assessment (Sonne, 2012). None of which can be similarly said for agricultural workers

Alternatively, blue-collar workers do not see all these conditions. Traditionally blue-collar workers are viewed as having technical skills that require some physical effort to complete their job. Examples of these jobs would be welders, carpenters, nurses, machinists, and other vocational skills. By comparison, the number of salaried positions in blue-collar jobs is less than what is seen in white-collar jobs. Another critical difference between these two groups is the physical demand put on the workers showing a higher activity level (Church, 2011). One difference not evident from the Bureau of Labor Statistics is the number of employed full-time workers, and the amount of overtime blue-collar workers complete separate from white-collar (see Table 2.1 below). The median age of these workers is 42.7 years old, and they can also earn overtime pay (Department of Labor).

Commonly lumped in with blue-collar workers are those working in the agricultural sector, herein called "leather-collar workers". These workers frequently work outdoors with little shelter from the elements. These professions are typically family businesses such as farming and ranching and include fish hatcheries and forestry professions. This group's average hours worked per week (including part-time workers) is greater than a standard workweek. In contrast, the blue and white-collar workers work less than 40 hours when part-time workers are included (see Table 1). This kind of work exposure has caused agriculture workers to be exempt from the Fair Labor Standards Act; the exemption states that workers in the agricultural sector may not receive the mandatory overtime rate. This lack of overtime means that employers do not have to pay 1.5x the hourly rate for every hour worked beyond a standard week (Department of Labor-Wage and Hour Division, 2008).

Additionally, due to its seasonal nature, this agriculture workforce does not fit with the traditional ergonomic assessment techniques of repetitive work. While a single task can be completed over a day or potentially a week, this is rarely the case. Required tasks to be completed in this industry change from day to day based on what is necessary to get their goods to market. Comparatively, the way a white-collar worker completes tasks is dramatically different from the agricultural sector. Specifically, we see a much more physically demanding workday today. Not only is this work more demanding physically it also being put onto an aging population, boasting a median age of 47.5-year-old (Bureau of Labor Statistics).

Some jobs are exceptions to working extended hours and variable schedules, such as road construction crew, utility, and maintenance workers. These exceptions allow for overlap in tools in key risk factors such as outdoor/indoor exposure, load type, the force required, posture, and repetition. Thus, many of the tools applied to one can be applied to the other, just as white-collar or office work can use the same tools as red-collar or governmental work. The distinction made here specifically for leather-collar workers is that many agricultural workers are both owners and operators (see the last row of Table 1).

In the owner/operator case of the agricultural worker, job ownership is not just psychological; it is financial. It is hypothesized that this job ownership is taken to the extremes where sick days are almost non-existent. An extreme comparison would be to compare the owner of a small agriculture operation calling in sick to that of a parent calling in sick to their child. Whereas in the other previously mentioned outdoor workers are given benefits such as paid-time-off for overtime worked or allotted personal days. Another more straightforward distinction between leather-collar and the other collars is easily outlined in the Fair Labor and Standards Act. Any worker in the agricultural sector is not entitled to receive overtime compensation by their employer (Department of Labor-Wage and Hour Division, 2008). In conclusion, agriculture work or "leather-collar" work is a distinct group with its own ergonomic, cultural, and economic challenges to be considered in the development and accessibility of ergonomic assessment tools.

Table 2. 1: Department of Labor summary of Industry Characteristics separated by Collar

Characteristic	White-Collar	Blue-Collar	Leather-Collar
Age (Median/Weighted Mean)	43.3/41	42.7/41.78	47.5 / 45.15
Median Weekly Income Men/Women	1223.61/886.41	731.76/505.05	591.64/472.10
Average Hours worked/ Week [Average without part time workers]	38.7 [42.4]* (Numbers joined as Non-AG together)	38.7 [42.4]* (Numbers joined as Non-AG together)	43.7[48.7]

Percent of Full Time that get Overtime [60+ hour week]	24.9 [6.4] * (Numbers joined as Non-AG together)	24.9 [6.4] * (Numbers joined as Non-AG together)	40.6 [21.2]
Environmental Exposure	Office	Factory	Vehicle/Outside
Percent of total workforce working beyond 65	6%	5%	15%
Percent of Self-employed	6% (Numbers joined as Non-AG together)	6% (Numbers joined as Non-AG together)	35%

There certainly is a reason to view the leather-collar worker as separate from traditional white and blue-collar workers. However, most ergonomic evaluation techniques focus on jobs that are distinctly blue-collar or white-collar in nature. As such, a review of standard ergonomic evaluation techniques that focuses on their ability to address leather-collar work is needed.

Agricultural Workers

> "Farming in all its branches and among other things includes the cultivation and tillage of the soil, dairying, the production, cultivation, growing, and harvesting of any agricultural or horticultural commodities (including commodities defined as agricultural commodities in section 1141j(g) of U.S.C. Title 12), the raising of livestock, bees, fur-bearing animals, or poultry, and any practices (including any forestry or lumbering operations) performed by a farmer or on a farm as an incident to or in conjunction with such farming operations, including preparation for market, delivery to storage or to market or to carriers for transportation to market."
>
> -Fair Labor and Standards Act

Agricultural workers do not see a standard workday was many ergonomists are accustomed to analyzing. The agriculture sector is filled with a myriad of manual material handling tasks. Many of the loads being moved here have a variable load center, which means that the center of mass can change as it is being held. Specific examples of these loading situations would include seed/grain handling, live animal handling, or a bucket of water. For the remainder of this article, we will refer to this as dynamic loading. Dynamic loading and its potential sudden changes in acceleration (also known as a jerk) drive the increased injury rates displayed in epidemiology survey studies that have been done earlier (Holmber, 2002; Lyman, 1999; Rosecrane 2006).

Dynamic loading is different from dynamic work, as Nussbaum describes in 2001, where the task itself was changing or dynamic. These tasks are also present in the agricultural sector. It is not uncommon in ranching and animal handling operations to constantly tighten or repair animal restraint systems for a given task, i.e., manual squeeze chutes, wire fence lines, fence post replacement.

In addition to these workers' dynamic loading exposure, they are also subject to variable tasks across various weather conditions. Many daily chores must be completed within the agriculture sector, ensuring food and water for livestock. Still, most of their time is spent doing tasks that vary from day to day, week to week, and even season to season. Through the use of techniques such as work enlargement, industrial workers, as described as one of Deming's 14 points, experience similar variations of day-to-day or week-to-week tasks (Deming, 1982). Although the work cycles will remain smaller than those found in the agriculture sector, the variability of the agricultural work varies both in duration and outside. The agriculture workers' seasonality makes detecting cumulative trauma more difficult, as many techniques, such as REBA, RULA, do not accumulate across various tasks.

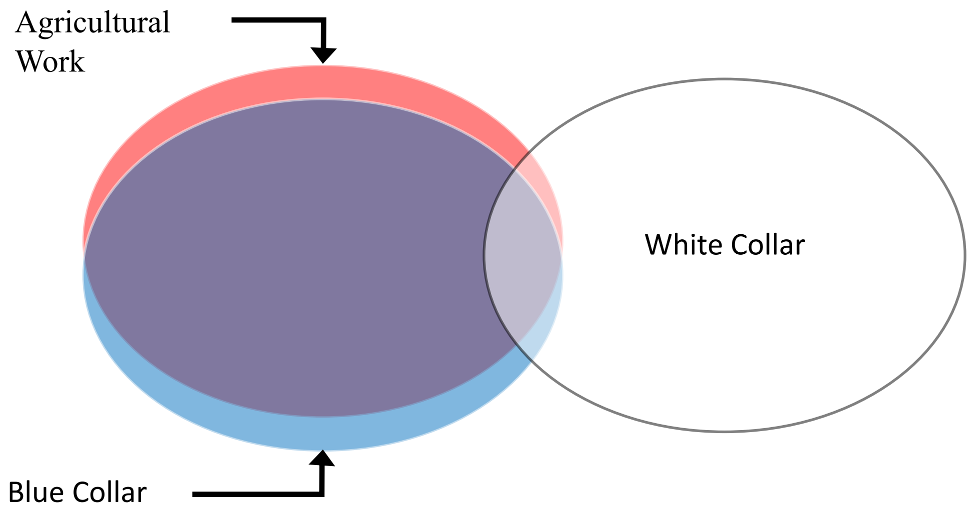

Figure 2. 1: Conceptual Venn Diagram of Types of Work

Lastly, as outlined in the Ovako Working posture Analysis System (OWAS), an analysis tool should give concise and clear outputs and should be simple to use at an introductory level (Karhu, 1977). Many factors affect how tasks are completed in the agricultural industry, and these variables should be considered in work evaluation. Currently, no tool can account for this level of diversity that is present in the agriculture industry. This paper discusses core tools to the ergonomist tool bag and a newly developed tool to fill a void. Each tool critiqued is grouped into categories based on the complexity of the assessment method.

Job Analysis

Federal agencies have provided valuable demographic data on different types of workers, which helps provide a structure for how society views work. Although this data does not explain the underlying causations or descriptions of what drives these facets of work, more analysis was necessary. Specifically, an analysis of what fundamental differences are in the job causes these distinct differences in demographic data and subsequently aid in providing risk assessment tools that can benefit the agriculture sector.

Our analysis began with informal interviews with persons from the three separate sectors, such as secretaries and accountants for white-collar, welders and mechanics for blue-collar, and landscapers and ranchers for leather-collar. The interview focused on asking questions about specific skills, mindsets, and strategies that they believe made them successful at their job. Many of their responses were categorized and compiled in the table below. The interview responses were supplemented with documentaries and video testimonials. In addition to skill sets, the interview also gathered data regarding work tasks by season and work exposure or how much time they spent at work.

The informal interviews were done also discussed variability in work by season. When asked how work changes from season to season, the magnitude of differences in agricultural work becomes very clear. Data in Table 2.3 below, shows the mean and standard deviation of reported work tasks from one season to another. For example, blue-collar workers saw an adjustment of two and a half (2.5) functions from fall to winter. In the same window, agricultural work varied by seven (7) tasks on average. It can be seen that across the seasons, white-collar work did not seem to change. In addition to this, the reported work exposure for both white and agricultural work was reported to be greater than the standardized 8-hour work day.

Table 2. 2: Reported Skills and Mindsets of Success by Sector

Agricultural Work	White Collar		Blue Collar
Adapting to Situations	Bilingual	Personnel Management	Adapting to situations (weather)
Communication Skills	Broad Leadership Skills	Problem Solving and Root Cause analysis	Communication Skills
Job Specific Knowledge	Communication	Punctual	Delegation Skills
Long Attention Span	Critical Thinking,	Reporting Research,	Hard work Ethic
Mechanical Skills	Data Analytics	Software Skills	Job Specific Knowledge
Physically Strong	Dealing with Stress	Teamwork	Not afraid to get dirty
Problem Solving	Decision Making Skills	Time Management	Operate Heavy Machinery
Record Keeping	Job Specific Knowledge		Patience
Self Motivated	Listening Skills, Empathy		Physically Capable
Time Management	Mental Math and Memorization		Record Keeping
Working Long Hours	Multitasking		Troubleshooting
Working With your hands	Organization		Understanding of tools and equipment
	Patience		Working Long Hours

Table 2. 3: Season to Season Task Variability

Change	White Collar	Blue Collar	Agricultural Work aka Leather Collar work
Spring to Summer	0 (0)	1 (1.41)	8 (0)
Summer to Fall	0 (0)	0 (0)	8.5 (2.12)
Fall to Winter	0 (0)	2.5 (3.54)	7 (0)
Winter to Spring	0 (0)	3.5 (4.95)	5.5 (7.07)
Yearly	0 (0)	1.75 (2.76)	7.33(1.75)

While the informal interviews provided an impressive level of detail about the work and worker for each of the sectors discussed, there was simply no way to interview enough workers to capture every job and summary adequately. Instead, the research team developed a web scrapper to analyze the Indeed.com job board for job summaries. Once a list of job summaries was generated, the text was analyzed for common phrases and skills designated in Table 2.2. The scraper was done three times for each of the sectors using common examples of each sector as its search parameters, and a total of 1,170 jobs were scraped.

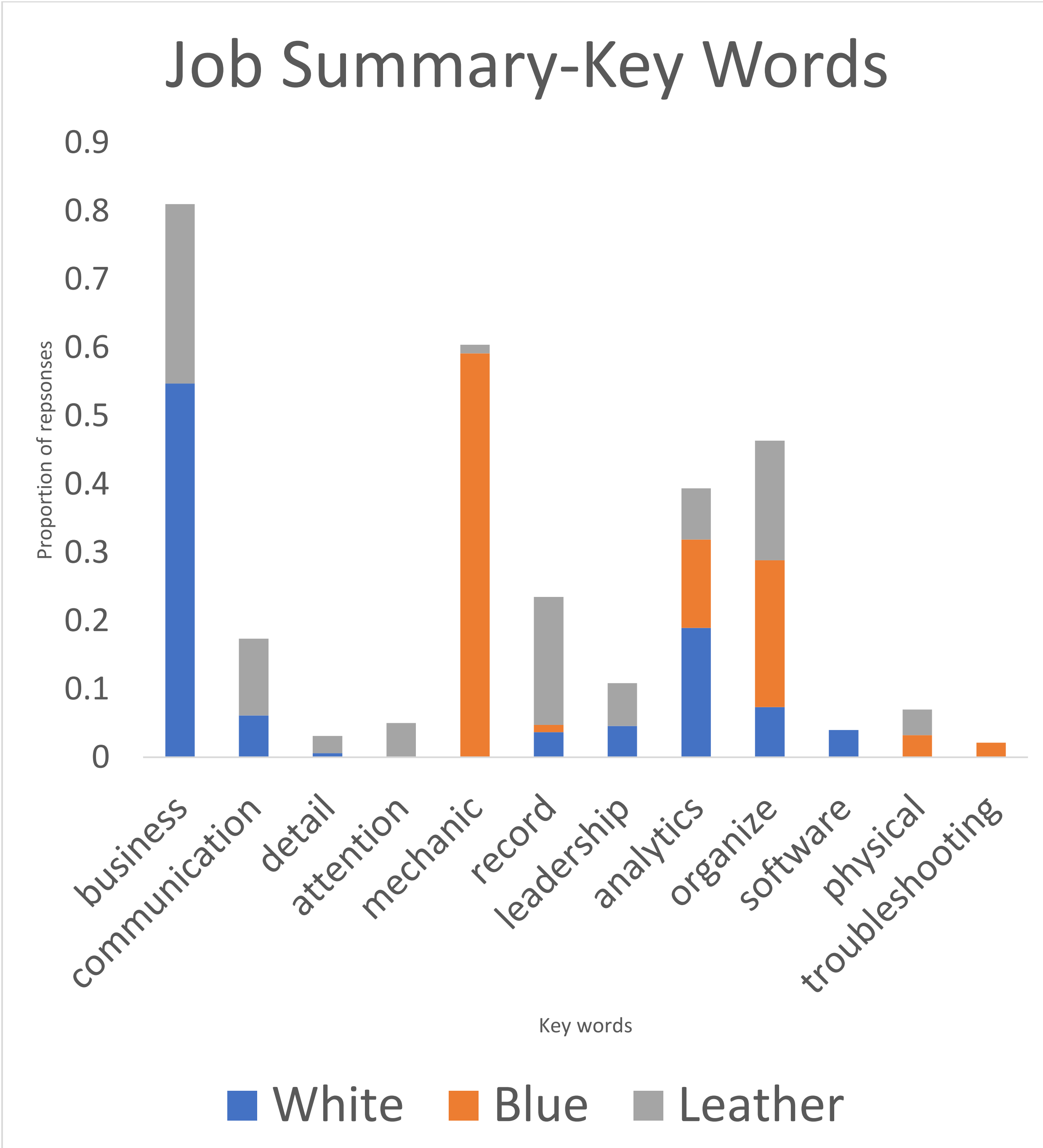

Figure 2. 2 Web Scraper Key Word Analysis

Summary of Worker Characteristics

Through informal interviews and video analysis, it was determined that there is evidence of agriculture work varying more from season to season than blue and white collars, as seen in Table 2.3. Agriculture work also shows a work exposure higher than other collars confirming the first hypothesis listed in Chapter 1 and in agreement with the Department of Labor data and Rosecrance (2006). The interviews also yielded interesting reflective job summaries on what skills made them successful in their profession. The interview's key terms show a heavier overlap of leather-collar work and white-collar work than previously thought. This overlap is likely due to the fundamental skills necessary for self-employment, further backed up by the web scraper's job summary analysis with terms such as business, leadership, communication, and even recordkeeping being heavily split between white-collar and leather-collar.

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CHAPTER 3: INTRODUCTION TO ERGONOMIC ASSESSMENT TOOLS

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Abstract

This chapter discusses the core types of ergonomic analysis tools, each categories' strengths, weaknesses, and ability to serve the agricultural worker population.

Introduction

Before 1938, worker rights and fair labor practices were nearly non-existent, allowing mechanization sans safety devices and child labor to become common place. Companies only needed to prove that a worker had assumed the risk of the job, was partially at fault, or another worker caused the accident to avoid paying the worker any compensation at all. In 1970 the Occupational Safety and Health Act (OSHA) was passed, and finally, companies had safety guidelines to follow/be accountable for. With a federally backed agency enforcing safety regulations, companies finally had the push they needed to launch internal ergonomics and safety programs.

In 1977 Karhu produces one of the first risk assessment tools for broad industry application to reduce musculoskeletal disorders. In the publication of the Ovako Working Posture Analysis System (OWAS), he states an analytical tool must meet three criteria "(a) it must be simple enough to be used by ergonomically untrained personnel, (b) it must provide unambiguous answers even if it results in over-simplification, (c) it must also offer possibilities for correcting the oversimplified ergonomic approach."(pg. 199). The tools discussed below attempt to hold to these principles, but arguments can be made to simplicity and unambiguous answers.

The tools discussed in this chapter are broadly broken into three categories, qualitative, semi-quantitative, and quantitative. Each has its strengths and weaknesses, and all have been used to reduce the prevalence of workplace musculoskeletal disorders.

Qualitative Tools

As discussed in this paper, qualitative analysis tools describe any survey or checklist used to evaluate workplace tasks. The tools are straightforward to use as they are typically binary decisions or filled out by the persons doing the work. Thus, fulfilling Karthu's first requirement of any ergonomic analysis tool, meaning that it should be simple enough to be used by none ergonomic professionals.

In particular, a few checklists have been used to describe work, such as the Keyserling Checklist (Keyserling, Brouwer & Silverstein, 1992). Although the checklist often involves observation, they rely heavily on subjective interpretation. They rarely reflect the direct variable specific to biomechanical evaluation. The one significant drawback of these checklists and surveys is that they cannot describe the injury mechanism or identify areas for a redesign.

Keyserling Checklist

The Keyserling Checklist was developed by Dr. W.M. Keyserling, Dr. M. Brouwer, and Dr. B.A. Silverstein at the University of Michigan in 1992. This evaluation tool rapidly screens cyclical work (5 minutes or less) involving awkward postures of the lower extremities, trunk, and neck by utilizing a one-page checklist and then outputs the ergonomic risk factors. To evaluate this tool, 335 cyclical tasks were observed and evaluated. Because this is an evaluation tool meant to rapidly evaluate work, it cannot evaluate non-cyclical jobs. It cannot identify the exact issues that are causing potential ergonomic hazards (Keyserling, 1992).

Quick Exposure Checklist

The Quick Exposure Checklist (QEC) is originally developed in 1995 by Dr. Guangyan Li and Dr. Peter Buckle for the Robens Centre for Health Ergonomics at the University of Surrey. This assessment seeks to allow for a quick (within 10 minutes) assessment of potential work-related musculoskeletal risk factors (WMSDs) by assigning scores to various body parts based on the posture, duration, weight, force, and other relevant factors. Additionally, other assessments regarding the work can be made. After, these observations will show potential ergonomic hazards and help prioritize interventions that must be made. Originally, this methodology was developed over the course of 2 phases, with 206 occupational health and safety practitioners evaluating various tasks. Because this is meant to be a quick assessment, there are many factors and other situations that may not be as accurately evaluated by this tool; when nonstandard work occurs, it can become difficult to assess ergonomic risks accurately (Li & Buckle, 1999).

Snook & Ciriello Tables

The Snook & Ciriello Tables, also known as The Liberty Mutual MMH Tables because the Liberty Mutual Insurance Company developed them in the late 1970s, is an ergonomic evaluation tool that utilizes psychophysical observations and is focused on the lower back by evaluating the capability and limitations of workers during material handling tasks. These tables will look at important variables, such as the load weight, lifting distance, duration, and frequency, then estimate the percent of the population that can physically perform these tasks.

It was also experimentally validated by Snook & Ciriello, which utilized over 30 industrial workers. One of the major limitations is that because this is a psychophysiological evaluation instead of a biomechanical one, they may be slightly less precise than other biomechanical tools. Additionally, because the output is merely an estimate of the percentage of the population that can perform a task, it may not fully assess the task's specific aspects that need to be changed (Snook & Cirello, 1991).

Agriculture Upper Limb Assessment (AULA)

The Agriculture Upper Limb Assessment, or AULA for short, is an ergonomic assessment tool created by Dr. Yong-Ku Kong, Dr. Soo-Jin Lee, Dr. Kyung-Suk Lee, Dr. Jun-Goo Han, and Dr. Dae-Min Kim primarily at Sungkyunkwan University in 2010. This assessment tool is an ergonomic checklist that evaluates farmers' upper body limb positions by assigning levels based on various postures and durations to output a score evaluating risk. During the initial study, 14 upper limb postures were evaluated (Kong, Lee, Lee, Han, & Kim, 2011). Still, in the next study in 2020, 196 farm tasks were evaluated, and then results were compared to REBA, RULA, and OWAS (Choi, Kim, et.al 2020). The researchers found that the results of the AULA were the closest to the ergonomic experts' evaluations. Though more accurate, these results are constrained only to the upper body, so a separate evaluation tool also needs to be used. This separate evaluation tool was proposed to be Agriculture Lower Limb Assessment (ALLA) (Kong, Han, & Kim, 2010).

Agriculture Lower Limb Assessment (ALLA)

The Agriculture Lower Limb Assessment, or ALLA for short, is an ergonomic assessment tool designed by Dr. Yong-Ku Kong, Dr. Jun-Goo Han, and Dr. Dae-Min Kim Sungkyunkwan University in 2010. This tool focuses on evaluating the lower-limb postures

(Kong, Han, & Kim, 2010). It can be paired with the AULA to create a full-body, ergonomic assessment that analyzes the risk of developing WMSDs (Kong, et.al, 2015). An ergonomic checklist was created to evaluate these tasks and postures, which assesses the risk based on the leg posture and duration. During the initial study, 13 postures commonly associated with farming tasks were evaluated. Then results were compared to other ergonomic assessment tools. Ultimately, this methodology is limited in the opposite way as the AULA; it evaluates the lower-limb postures, so it must be paired with AULA for a full-body, ergonomic assessment.

Semi-Quantitative Tools

Semi-Quantitative tools are the introductory level of tool that gives a concise, unambiguous answer as to the risk of injury for a given task. These are typically done using a pen and paper and observing the task with minimal calculations or coding systems to summarize the risk a specific task has to the human body. As seen in Table 3.1, there have been many postural analysis tools and checklists, not to mention the use of discomfort surveys that can be used to drive change in work tasks. Unfortunately, many of these tools go unused (usages less than 25%) because certified ergonomists are unfamiliar with them or were not necessary for the analysis being done (Dempsey, 2005). RULA was the only tool in the category to receive higher than 50% usage, with many ergonomists replying they used it because it was appropriate and easy to use (Dempsey, 2005). This depressed usage/familiarity of these tools is partially caused by the sample being certified ergonomists having more complex tools available for specific situations. It could also be drawn from the limitations of these tools. For example, these tools often lack the resolution to tell the user exactly where an injury will occur in the body, what structure will fail, or what kind of trauma is expected. Many of these tools output risks to tiered systems that give recommended actions concerning that task. These recommendations range from "No action needed" to "Stop work immediately, injury imminent" (OWAS, RULA, REBA).

It should be noted that this information in the hands of a skilled ergonomist can determine the injury's origin. However, this ability is still limited to the resolution of the tool utilized. These tools are also limited in that they only take snapshots of a single task in a given workday; this raises two more significant concerns. These snapshots are usually specific to elements of the task that are deemed to be the riskiest first. As discussed earlier, what if a job requires multiple tasks to be done throughout a day without rest/recovery? Only two of the methods discussed below have been developed to evaluate multi-task workdays, precisely PATH, PERA, and Strain Index (Bao,2009).

The tools described in Table 3.1 are a subset of the fifteen semi-quantitative analysis tools researched. The tools not included in this discussion are too specialized for specific tasks or specific regions of the body. Previous lists discussing the comparison of analysis tools compared a mix of tool types (semi-quantitative, fully quantitative, and qualitative) (Dempsey, 2005; Pascual,2015; David, 2005) or applied different categorizations (Li and Buckle, 1999). Each tool selected has been used in multiple industries, but this paper focuses on discussing each tool's origins. One limitation of these methods is that there is little detail about the injury mechanism or location. However, all provide an unambiguous answer as to what level of risk the task is. Although these tools may not be ideal, they allow for identifying risk and offering a reasonable if not limited ability to seek solutions. Lastly, many of these tools provide quantification and corresponding coding system; this allows the user to see how they can manipulate work to make it safer.

Ovako Workplace Assessment System

The Ovako Workplace Assessment System, or OWAS for short, is an ergonomic assessment tool created by Ovako Oy, a Finish steel industry company, in 1973 (Karthu,1977). It attempts to classify different postures of the back, arms, legs, and weight of the load into four categories, showing whether ergonomic change is needed. With the various combinations of the postures, there are a total of 252 possible postures, which are then used to output one of the scores in the four categories. To assess the validity of this tool, there have been many studies performed which compare the results of this tool with other assessments. However, some limitations include not differentiating between the right and the left. It is time-consuming, it does not consider repetition or duration, requiring training to use properly.

Table 3.1: Semi-Quantitative Analysis Tools

Tool	Original task Development	Limitations	Author
Occupational Work Analysis System- (OWAS)	Steel industry	Static posture analysis	Karhu, 1977
Rapid Upper Limb Assessment (RULA)	Various Tasks	Upper Limb analysis and Static Posture analysis	McAtammey, 1994
Rapid Entire Body Assessment (REBA)	Nurses moving patients	Utilizes Repetitive motion in frequency	Hignet, 2000
Posture, Activity, Tool and Handling (PATH)	Highway Construction		Buchholz, 1996
Rapid Office Strain Assessment (ROSA)	Office work	Specialized to White-Collar work	Sonne, 2012
Postural Ergonomic Risk Assessment (PERA)	Vehicle Seat Assembly and Installation	Only Used in Cyclical Work	Chandler, 2017
Strain Index	Manufacturing Plants (Rucker and Moore, 2002)	Only Evaluates Single Tasks	Moore and Garg, 1995
PLIBEL	Machine Work, Bookbindery, Garbage Collection, Laundry Work	Not a Quantitative Measure	Kemmlert, 1995
European Worksheet Analysis System (EWAS)	Automotive Industry	Only used for Highly Repetitive Work	Shaub, 2013
Occupational Repetitive Actions (OCRA)	Repetitive movements, Number of Tasks, Multiplier Factors for Force/posture/Additional, Duration, Recovery Multiplier	N/A- Repetition Based	Occhipinti, 1998

Posture, Activity, Tools, and Handling (PATH)

PATH (Posture, Activity, Tools, and Handling) is an ergonomic assessment tool that is focused on assessing musculoskeletal disorders for the lower extremities, back, neck, and shoulders in non-repetitive work, specifically in construction—created in 1996 as a part of the Construction Occupational Health Project by the Department of Work Environment at the University of Massachusetts Lowell by Dr. Bryan Buchholz, Dr. Victor Paquet, Dr. Laura Punnett, Dr. Diane Lee, and Dr. Susan Moir (Buchholz, et.al, 1996). To evaluate work, codes are utilized to analyze the posture, worker activity, tool use, load handling, and grasp type. Then, output results show which specific operations and tasks pose physiological/ergonomic risks. To test this, six construction workers were tested while performing four construction operations. This methodology is limited in that it does not focus on the distal upper extremities, so it has trouble evaluating hand and wrist-specific activities.

Rapid Office Strain Assessment (ROSA)

The Rapid Office Strain Assessment (ROSA) is an office ergonomic risk checklist developed by Dr. Michael Sonne, Dr. Dino Villalta, and Dr. David Andrews (Sonne, Villalta,& Andrews, 2012) . They are a part of the Department of Kinesiology at the University of Windsor, in 2012. It focuses on assessing static and repetitive office work and utilizes a picture-based posture checklist to output a score that can prioritize areas with potential ergonomic risks. This tool was first assessed on 72 different office workstations. It correlated ROSA scores with discomfort levels reported by office workers. Though effective, this also led to the limitations of the initial assessment of ROSA; workers can overestimate discomfort levels, and because workers knew that they had to report their scores, it may have contributed to them overestimating their discomfort levels. Additionally, discomfort is not the only and not necessarily the most accurate metric to evaluate relative to, so other metrics could potentially be used to further validate the tool.

Rapid Entire Body Assessment (REBA)

The Rapid Entire Body Assessment, popularly known as REBA, is an ergonomic assessment method developed in 1995 by Dr. Sue Hignett and Dr. Lynn McAtamney University of Nottingham (Hignett, McAtamney,2000). This methodology seeks to evaluate the risk of Work-Related Musculoskeletal Disorders (WRMDs) for the entire body. It does this by analyzing various postures and other variables (such as load size), which can then output a score that determines potential for a WRMD. These scores and evaluations are determined based on the static positions that workers are in during tasks. During one of the original studies, hundreds of posture combinations were evaluated and compared with ergonomists' assessments. However, like RULA, this assessment does not consider the task duration, will only evaluate the worst possible posture as it is only a moment in time, and does not evaluate more specific variables, such as vibration.

Rapid Upper Limb Assessment (RULA)

The Rapid Upper Limb Assessment, commonly referred to as RULA, is a methodology focused on evaluating the upper limb and potential disorders that can arise from work. It was first developed by Dr. Lynn McAtamney and Professor E. Nigel Corlett at the University of Nottingham in 1993 (McAtamney, Corlett, 1993). RULA ultimately is just a survey to assess any upper limb disorders by evaluating various postures, positions, and other metrics (like duration) to output a score that shows whether the work is safe to perform or not. In the initial study, the researchers first tested this system on 16 participants, but there have been countless studies since which continue to reaffirm RULA's validity as a valuable ergonomic assessment tool. Though one of the most popular evaluation tools, RULA has trouble evaluating whole-body tasks, varying tasks, and is focused on just the extreme positions at a moment in time instead of the movement of an entire task.

Occupational Repetitive Action (OCRA)

OCRA is an ergonomic evaluation tool created by Dr. Enrico Occhipinti, a professor at the University of Milan in the Department of Biomedical Science, as a part of the EPM Research Unit. This methodology was published in the journal of Ergonomics in 1998 (Occhipinti, 1998), and its purpose is to evaluate potential exposure levels for subjects experiencing overhead, repetitive motion by taking the actual number of repetitions performed and then outputting a recommended amount. Its methodology is heavily based on NIOSH's procedure for calculating the Lifting Index. In the study created and validated in 1998, but in a later study, there were eight investigations with a total of 462 workers exposed to occupational risk relative to another group of 749 workers not exposed to occupational risk (Greico, 1998). This model will output a risk factor for overhead lifting tasks, but it will not explicitly say or predict which exact exposure or effect variable was responsible for the increased risk. This predictive model was stated as a potential future work of the experimental study.

Postural Ergonomic Risk Assessment (PERA)

Postural Ergonomic Risk Assessment was created by Dr. Diviyasksh Chandler and Dr. Maria Cavatorta at the Politecnico di Torino of Italy in 2017 (Chander,Cavatorta, 2017). This method was designed to assess postural risk for cyclical work. The tool works by breaking a single cycle into distinct postures/ tasks. These tasks are then scored using a "cube" method to create a work task score. These work task scores are then averaged to create a work cycle score. The ergonomic risk is then derived by what range the work cycle score fall. This tool was developed for automobile assembly processes and validated against scores from the European Worksheet Analysis System, where it was in strong agreeance. The key limitations of this tool are that it is highly specialized for cyclical work and is subject to user judgment on what is considered a task and what is not.

Strain Indexes

Revised Strain Indexes were created by Dr. Arun Garg, Dr. J. Steven Moore and Dr. Jay M. Kappelusch at the Universities of Wisconsin – Milwaukee and Texas A&M University in 2016 (Garg, Moore, Kapellusch, 2017) but were based on the original strain index created in 1995 (Moore, Garg, 1995). This assessment evaluates the distal upper extremity's physical exposure by considering the intensity, frequency, duration, posture, and repetitions of a particular task during a day. This tool will take objective observations, such as the force or frequency of exertion, and then utilize continuous multipliers to output a score that says whether a task is safe or hazardous. During this study on the Revised Strain Index, evaluations with both the original and revised strain indexes were performed on a simulation of 13,944 tasks. In regards to limitations, the Revised Strain Index does not account for additional variables regarding the specific number of times work is performed (and the times when workers recover) as well as the "speed of work."

PLIBEL

PLIBEL is a "Method for the identification of musculoskeletal stress factors which may have injurious effects" (Kemmlert,1995, p.199) and was created by Dr. Kristina Kemmlert at the National Institute of Occupational Health in the Department of Rehabilitation and Physical Medicine at Karolinska Institute in 1995 (Kemmlert, 1995). This evaluation is a checklist that can identify specific ergonomic hazards relative to different body parts and can rapidly and accurately assess the work environment. The body was broken into five different regions, and each was evaluated based on the posture, potential for movements to be tiring, poor designs of tools or workplace, and the environmental or organizational conditions. After observations are made, potential musculoskeletal injuries to specific body regions can be evaluated. To validate this tool, seventeen physiotherapists and seven ergonomics researchers with experience with occupational overuse symptoms evaluated four jobs with a total of 67 items in the five body regions assessed. This methodology struggles in that it requires someone with an ergonomic background to be making this assessment, and unusual conditions, which are not evaluated but can be significant hazards, can be overlooked by this tool.

In summary, these tools are suitable for a quick analysis. The occasional work-study engineer is used to evaluate the risk of specific operations tasks and potentially change the work to mitigate the risk associated with it. When these tools are used in compilation, they can provide a good view of the exposure to injury, but using a single one will rarely show the entire picture. Lastly, only the PATH, PERA, OCRA (See Section 3.4, further note that this is also interpretable as a semi-quantitative method) and Strain Indexes have been adapted/designed to handle the risk evaluation across an entire workday.

Quantitative Tools

The NLE the most commonly used tool of professional ergonomists and likely the most famous quantitative analysis tool to date (Waters 1993; Lowe,2019). Quantitative analysis tools can be used to evaluate work both prospectively and retrospectively, meaning that these tools can be used to tell if a task is risky and evaluate the proposed future lifting tasks. These tools strongly align with Karthu’s second and third guidelines for ergonomic analysis.

This ability to recommend lifting conditions before the build phase of a new workstation is one of this type of ergonomic evaluation tool's biggest strengths. Also, these tools use simple, measurable inputs to create entirely data-driven results. However, this predictive ability is not exclusive to lifting equations.

Predictive lifting indexes do make some tradeoffs, though, for its strength. These tradeoffs or limitations come as the restrictiveness in their use. Many models are restricted to specific lifting ranges, whether from ground to knee, knee to hip, hip to the chest, etc. This can cause problems when lifting conditions exceed any single range for a lifting equation. Some of these lifting equations have additional lifting restrictions on them; see below. While some equations below do take sex and stature into consideration, there is little to no consideration for whole-body strength capacity; the closest dependent metric is body weight. For example, as stated earlier, those working in the agriculture sector may have developed whole-body strength that is not present in white-collar workers. This additional strength may not be evident in any physiological attribute used in the model but can result in a risky task being safe for that user.

In summary, lifting equations are great tools when the task is well defined and the correct index can be applied, but many times they overly restrictive to the tasks or should not be used due to an individual model's restrictions.

NIOSH Lifting Equation

The NIOSH Lifting Equation is a tool that has been developed by the National Institute of Occupational Safety and Health (NIOSH) as a way to evaluate potential lower back pain (LBP) and work-related musculoskeletal disorders (WRMDs) (NIOSH, 1981). It became the revised NIOSH Lifting Equation in 1991 and was headed by Dr. Thomas Waters, Dr. Vern Putz-Anderson, and Dr. Arun Garg (Waters, Putz-Anderson, Garg, 1991). This equation will evaluate the safety of tasks being performed as objects are being moved by considering the angles, distances, symmetry, coupling of boxes, and frequency. These factors are then measured and put into the equation, which has various weights and then can output a recommended weight limit for a task to be performed safely. The NIOSH Lifting Equation is limited in that it is focused on just two-handed lifting tasks, so its scope is relatively narrow as it cannot consider many other slightly different lifting tasks, such as one-handed lifting tasks. Additionally, other tasks performed during the lift, such as walking or climbing, are excluded.

Merrywether Predictive Lifting Capacity

The back compressive force estimation model developed by Dr. Merryweather, Dr. Loertscher, and Dr. Bloswick at the University of Utah used an iterative approach in conjunction with the University of Michigan 3D Static Strength Prediction Program to refine a hand calculation that provided strong correlations with spinal compressive forces (Merryweather, Loertscher, Bloswick, 2009). The hand calculations used required gender-specific calculations, torso flexion angle, and upper body center of mass location. The team worked from an existing model to evaluate 6000 different lifting tasks. The authors go on to state that this tool serves more as a litmus test to determine which tasks should be evaluated using computer modeling.

Table 3. 2: Predictive lifting Capacities

Researchers	Dependent Variables	Height level	Sex
Ayoub, 1978	Load of lift, Weight	Floor to Knuckle	Both
Ayoub, 1978	Load of lift, Weight	Floor to Shoulder	Both
Ayoub, 1978	Load of lift, Weight	Floor to Reach	Both
Ayoub, 1978	Load of lift, Weight	Knuckle to Shoulder	Both
Ayoub, 1978	Load of lift, Weight	Knuckle to Reach	Both
Ayoub, 1978	Load of lift, Weight	Shoulder to Reach	Both
Ayoub, 1976	Load of lift	Shoulder to Reach	Female
Ayoub, 1976	Load of Lift	Shoulder to Reach	Both
Ayoub, 1976	Load of Lift	Floor to Knuckle, Knuckle to Shoulder, Shoulder to Reach	Both
Merrywether, 2009	Estimated compressive load, body weight, body height, anterior distance of hands to the L5-S1, hand load, trunk sagittal flexion angle from vertical	N/A, Expression of compressive load in low back	Non-Specific
Waters, 1993 a.k.a. NIOSH Lifting Equation	Horizontal, Vertical, Asymmetry, Distance, Coupling, Frequency	Floor to Reach	Non-Specific

Ayoub Predictive Lift Capacity Equations

Dr. Ayoub of Texas Technological University produced several different predictive lifting capacities years before the first NIOSH Lifting Equation was published (Ayoub, Dryden, et.al, 1976). Working as a contemporary of Dr. Garg and Dr. Mital, predictive lifting capacities ranged from the heart rate to oxygen consumption (Ayoub, Dryden, et.al, 1976; Ayoub,El-Bassoussi, et.al, 1976; Ayoub, Bethea, et.al., 1978) . The equations research and created helped to shape psychophysical validations, but they fail to meet Karthu's guidelines of usability, clarity, and actionability.

Summary

There are many different methods to analyze ergonomics that each produces varying degrees of resolution. Each of the tools discussed above has some drawbacks that would make it unsuitable for analyzing work done by the agricultural worker as described in Chapter Two due to their jobs varying wildly throughout the year or simply because the tools are too complex for a novice user to evaluate their work. The agriculture sector needs a tool that can take the precision and resolution of a tool such as the NIOSH Lifting Equation and make its ease of use comparable to a checklist or simplified semi-quantitative tool.

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CHAPTER 4: DESIGN AND EVALUATION OF A SIMPLIFIED AGRICULTURE CHECKLIST FOR LIFTING AND EVALUATION

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Abstract

This chapter outlines the methods for the design and evaluation of a new ergonomic analysis tool that for use in evaluating lifting tasks and repetitive tasks.

Introduction

The Occupational Safety and Health Administration (OSHA) was established in 1970 to ensure safe and healthy work environments. OSHA operates to enforce safety standards that reduce accidents and injuries at work. Many of the standards enforced are considered immediate dangers to the worker, with regulations focused around industrial hygiene. This commitment to safety and new oversight meant that companies needed to take a closer look at the work and its effects on the worker, and in 1977 the Ovako Working posture Analysis Systems (OWAS) was developed (Karthu,1977).

This kicked off several epidemiological studies on workplace musculoskeletal disorders as a foundation to build ergonomic analysis systems to design safer work. In this era, tools such as the NIOSH Lifting equation, Rapid Upper Limb Assessment, and Rapid Entire Body Assessment were made (Waters,1993; McAtammy, 1993; Hignet, 1995). A 2019 study found that these tools account for 3 of the top 4 most widely used ergonomic assessment methods by ergonomic professionals, with Snook and Cirello tables being the fourth (Lowe, 2019; Snook,1991).

The NIOSH Lifting Equation (NLE) is so widely used in part to its quantitative nature and ability to generate a specific recommended weight limit for the given set of lifting parameters which can is very beneficial to designing work. It can help lift and lower tasks and even consider the psychophysical response to lifting tasks (Waters,1993). Overall the NLE a great tool for industrial settings; it is limited in the assumption that every lift is done with both hands and can artificially inflate its recommended weight limit for persons with taller anthropometries.

The Rapid Upper Limb Assessment and Rapid Entire Body Assessment are the other two widely used tools by professional ergonomists in which work is observed, and body positions are fit into categories (McAtamney,1993; Hignett, 2004). These categories are then compiled and indexed to produce a final score for the level of ergonomic risk. These tools are great as they provide the user with an instant assessment of the work design and can even be used to find areas to improve work.

These ergonomic assessment tools work to go above and beyond the OSHA regulations and help to reduce the number of OSHA recordable injuries/illnesses. These tools were developed to fit the needs and focus of the types of work most regularly evaluated by OSHA. These types of work permeate inspect nearly every industry that produces a good from welding operation to power generation and even providing bakery guidelines for safety and health. Unfortunately, the OSHA regulations have a blind spot, specifically when it comes to the agricultural sector.

The only area of protection that OSHA affords to farmers and ranchers is tractor and motor vehicle safety. OSHA exempts the agricultural sector entirely from the grain handling guidelines. Since there is little regulation or investigation in the agricultural sector, there are assumptions violated for these tools. For example, the NIOSH lifting equation assumes that all lifts are completed with two hands; agriculture work frequently violates this during grain handling operations where buckets and shovels are used.

This focus is mirrored in the prevalence in the area of practice for many professional ergonomists. A majority of ergonomic professionals work in areas ranging from construction to mining and oil extraction to manufacturing. The latter is the most dominant at 69.1%. Conversely, the smallest represented industry is the agriculture, forestry, or fishing industries, which combined account for less than 6% of all professional ergonomists' areas of practice and less than 5% of US only practice (Lowe, 2019).

This blind spot of OSHA is merely a product of previous exemptions made to the agricultural sector. Specifically, the Fair Labor and Standards Act of 1938, which created minimum wage and overtime pay, defines agricultural work and omits workers meeting this classification from collecting overtime pay. This has led to the systematic neglect of the people who produce our food. A 2006 study of Kansas farmers found that low back pain was not only higher than in other working populations but was actually on the rise when compared to previous studies on farmers (Rosecreance,2006).

This lack of ergonomic evaluation for the agricultural sector was finally addressed in 2010 and 2011 with the instruction of the Agriculture Lower Limb Assessment (ALLA) and Agriculture Upper Limb Assessment (AULA) tools (Kong,2010; Kong,2011). These tools were eventually combined to create the Agriculture Whole Body Assessment (AWBA) in 2015 (Kong,2015). In each case, agricultural work was evaluated by experts and validated against the same experts' initial opinion of ergonomic risk, aggregated. Here lies its fundamental issue, the AWBA assessment and its agricultural predecessors were designed for professional ergonomists to use and evaluate agricultural work, and in this case, it does not outperform the likes of previous tools.

As discussed earlier, there is a lack of professional ergonomists whose field of practice is the agricultural sector; thus, we have a tool that too few can use. The purpose of this study is to develop an ergonomic assessment tool that can be used by novices and provide results equal to or better than that of commonly used tools by professional ergonomists. This paper describes the method and its development and validation.

Methods

The development of the Agriculture Cumulative Risk Evaluation System (ACRES) is to:

- Provide quick ergonomic risk assessments as done by non-ergonomists
- Provide assessments that non-ergonomists can quickly assess
- Provide an assessment that only requires pen and paper
- Make the interface simple enough that a non-ergonomist can improve the work design
- Make the interface and outputs easy enough to use that it can be done repeatedly for high variability work.
- Provide a tool that accounts for user experience when doing a task.

Tool Development

ACRES was created using the NIOSH lifting equation's underlying epidemiology and the Ovako Working posture analyzing system (Water 1993; Karhu, 1977). Following the formulas outlined in the NIOSH lifting equation (NLE) a discrete set of anthropometries were simulated through the NLE. The simulation ran through every combination of the lifting variables creating a dataset of recommended weight limit. This data set was then blocked by the variables of interest and averaged. The differences between these average recommended weight limits is the magnitude of effect it holds over the final RWL, this is where the ACRES integer was generated.

In application, factors such as horizontal distance, vertical starting height, lifting distance were either given or derived from the discrete set of anthropometries. Factors such as axial rotation, coupling, and duration were also given as discretized sets. However, the NLE requires an extensive table to determine the correct lifting modifier and the simulation discretized that table by examining the data for natural breaks in the set of multipliers. This discretized set of natural breaks was then selected based on the combination of other factors. Take for example the Horizontal lifting integers, this factor was held constant at 10”, 15” and 25” while every other combination of lift was examined.

In the development of postural analysis, many of the epidemiological considerations follow REBA, RULA, and OWAS with slight changes where then each variable is broken into categories and given an estimated exposure time based on the posture. Exposure times were generated according to the magnitude that other tools used. If any of the tools had multiple levels of posture with increasing levels of risk in mirrored that reducing the exposure time for non-ideal postures.

In both cases, the number of potential options is reduced and distilled to a level where simple arithmetic can be used to reach a final solution without the need for tables and multiple pen and paper sheets. ACRES operates by splitting each ergonomic factor into categories then setting the middle level to zero. As the system is used, areas for improvement to work can be noted, and the work can be changed at the level of the worker.

Lifting Assessment Tool

The above simulation method was repeated for several key lifting factors. For each factor each level was held constant and with all other combinations present. The average recommended weight limit for each level of a factor was order in decreasing order. For all factors with three levels the middle point of recommended weight limits was set to zero and the differences up and down were rounded to the nearest whole number to create the integer changes found below in tables 4.1-4.6.

Table 4. 1: Horizontal Integer Changes

Horizontal	lbs.
10” from instep	6
15” from instep	0
25” from instep	-5

Horizontal distance is one of two key factors affecting the amount of trunk flexion and load moment. Someone bends over to perform a lift; the farther away from the object's center of mass, the more flexion experienced by the trunk and greater the moment created by the load. ACRES operates within a similar window as the NIOSH lifting equation between 10 and 25 inches. Through simulation and other lifting characteristics as inputs to a biomechanical model, the average recommended weight limits were determined for each of the horizontal constants. We then, using the differences between these recommended weight limits, the horizontal integers were obtained, Table 4.1. ACRES splits this allowing the middle number to remain zero to show the user how adjusting it to be closer can affect the ending recommended weight limit. The model reduces the recommended weight limit if the object is lifted farther away while increasing it at closer distances.

Table 4. 2: Starting Point Vertical Integer Changes

Vertical Factor	lbs.
Knee	0
Hip	1
Chest	-1

Table 4. 3: Lifting Distance Integer Changes

Lifting Distance	lbs.
Knee to Hip	1
Hip to Chest	0
Knee to Chest	-2

The second key factor affecting trunk flexion angle is the object's vertical height at the start of the lift and the total distance lifted. The revised NIOSH Lifting equation and other predictive lifting indexes consider the object's height at the start of the lift, and the overall vertical distance traveled. ACRES discretizes these lifts into three areas for starting, the knee, hip, and chest and quantifies these areas using constant anthropometry. Using a simulation that held each starting point constant and yet varying all other lifting parameters, the mean recommended weight limits for each starting height were found, and the difference was used as the vertical factor integers (Table 4.2). This meant that when lifts started at the hip, the recommended weight limit could be increased by a pound, but if the lift started at the chest, it is reduced by one pound. Lifting distance also plays a critical role. By holding the vertical factor static and changing the destination, a simulation is able to capture the effects of all other varying factors into three distinct recommended weight limits where the difference is collected (Table 4.3). ACRES instead utilized the relative anthropometry of the person performing the lift. This does two things; first, it limits the artificial reduction of recommended weight limits for taller individuals. The second makes estimating a recommended weight limit through video analysis.

Table 4. 4: Axial Rotation Integer Changes

Axial Rotation	**lbs.**
Neutral	1
15<Slight twist <45	0
Twist >45	-1

The axial trunk rotation or the amount of twist done during the lift also plays a significant role in estimating a recommended weight limit. It is a significant factor as twisting increases the erector spinae muscle's activation while reducing the obliques' recruitment, a contributor to trunk stability and intra-abdominal pressure (Marras,1998). ACRES captures this characteristic by quickly capturing high, low, and midpoint ranges of trunk rotation as individual recommended weight limits. As was the case, the horizontal factor in the midpoint range of twist is considered to have no adjustment (Table 4.4).

The last three factors of importance included in this analysis tool are coupling, duration, and frequency. Coupling and duration followed the same process outlined above where the midpoint was zero with adjustments up and down. In the case of lifting frequency this category was split into four levels rather than three. The integer adjustment technique was approached by averaging all the RWLs and letting the adjustments fall according to the change in that level's specific recommended weight limit.

Table 4. 5: Coupling Integer Changes

Coupling	lbs.
Good	1
Fair	0
Poor	-1

Table 4. 6: Lifting Duration Integer Changes

Duration	lbs.
1 hour	3
2 hours	0
8 hours	-4

Table 4. 7: Lifting Frequency Integer Changes

Frequency	lbs.
Slow (<1 lift per minute)	5
Moderate (1-6 lifts/ minute)	2
Fast(7-9 lifts/ minute	-3

Very Fast (>9 lifts/ minute)	-4

Postural Assessment Tool

Following the categorical precedence of tools such as REBA, RULA, OWAS, ALLA, AULA, and other posture analysis tools, ACRES breaks the body positions into ranges for evaluation. The key difference between ACRES and other tools is that rather than providing a code or score to determine risk exposure, it provides and recommended exposure time. A recommended exposure time more appropriate output for novice users as well as workers in the agricultural sector as it removes the ambiguity of what action should be taken. This follows with Karthu's second guideline stating that the outcome should be clear even it is oversimplified. ACRES as a posture analysis system estimates the recommended exposure time (ret) before taking a breakthrough addition and subtraction from a 1-hour base to get a final RET Score.

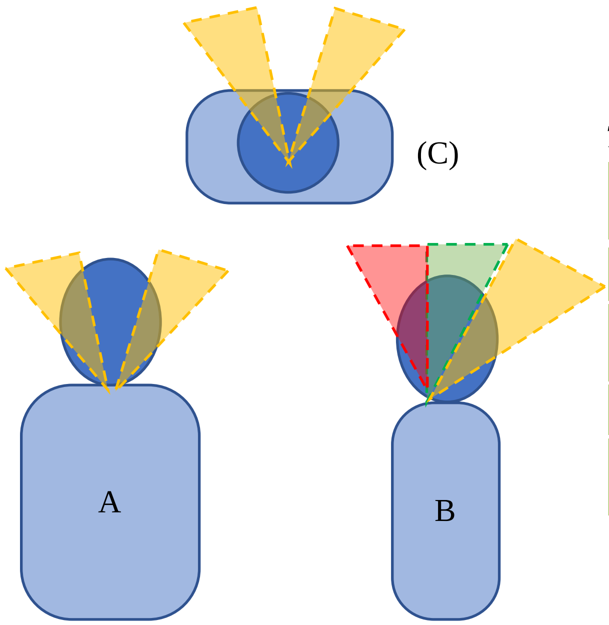

Figure 4. 1 Example Postures of the Neck, (A) Front, (B) Right Side, (C) Top View

Table 4. 8: Neck Posture Integer Changes

Neck Posture	**Presence**	**Modifier (minutes)**
Neutral		+10
Flexed (>20degrees)		-5
Extended		-5
Twisted/ Side Bending		-5

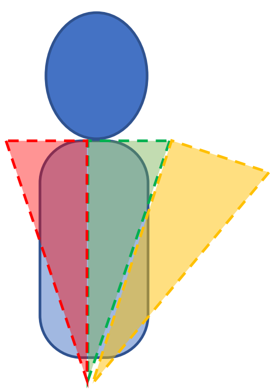

Figure 4. 2: Example Postures of the Trunk (Side View)

Table 4. 9: Trunk Posture Integer Changes

Trunk Posture	**Presence**	**Modifier (minutes)**
Neutral		+15
Extended		-5
Flexed (<20degrees)		-5

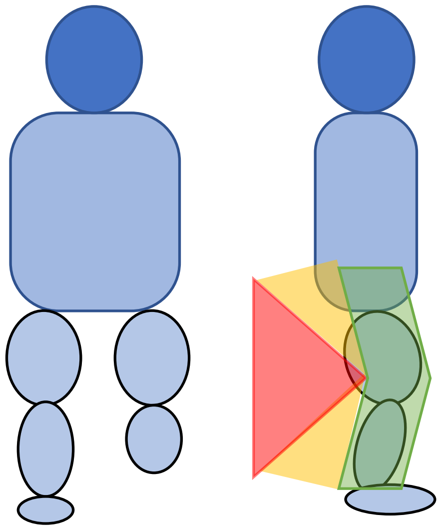

Figure 4. 3: Example Leg Postures, One Legged Stand (Left), Legs Bent (Right)

Table 4. 10: Leg Posture Integer Change

Leg Posture	**Presence**	**Modifier (minutes)**
Neutral		+10
One-leg Stand		-5
Leg Bend (30-60 degrees)		-10
Leg Bend (>60 degrees)		-15

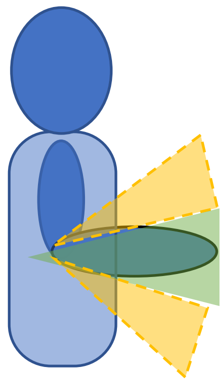

Figure 4. 5: Example Postures for Lower Arm

Table 4. 12: Lower Arm Integer Changes

Lower Arm Posture	Presence	Modifier (minutes)
Neutral (60- 100 degree)		+5
Flexed (<60 degrees, >100 degrees)		-5

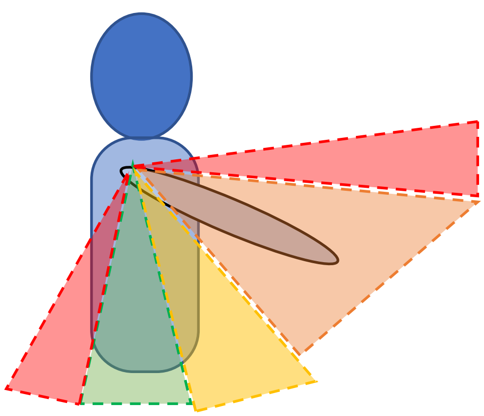

Figure 4. 4: Example Postures for the Upper Arm

Table 4. 11: Upper Arm Posture Integer Change

Upper Arm Posture	Presence	Modifier (minutes)
Neutral (+/- 20 degrees)		+10
Extended (>20 degrees)		+5
Flexed (20-45 degrees)		+0
Flexed (45-90 degrees)		-5
Flexed (>90 degrees)		-10
Abduction		-5

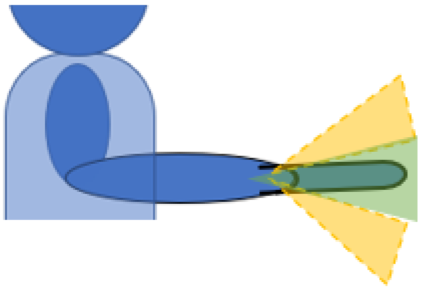

Figure 4. 6: Examples of Wrist Posture

Table 4. 13: Wrist Integer Changes

Wrist Posture	Presence	Modifier (minutes)
Neutral +/- 15 degrees		+5
Flexed/ Extended +/- 15 degrees		-5

Table 4. 14: Work Intensity Integer Changes

Work Intensity	Presence	Modifier (Minutes)
Leisurely		+30
Moderate		+15
Semi-Vigorous		
Vigorous		-30

Table 4. 15: Work Movement Integer Changes

Work Movement	Presence	Modifier (Minutes)
Static		-15
Rapid		-15
Large Macro Movements		-15

Tool Instructions

As the name suggests, ACRES is a cumulative evaluation tool. As such, to reach the end result, the users simply need to add each individual factor to the base weight or time that is appropriate. The base weight for ACRES as a lifting evaluation tool is determined by the expertise of the lifter, where those with proper form are able to reduce the effective spinal compressive force through proper lifting techniques and muscle development. This also helps to protect lifter that may be less than capable; an aspect lost to both the NIOSH lifting equation and the Rapid Entire Body Assessment.

Table 4. 16: ACRES Posture Summation Guide

Recommended Task Time	
Starting Point	60 minutes
TOTAL-Core	
TOTAL- Arms	
TOTAL- Work	
REC. EXP. TIME (RET)	

Table 4. 17: ACRES Lifting Summation Guide

BASE WT.	
Horizontal	
Vertical	
Lifting	
Angle	
Coupling	
Duration	
Frequency	
Asymmetry	
TOTAL (RWL)	

Validation of ACRES

Participants

The psychophysical and quantitative study had 49 and 20 participants, respectively. The psychophysical group had minimal experience with ergonomic analysis tools, specifically ACRES, NLE, and REBA. The quantitative group was mixed between those with intermediate and novice experience with ACRES, NLE, and REBA.

Task

ACRES was validated over the course of two studies; the first was a psychophysical response, as measured by Borg RPE, to the posture analysis during three repetitive tasks and then compared to the risk exposure score of REBA and the recommended exposure time of ACRES. The tasks that were done included digging a post hole, typing at a computer, and a drywall joining operation. The second study that was done was a quantitative measure of spinal compression forces, as measured using the University of Michigan 3-dimensional simulated static posture program (UM3DSSPP) to the recommended weight limits of ACRES and NIOSH Lifting equation.

Results

In the case of the lifting validation study, a spinal compression index (sci) was used as a comparison to the lifting indexes defined by the NIOSH Lifting Equation and similarly used by the ACRES RWL. This comparison allowed for direct correlational analysis. In this analysis, we find that novice users can explain 8.9% more of the spinal compressive force using ACRES than the NIOSH Lifting Equation, however this in not suffiencent enough evidence to reject null hypothesis 12.

When the psychophysical validation of ACRES is compared with REBA using the Borg RPE as the metric of psychophysical response, we find that ACRES significantly outperforms REBA in explaining approximately 13% more of the variation than REBA. Significance is attributed via the absolute value of each R^2 value's confidence interval not containing the mean of the other, as seen below.

Table 4. 18: Summary Table of Quantitative Correlational Analysis and Simple Linear Regression Plots for Lifting Tools

Spine Compression Index vs	R^2	Count	Correlational P-value	Linear Approximation	Linear Fit P-value
NIOSH RWL	0.397 (.232, .540)	117	<.0001	SCI=.89413+NRWL*.16293	<.0001
ACRES RWL	0.486 (.334, .613)	117	<.0001	SCI=.62801+ARWL*.40116	<.0001

Table 4. 19: Summary Table of Psychophysical Correlational Analysis

BORG RPE vs	R^2	DoF	Correlational P-value
REBA	0.633 (0.543, 0.710)	201	<.0001
ACRES Posture	- .76293 (-0.824, -0.685)	144	<.0001

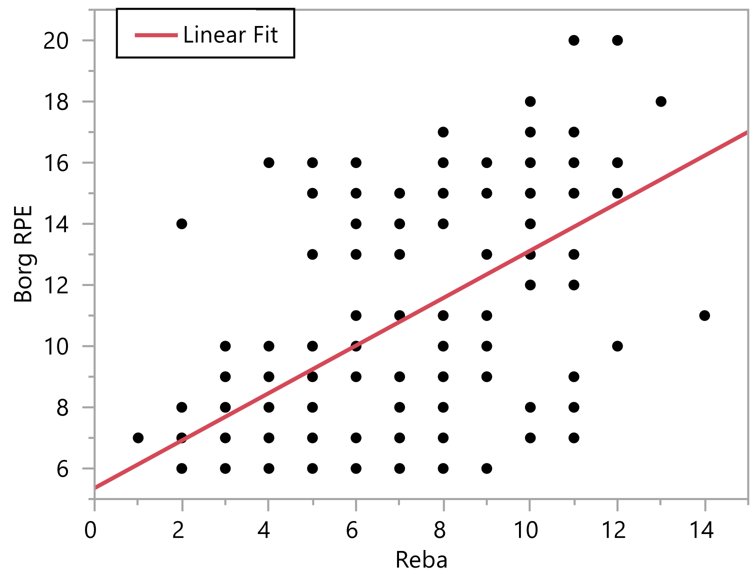

Figure 4. 7: REBA Values Vs. Perceived Exertion Scores

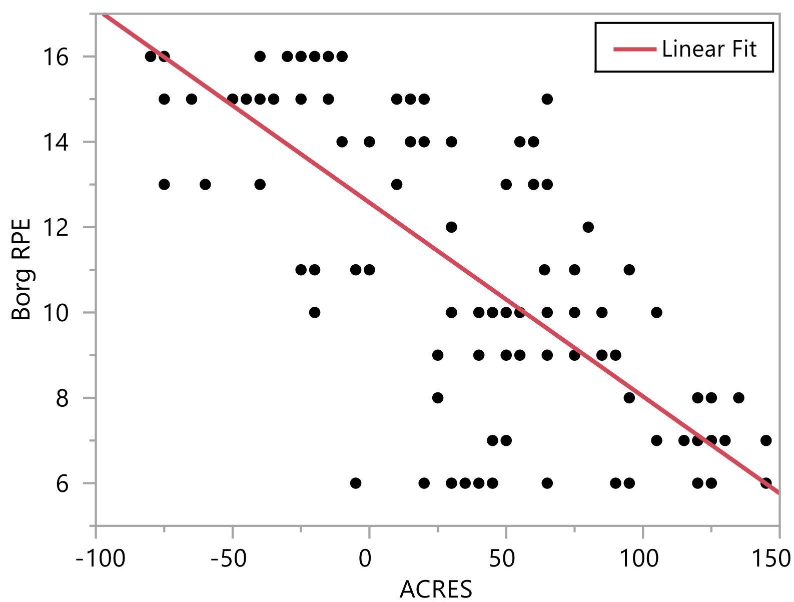

Figure 4. 8: ACRES Values vs. Perceived Exertion

Discussion

As discussed in the introduction, there is a need for a novel tool to be developed for non-ergonomists who frequently experience high variability in their work. The most prevalent example of this work is of those in the agricultural sector when seasonality and self-sufficiency require the worker to be multi-skilled and change between tasks regularly. The quick succession of tasks requires a valid tool that can be used in quick succession by novice users, which ACRES provides.

The Agriculture Cumulative Risk Exposure System simplifies many of the factors of both the NIOSH lifting equation and the Rapid Entire Body Assessment into a method that novice users can better estimate exertion and spinal compressive load. The ACRES model is designed for simplicity and limited options, with only one factor having more than two categories. Additionally, it is designed to capture the more rigorous types of lifting commonly found in the agricultural sector; thus, it was really only designed with lifting tasks instead of both lifting and lowering tasks as the NIOSH lifting equation is capable of handling. ACRES better fits the need of the agricultural worker due to its shorter evaluation time and better representation of the perceived exertion for repetitive tasks.

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CHAPTER 5: USER PERCEPTIONS ON USABILITY AND APPROPRIATENESS OF COMMON ERGONOMIC ASSESSMENT TOOLS AND ACRES

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Abstract

This chapter looks to address a deeper understanding how novice users can develop the skills to effectively use the traditional tools and the novice ACRES tool. The chapter further investigates the perceptions the users had of the tools to estimate usability and approachability of different tools.

Introduction

It should be incredibly evident by now that current ergonomic assessment tools work well for industrial environments when used by trained ergonomic personnel. Whether the person utilizes REBA or QEC or some checklist, they can often leave a work task in better shape than they found it. The use of tools that recommend weight limits for manual material handling tasks can also reduce the risk of injury to works. However, these tools may be difficult to apply to the agriculture sector, where worker values, training, time constraints, and financial constraints limit the accessibility to ergonomics tools. The following section follows the logic, formulations, and goals for a new ergonomic assessment system designed from the being to be usable in the end while addressing the limitation of current tools.

ACRES Lifting

When observing the critical factors of a lift outlined by quantitative tools such as the NIOSH Lifting Equation, it becomes apparent that anthropometrics of the “performer” or lifter are inconsequential. In addition to anthropometrics, the lifter's skill and the package's influence on the risk of the lift only come in the definition of the handle (which accounts for a 10% change in the recommended weight limit).

For example, a manual material handling task of depalletizing paint cans and stocking shelves in a home improvement store and the cans need to be taken off a pallet and carried to their destination and racked. In a warning by Potvin, the NIOSH Lifting equation was considered more conservative than the acceptable composite load developed by Snook and Cirello (Potvin, 2014). Overall, ACRES seeks to improve approachability by internalizing the system of equations for the NLE similarly to the generation of the comprehensive lifting model (Hildago, 2010).

ACRES Posture

Introduced in Chapter Four, several posture analysis tools have been developed starting in 1977 with OWAS. As the research area of posture analysis matured, certain risk factors became critical indicators of potential acute and cumulative trauma. The widely agreed risk factors for REBA, RULA and QEC are trunk posture, shoulder/arm posture, wrist/hand posture, neck posture. The Rapid Entire Body Assessment (REBA) begins quantifying the risk associated with impact forces and large body movements.

Additionally, posture analysis tools have evolved to be specialized for areas of office work, highway construction, use of tools in right/left hands. While valuable, these tools have specialized themselves out of most users' ability, specifically agricultural workers. There exists a single tool designed for assessing agricultural work, the Agricultural Lower-limb Assessment (ALLA). This tool again is highly specialized to understand the postures of just the lower limb.

The posture analysis of the ACRES takes into consideration the user and understanding that their work must be completed. This consideration comes by recommending what level of exposure is acceptable before recovery/rest should be taken. This concept of recommending a "safe" exposure level will help in adopting the tool down the line because it never stops work, as inclinations from chapter two suggest a confident attitude that "work must be completed no matter what." Take, for example, the task of cleaning out bunks with a shovel. In "good" animal feeding operations, the animals must always have access to food. The side effect of this that eventually, a bottom layer of rotting food develops, which can cause disease and pests to thrive and ultimately hurt performance. This is a task that must be done, but according to many of the posture analysis tools available, it is hazardous, and work should not be done.

ACRES-Posture overcomes this by never restricting the work that can be done, only limiting the exposure to healthy levels; it is not the goal of this dissertation to determine with absolute certainty the magnitudes each posture has of the recommended exposure time. Although ACRES has been validated to more closely align with the psychophysical stress or work beyond REBA (Hignett, 2000). The purpose of this study is to test the usability and reliability of ACRES against similar tools.

Comparisons Ergonomic Tools for Usability and Reliability

The realm of ergonomic assessment tools is vast and diverse, with each tool presenting its own set of challenges and limitations. Some of the most common tools used by ergonomists are the Rapid Entire Body Assessment (REBA) and the Quick Exposure checklist (Stanton, 2004).

In comparing tools across farm work, a lower leg posture system proved to be more sensitive to leg postures than REBA and OWAS (Kong,2018). In a comparison of the timber industry, REBA and OWAS were found to be statically different in their assessment of risk (Enez, 2019). Conversely, when evaluative tools are compared in blue-collar settings, tools tend to be more in agreeance. A comparison of ergonomic assessment in 40 different jobs in an engine oil company found that the final scores between QEC-REBA correlated quite highly (Majid, 2011). Similarly, in a study of forklift operators, the researchers reported that both tools were effective in assessing risk but stated that QEC provided more possible solutions to reducing musculoskeletal disorders (Jach, 2020). While QEC and REBA seem to have agreeance, RULA and Strain Indexes prove very little when evaluated inside the automotive industry (Drinkaus, 2003).

One extensive comparison of work-study compared eight different assessment tools for 224 workstations from various manufacturing and plant nurseries locations. The study discussed the effort required by each to and stated tools such as QEC and REBA as similar in terms of effort while tools such as OCRA tool well over for an hour to complete (Chiasson, 2012). The study stated that no two tools were in perfect agreement across all workstation types

(Chiasson, 2012). A similar assessment focused on computer work stated that no method all of the potential risk factors in an office environment (Rahman,2017).

In summary, the agreement between ergonomic assessment tools depends on both the work being done and the tools being compared, with no tool proving to be perfect in every circumstance. Only one study seemed to mention the idea of usability of the tool or how effectively it can be used to evaluate a task (Chiasson, 2012). In all cases, though the evaluators were trained in ergonomics, it would indicate what the value means and how to improve work. This research aims to compare the risk exposure scores for novice users across various types of work while also noting the user perceptions on ease of use and appropriateness in the application.

Methods

Participants

Forty-nine participants evaluated different tasks that would be found in the different facets of work. The participants selected had little to no ergonomic experience, making them novices to using the tools outlined below. Participants used tools such as REBA, QEC, NIOSH, Snook&Ciriello Tables, and ACRES. Participants were then asked to evaluate each of the tools they used in terms of appropriateness and ease of use.

Task Descriptions

Random "actors" performed three lifting tasks, *Table 5.1*(below), and three repetitive tasks, T*able 5.2* (below), which were then evaluated by the participants using pairs of appropriate tools. In the first round, the pairs of tools being compared were REBA (Rapid Entire Body Assessment) and QEC (Quick Exposure Checklist) to assess the risk of repetitive/postural tasks. At the same time, NIOSH Lifting Equation and Snook tables were used to evaluate the lifting tasks. The same tasks were used in the second round, but QEC and the Snook tables were replaced with ACRES. The users were given supplementary material with information on how to use and interpret results from the tools.

Table 5. 1: Objects used as part of Lifting Task

Collar of Work	The object being lifted (wt)
White	Box of Paper (40lbs)
Blue	Toolbox (40lbs)
Red	Feedsack (50 lbs), Water buckets (40lbs), Bale of Straw (25lbs)

Table 5. 2: Description of Tasks for Repetitive Work

Collar of Work	Repetitive task	Description/ Sample work
White	Typing task	Actors completed a two-minute typing test
Blue	Drywall	Actors filled a four-foot section of drywall with joining paste
Red	Digging a Posthole	Actors dug a three-foot-deep hole using typical post hole diggers

Data Analysis

The data analysis plan was to analyze the distribution of scores to determine how well any two tools agreed with one another when used by novices across all tasks, and tool scores were left unadjusted or raw since ACRES works with a continuous exposure time rather than a final score to determine risk. The agreement was then blocked out by the task done as a method of determining if tools would agree based on what the task was being evaluated. This analysis was done twice since not all participants used all three tools. Next, the distributions of each tool were analyzed to determine if one tool proved to be more consistent than the others, as this would be an indication of usability since the tasks were unchanged between groups.

For the analysis of the perceptions data, a Likert score was used. In the case of the perceived appropriateness for the task being evaluated a 0 indicated that the tool was not at all appropriate for the task being evaluated and 10 indicated that the tool was very appropriate. Similar to the anchors for appropriateness 0 indicated that the tool was not easy to use and 10 indicated that the tool was very easy to use. To analyze the likert score data, the difference between Likert scores by the same person and generated a distribution and a 95% confidence interval was put around the mean to determine if the difference was significant. This was also blocked by task for the question of appropriateness for each task. The following results are used as evidence to reject null hypotheses H2-H11.

Results

Summary of Distribution of Lifting Task Outputs

When examining the variation of novel users recommended weight limits for the tasks there was no evidence to suggest that the NLE provided more consistent results than the Snook and Cirello tables (Table 5.3) (H2). The similarly there was no evidence to suggest that the NLE derived recommended weight limits (rwls) nor the rwls from the Snook and Cirello tables were more restrictive than one another, with confindence intervals of [22.09,25.79] and [21.64,31.85] respectively (H3).Conversely Table 5.3. identitfies that the variability of novice users recommended weight limit using the ACRES method as significantly less than the variability of the NLE (H7). Additionally it was found that the NLE was consistently more restrictive than ACRES with confidence intervals of [22.09,25.79] and [26.82,28.82] respectively (H8).

When moving forward, ACRES-lifting is more like the NIOSH Lifting Equation using mathematics to develop a recommended weight limit; they do share a significant, although weak, correlation. This correlation becomes more apparent when the results are blocked by the object. The box of paper is how objects are portrayed in the NLE, but it can be seen that any correlation dissolves when objects become more “complex.”

Distribution of Lifting Task Outputs

Table 5. 3: Test of Equal Variance for Lifting Tools

Descriptive Statistic	**NIOSH Lifting Equation**	**Snook (lifting)**	**ACRES**
Mean	23.94	26.74	27.82
SD	12.89	12.90	5.98
N	189	27	140
Connecting Letters report	A	A	B

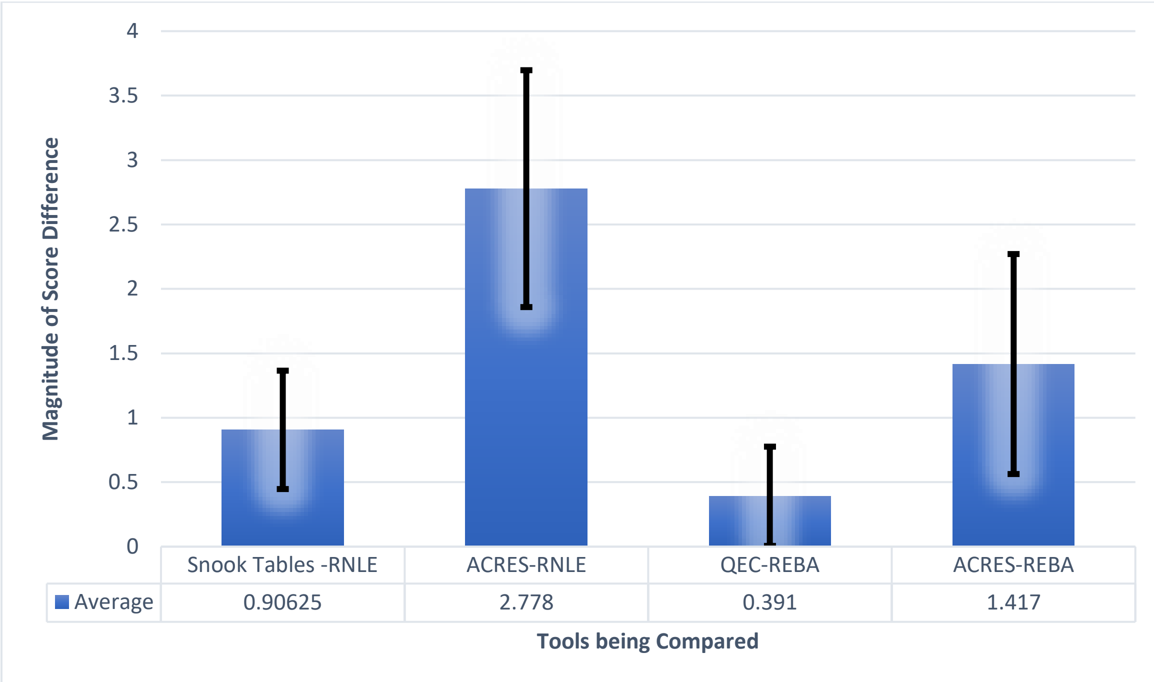

Figure 5. 1: Summary of Perceived Ease of Use Likert scores

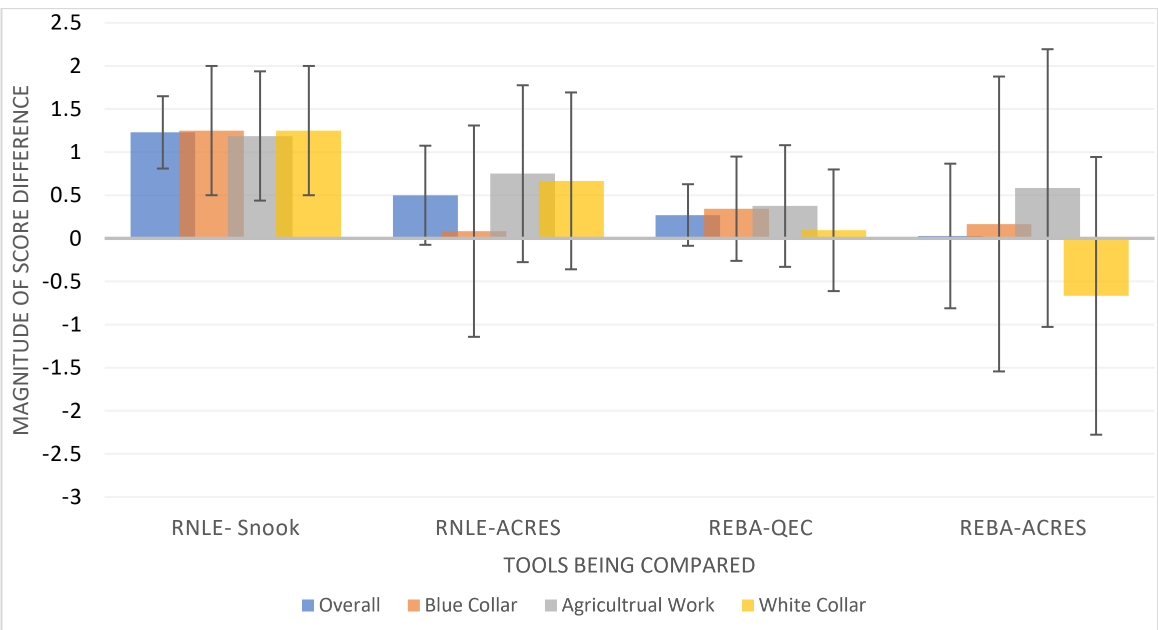

Figure 5. 2: Summary of Perceived Appropriateness Likert Scores

In part one of the study traditional tools were compared,there is significant evidence to reject the null hypotheses H4, H5, as seen in figures 5.1 and 5.2. Figures 5.1 and 5.2 indicate the mean difference in likert scores for their respective metrics. The Snook and Cirello tables were easier to use, but were found to be less appropriate than the NLE for the evaluation of the lifting tasks. In the comparison of REBA and QEC scores for perceived ease of use and appropriateness only the ease of use proved to be significantly different indicating that novice users felt that the QEC was easier to use(H6). However, there was no evidence to suggest that REBA was perceived as more appropriate than QEC, (H4).

In part two of the study NLE and REBA were compared to ACRES. In the case of appropriateness there was no evidence to suggest that novice users felt one tool was more appropriate than another as seen in figure 5.2 (H9). However the participants did respond that they felt ACRES was significantly easier to use than both NLE and REBA as indicated in figure 5.1 (H10 & H11).

Discussion

Usability can mean a number of different things; it can mean refer to capability, intuitiveness, or even practicality. This study addresses each facet of usability, and ACRES proves consistent or outperforms the other five tools tested. Considering the user's capability to use the tool, it was found that novice users had a significantly wider distribution of answers for both the NIOSH Lifting Equation and the Snook and Cirello Tables than the recommended weight limits for ACRES.

The next facet of usability to be discussed would be intuitiveness, and novice users found the NIOSH Lifting Equation and REBA the most difficult tools to use for their respective categories. The last facet of usability is practicality or does this tool even do what I need it to/ is it appropriate for the task being evaluated. The study shows that ACRES was perceived to be just as appropriate for evaluating lifting and posture analysis tasks REBA and the NIOSH Lifting Equation. In summary, ACRES is a tool that is able to get the buy-in or trust of novice users, thus increasing the likelihood they will use it in the future as a fast and effective way to evaluate work.

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CHAPTER 6: DEVELOPMENT AND VALIDATION FOR THE SIMPLIFICATION OF DYNAMIC FORCES DURING LIFTING TASKS

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Abstract

This chapter reviews the basic tenants of physics and their application in a monte-carlo simulation approach dynamic lifting tasks and resulting effects on biomechanical load. The chapter goes on to apply these effects into a simplified model for ergonomic evalauation of lifting tasks.

Introduction

In Chapter Four, ACRES proved that using simulation estimated integers could replace more complex biomechanical models with simple integers to provide recommended weight limits with similar correlations to spinal compressive load as the NIOSH Lifting Equation. This proof of concept coupled with the “buy-in” or perceived usability and appropriateness found in Chapter 5 can lead to bigger and better simulations. The bigger and better simulations could contain the complex mathematics to account for dynamic movement inside of the package being lifted. The dynamic nature of the center of mass of many items lifted in agricultural application is a unique and important aspect of agricultural manual material handling activities.

The primary motivation for include this type of evaluation is rooted in animal husbandry, specifically handling of baby livestock, feeding operation, and watering operations. In each of these lifting tasks, the center of mass can shift as you lift it. The baby calf can jump away, the water in the bucket could splash, and the grain needs poured out of the bucket. There is currently no lifting equation or predictive lifting capacity that can account for this movement or shift in the center of mass of something as its being lifted. This Chapter seeks to define the process of applying the Monte-Carlo simulation to overcome this limitation in the evaluation of lifting tasks and internalize the complexity into a novel tool, then validate that novel tool against the NIOSH Lifting Equation. The tool used in the proposed method will be the Acceleration of Trunk and Limb Assessment System (ATLAS), as it begins to account for the dynamic movement of the contents of the package.

Newtonian Motion and Work

According to Newton's first law of motion to move a package, the force applied must be significant enough to overcome the object's inertia and the reactionary forces of gravity and friction. When applying a force on an object great enough to move an object, the force multiplied by its displacement is defined as work, and in our case, this specifically is the lift being modeled. Any variability in that force appears to be negated when we observe the Impulse-momentum theorem. The impulse-momentum theorem states that any change in the momentum over time can be taken as the sum of all forces over that time; see the definition of impulse in the equation below.

Impulse Momentum Theorem

$$\vec{J} = \int_{t_1}^{t_2} \sum \overrightarrow{F} dt \quad (1)$$

*Formula Derived from Sears and Zemansky's University Physics (Young, Freedman, Ford, & Sears, 2008)

While this definition of work and the applied momentum-theorem work well when applied manual material handling tasks with static centers of mass; but begin to break down when the package loses that static center. If we observe a water glass, the same work can be done in infinite ways, but the water reacts to the forces being applied differently. The center of mass of the water is correlated but not fixed in step with the center of mass of the glass. This creates small internal moments within the glass that need to be accounted for somewhere, and the body must take up those forces. While this example may have minor effects on the body, what happens when the moment arms increase, such as a server holding a tray of glasses or when the center of mass has less correlation with the outside of the package. We will be referring to these forces as internal work.

$$Work = D_{package} * \sum F_{displacement} + \int F_{reaction} * D_{com} dt \quad (2)$$

Revised Work formula with internal work

Where:

- $D_{package}$ is the distance the package travels during the lift
- $F_{displacement}$ is the force required to move the package over the distance
- $F_{reaction}$ is the force generated by the movement of the center of mass inside the package
- D_{com} is the distance the center of mass moved inside the container

Internal Work

Internal work is the sum of the reactionary forces of the content's center of mass ($F_{reaction}$) and its displacement of the duration of the lift. During the lift to keep the package level or stable, the reaction forces will include overcoming its internal moments; thus, we define the internal moment as torque at time t. If we consider a lifting task, the reaction force ($F_{reaction}$) becomes the mass times the acceleration of gravity or (*mg*). The last variable of understanding internal work is the displacement of the center of mass internal to the package, as seen in equation 3.

Internal Work for a lifting task

$$Internal\ Work = \int \mathrm{mg} * \mathrm{D_{com}}\, \mathrm{dt} \quad (3)$$

Since the internal displacement of contents of a package is correlated to the package, we can begin to define the constraints of the center of mass. When the contents are at rest, the center of mass is defined by the equation $\int \tilde{x}\, \rho dV$ where x defines the axis of interest, ρ is the density formula for the contents, and V defines the object's volume. When done across all three axes, a center of mass can determine when the package rests in a cartesian coordinate system.

$$\int \rho dV$$
(4)

As to the location of the center of mass, let's consider any regular shape, such as any solid, regular prism, or ellipsoid. We can define an envelope for the center of mass using the maximum displacement when an object is rotated about each of its axes and calculating the corresponding shift to its original location. The final product is a shape roughly defined by an irregular ellipsoid, of which the formula is defined below.

Equation for an Irregular Ellipsoid

$$\frac{4}{3}\pi(r_x * r_y * r_z) \tag{5}$$

The irregular ellipsoid components are defined by the maximum amount of movement the center of mass is capable of in each axis. The magnitude of this movement is constrained by how full the container is. If the sealed container is filled to 100% capacity, contents have no room to flow; thus, the mass center does not move. If we assume a fill percent of (φ), we can simplify the radii for the envelope to the equation below.

Single Axis-Envelope Formula

$$\Delta r_x = \frac{\int \tilde{x}\rho dV}{\int \rho dV} - \frac{\int \tilde{x}(\varphi)\rho dV}{\int \rho dV}$$

$$\Delta r_x = \frac{\int \tilde{x}(1-\varphi)\rho dV}{\int \rho dV} \tag{6}$$

$$\Delta r_x = \frac{(1-\varphi)\int \tilde{x}\rho dV}{\int \rho dV}$$

Methods

The development of the Accelerations of Trunk and Limb Assessment System (ATLAS) is to:

- Create a simplified tool that can approximate the effects of fill and package structure to account for dynamic movement.
- Improve the anthropometric considerations of ACRES
- Expand the lifting distances

Tool Development

ACRES filled the immediate need for evaluating agricultural lifting tasks but could be improved upon. This improvement comes with the application of the 2012 U.S. Army Anthropometric survey to serve as improvements to the starting height consideration and lifting distance.

Anthropometry

Where ACRES was selecting from a limited set of outcomes, ATLAS randomly selected a percentile from a Z-distribution. This percentile was then allowed to vary slightly, with the percentile acting as a most likely option and a +/- 5% for the lower bound upper bound of a triangle distribution. This allowed for slight variations in limb length and heights to generate similar individuals.

Package Contents and Structures

When considering how the contents of the package will affect the lift, there can be several factors at play. These factors include the density of the contents inside of the package, the structure of the package, the size and shape of the package, and the viscosity of the contents. The effects of density have shown that as density increases, there is an increase in acceptable weight limits (Mital, 1983). Factors such as the package structural integrity, size, and shape all factor in the size of the envelope. Viscosity, however, would affect the width of the distribution.

Using the formula above, two shapes were modeled, one being rigid and the other "soft." A soft package would refer to any sort of sack that does not have an inherent structure. These two packages generated their own center of mass envelope, which served as the truncation of a normal distribution. The truncation was transformed so that they would be equal to two standard deviations from a mean of zero. It is this distribution that a moment arm is randomly selected to be fed into the biomechanical model.

Monte-Carlo Simulation

Given the distribution and methods described above, a Monte-Carlo simulation was run generating 100,000 different anthropometries. Anthropometries were generated by selecting a Z-value to work as the seed for slight variations in generating unique anthropometries. For example, a single Z value was set as the most likely percentile in a triangle distribution. From this distribution four new Z-values were sampled all close to but varying slightly from the original. These four Z-values were then used to build the discretized set of anthropometries for knee, hip, chest, and overhead. Similarly to ACRES these discretized set of anthropometries were fed into the NIOSH LE based simulation as the vertical factors and generated unique sets of RWL. Each of these unique anthropometries then completed 62,208 different lifts. From this simulation, we were able to generate the following tables for integer adjustments to the recommended weight limit.

Table 6. 1: Horizontal Integer Changes

Horizontal	lbs.
10" from instep	6
15" from instep	0
25" from instep	-5

Table 6. 2: Starting Vertical Height Integer Changes

Vertical Factor starting position	lbs.
Knee	1
Hip	1
Chest	0
Overhead	-4

Table 6. 3: Lifting Distance Integer Changes

Lifting Distance	lbs.
Knee to Hip	1
Knee to Chest	1
Knee to Overhead	-2
Hip to Chest	2
Hip to Overhead	-1

Table 6. 4: Axial Rotation Integer Changes

Axial Rotation	lbs.
Neutral	3
Slight twist	2
Twist >45	0
Twist > 90	-1

Table 6. 5: Coupling Integer Changes

Coupling	Lbs.
Good	1
Fair	0
Poor	-1

Table 6. 6: Duration Integer Changes

Duration	lbs.
1 hour	3
2 hour	0
8 hours	-4

Table 6. 7: Frequency Integer Changes

Frequency	lbs.
Slow (<1 lifts/ minute)	7
Moderate (1-5 lifts/ minute)	3
Fast (7-9 lifts/ minute)	-3
Very Fast(>9 lift/ minute)	-11

Table 6. 8: Packaging Integer Changes

Packaging Fill Percentage	Rigid Package	Soft Package
>90 %	1	0
50-90 %	-2	-2
>50	-2	-1

Table 6. 9: Symmetry Integer Changes

Symmetry	lbs.
One-handed Lift	-5

Table 6. 10: ATLAS Final Summation Guide

BASE WT.	
Horizontal	
Vertical	
Lifting Distance	
Angle	
Coupling	
Duration	
Frequency	
Asymmetry	
Packaging	
TOTAL (RWL)	

Validation of the Accelerations of Trunk and Limb Assessment System

Participants

A total of twenty (20) people who previously had little to no exposure to ergonomic analysis were selected to take part in this study. Each participant was given an instruction sheet with all the necessary information to perform the analysis, as would be the case of a novice user attempting to complete each analysis.

Task Description

Participants were tasked with evaluating six different lifts with various packages and three different lifters. Certain constants were given for each lift, such as frequency and duration. Still, all other variables were derived from the videos. Participants were then prompted to enter each of the tools' recommended weight limit rounded to the nearest half a pound.

Results

As units for spinal compression load are in newtons, and NIOSH recommended weight limits are discussed as indices, the metrics were scaled to provide unitless measures to indicate risk. Spinal compression loads were divided by the critical threshold of 3400N (Anderson, 1983). ATLAS recommended weight limits followed the NIOSH Lifting equation's method of dividing the actual weight limit by the recommended weight limit to produce a lifting index. Thus, the data analysis compared metrics of risk where one or less is acceptable; an index of two is needed for administrative intervention. The index of three and above is an immediate need to change work.

As shown in the table below, the NIOSH lifting index explains just under forty percent of the variation in spinal compressive load. In comparison, the lifting index generated by ATLAS can explain forty-seven percent of the variation. This difference is not significant from one another; both tools significantly correlated with the spinal compressive load (H13).

Table 6. 11: Summary table of Quantitative Correlational Analysis and Simple Linear Regression Plots for Lifting Tools

Spine Compression Index vs	R^2	Count	Correlational P-value	Linear Approximation	Linear Fit P-value
NIOSH Lifting index	0.3970 (.2323, .5397)	117	<.0001	SCI=.8941+ NRWL*.1629	<.0001
ATLAS Lifting Index	0.4690 (.3142,.5995)	117	<.0001	SCI=0.6304 + ATLAS*0.4595	<.0001

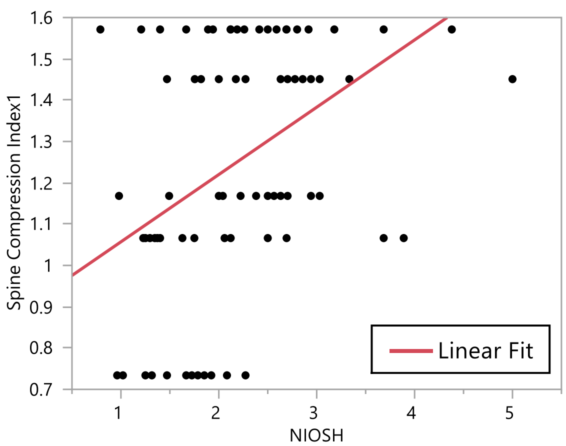

Figure 6. 1: Simple Linear Regression Model of SCI vs NLE

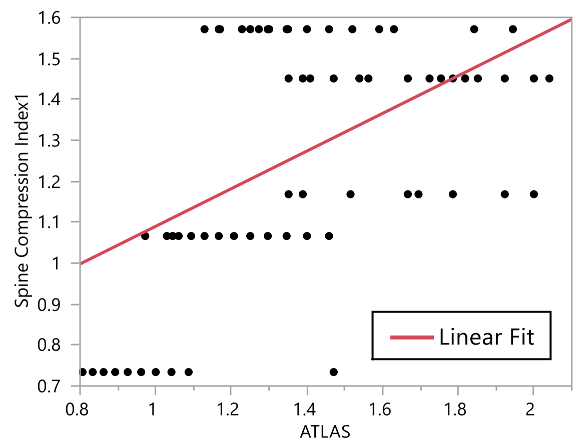

Figure 6. 2: Simple Linear Regression Model of SCI vs ATLAS

Discussion

At the onset of this chapter, it was hypothesized that using the monte-carlo simulation approach to biomechanical modeling could reliably internalize complex mathematics compared to traditional methods. This study observed six lifts at three different anthropometries were evaluated using the NIOSH lifting Equation and the Accelerations of Trunk and Limb Assessment System (ATLAS). Of these lifts, one stands out. That is the lifting associated with lifting a feedsack or bucket. A feedsack may have uniform distribution when laid flat. Still, the contents of the package can shift, reducing the NIOSH Lifting Equations effectiveness.

The need to account for shifting centers of mass is critical not only for agricultural work but also mechanics handling jugs of oil or professional painters moving paint cans. The fruits of the Monte Carlo simulation are endless. They can be used to expand ATLAS to address more lifts not previously considered. We have proven that this can internalize the complexity to the point that a fifth-grader can complete the analysis.

In the future, the Monte-Carlo simulation could be used to create job-specific lifting models that address more complex coupling methods such as "hug hold," where the lifter lifts the package close to the chest. This approach could also evaluate push-pull tasks in an attempt to replace the Snook and Cirello Push-pull tables.

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CHAPTER 7: GENERAL CONCLUSION

This dissertation fundamentally questions what makes a worker unique and challenges how ergonomists should view agricultural work. It discussed how they are a special at-risk group and how they are underserved by the ergonomist community. Chapter two confirms hypothesis one stating that the agricultural worker is subject to more variability in work tasks throughout a year than either blue- or white-collar work. Chapter Three then summarizes how poorly/ inadequate many commonly used ergonomic assessment methods serve the agricultural sector.

The work done as part of this dissertation succeeded in filling this need with developing and validating a novel assessment tool in ACRES. ACRES proved to be a significantly better measure of psychophysical stress than the Rapid Entire Body Assessment while also providing recommended weight limits consistent with the NIOSH Lifting Equation. Chapter five demonstrated evidence favoring ACRES's ability to provide more consistent recommended weight limits than the NLE when used by novices. Novice users also found ACRES easier to use than the NLE and just as appropriate to both NLE and REBA. ACRES is a tool that could supplant NLE or REBA for when immediate ergonomic risk needs evaluated and the user is untrained in ergonomics.

Despite all the strides ACRES made to fill agriculture's immediate need, more could still be done. The previous chapter discusses a novel approach to biomechanical modeling, Monte-Carlo simulation. The chapter outlines how the Monte-Carlo simulation was applied to biomechanics to internalize and distill dynamic movement inside a package to finally come to simple addition and subtraction to reach a final recommended weight limit.

In conclusion, this dissertation delivers two validated ergonomic models that novices can use and provide the framework by which to expand and create more. The future of the research would be of interest to groups such as NIH, FDA, CDC, and even the Department of Labor.

APPENDIX A: ACRES BASIC INSTRUCTION SET

Agricultural Categorical Risk Evaluation System- ACRES

This system categorizes lift aspects into components that can be quickly summed to generate a recommended weight limit.

RWL= (Base) + Horizontal + Vertical +Lifting+ Angle + Coupling+ Duration+ Frequency+ Asymmetry

First a base weight must be estimated for the person performing the lift. The categories are described as follows

Expert	Lift is done with proper form using a squat lift with proper breathing Lifter has adequate muscle development to perform the lift
Intermediate	Lift is done with proper form using a squat lift with proper breathing OR Lifter has adequate muscle development to perform the lift
Novice	Lift is not done properly and the user may lack proper muscle development for the lift

The remaining modifiers should be matched to the category that most closely resembles the lift being completed.

ACRES Lifting Sheet

Base Weight	lbs.
Expert	25
Intermediate	20
Novice	15

Horizontal	lbs.
10” from instep	6
15” from instep	0
25” from instep	-5

Vertical Factor starting position	lbs.
Knee	0
Hip	1
Chest	-1

Lifting Distance	lbs.
Knee to Hip	1
Hip to Chest	0
Knee to Chest	-2

Angle	lbs.
Neutral	1
Slight twist	0
Twist >45	-1

Coupling	lbs.
Good	1
Fair	0
Poor	-1

Duration	lbs.
1 hour	3
2 hour	0
8 hours	-4

Frequency	lbs.
Slow (< 1 lifts/ minute)	5
Moderate (1-5 lifts/ minute)	2
Fast (7-9 lifts/ minute)	-3
Very Fast (>9 lift/ minute	-4

Symmetry	lbs.
One handed Lift	-5

BASE WT.	
Horizontal	
Vertical	
Lifting	
Angle	
Coupling	
Duration	
Frequency	
Asymmetry	
TOTAL (RWL)	

APPENDIX B: ACRES- POSTURE ANALYSIS SHEET

Neck Posture	Present	Modifier (minutes)
Neutral		+10
Flexed (>20 degrees)		-5
Extended		-5
Twisted/ Side Bending		-5
Trunk Posture		
Neutral		+15
Extended		-5
Flexed (<20degrees)		-5
Flexed (20-60 degrees)		-10
Flexed (>60degrees)		-15
Leg Posture		
Neutral		+10
One-leg Stand		-5
Leg Bend (30-60 degrees)		-10
Leg Bend (>60 degrees)		-15
TOTAL-Core		

Upper Arm Posture	Present	Modifier (minutes)
Neutral (+/- 20 degrees)		+10
Extended (>20 degrees)		+5
Flexed (20-45 degrees)		+0
Flexed (45-90 degrees)		-5
Flexed (>90 degrees)		-10
Abduction		-5
Lower Arm Posture		
Neutral (60- 100 degree)		+5
Flexed (<60 degrees, >100 degrees)		-5
Wrist Posture		
Neutral +/- 15 degrees		+5
Flexed +/- 15 degrees		-5
TOTAL- Arms		

Work Intensity	Present	Modifier (minutes)
Leisure		+30
Moderate		+15
Semi-Vigorous		-15
Vigorous		-30
Pace		
Static		-15
Rapid		-15
Large Macro Movements		-15
TOTAL- Work		

Recommended Task Time	
Starting Point	60 minutes
TOTAL-Core	
TOTAL- Arms	
TOTAL- Work	
REC. TASK TIME	

APPENDIX C: ATLAS BASIC INSTRUCTION SET

Acceleration of Trunk and Limb Assessment System- ATLAS

This system categorizes lift aspects into components that can be quickly summed to generate a recommended weight limit.

RWL= (Base) + Horizontal + Vertical +Lifting+ Angle + Coupling+ Duration+ Frequency+ Asymmetry

First a base weight must be estimated for the person performing the lift. The categories are described as follows

Expert	Lift is done with proper form using a squat lift with proper breathing Lifter has adequate muscle development to perform the lift
Intermediate	Lift is done with proper form using a squat lift with proper breathing OR Lifter has adequate muscle development to perform the lift
Novice	Lift is not done properly and the user may lack proper muscle development for the lift

In addition to the base weight factor another less than obvious categorical variable is the packaging modifier which has two columns. The rigid column should be used for when the package does not deform at all under lifting. The second column is for soft packages which deform when lifted such as sacks and bags.

The remaining modifiers should be matched to the category that most closely resembles the lift being completed.

ATLAS Lifting Sheet

Base Weight	**lbs.**
Expert	25
Intermediate	20
Novice	15

Horizontal	lbs.
10” from instep	6
15” from instep	0
25” from instep	-5

Vertical Factor starting position	lbs.
Knee	1
Hip	1
Chest	0
Overhead	-4

Lifting Distance	**lbs.**
Knee to Hip	1
Knee to Chest	1
Knee to Overhead	-2
Hip to Chest	2
Hip to Overhead	-1

Angle	**lbs.**
Neutral	3
Slight twist	2
Twist >45	0
Twist > 90	-1

Coupling	lbs.
Good	1
Fair	0
Poor	-1

Duration	lbs.
1 hour	3
2 hours	0
8 hours	-4

Frequency	lbs.
Slow (<1 lifts/ minute)	7
Moderate (1-5 lifts/ minute)	3
Fast (7-9 lifts/ minute)	-3
Very Fast (>9 lift/ minute	-11

Symmetry	lbs.
One handed Lift	-5

Packaging Fill Percentage	Rigid Package	Soft Package
>90 %	-1	0
50-90 %	-2	-2
>50	-2	-1

BASE WT.	
Horizontal	
Vertical	
Lifting Distance	
Angle	
Coupling	
Duration	
Frequency	
Asymmetry	
Packaging	
TOTAL (RWL)	

APPENDIX D: NIOSH LIFTING EQUATION BASIC INSTRUCTION SET ABBREVIATED FROM THE STEP BY STEP GUIDE TO THE NIOSH LIFTING EQUATION

A Step-by-Step Guide to the NIOSH Lifting Equation. (n.d.). Retrieved May 1, 2021, from https://ergo-plus.com/niosh-lifting-equation-single-task/

NIOSH Lifting Equation Overview

The Revised NIOSH Lifting Equation is a tool used by occupational health and safety professionals to assess the manual material handling risks associated with lifting and lowering tasks in the workplace.

A lifting task is defined as the act of manually grasping an object with two hands, and vertically moving the object without mechanical assistance. The NIOSH Lifting Equation considers several job task variables to determine safe lifting practices and guidelines.

NIOSH Lifting Equation:

RWL = LC (51) x HM x VM x DM x AM x FM x CM

The NIOSH Lifting Equation is widely accepted as valid in the field of occupational ergonomics, providing occupational health and safety professionals an objective ergonomic risk assessment tool for manual material handling tasks. The NIOSH Lifting Equation is a great way to identify ergonomic opportunities and prioritize ergonomic improvement efforts, and it also provides an objective baseline from which you can document ergonomic improvements.

NIOSH Lifting Equation Outputs:

Recommended Weight Limit (RWL): Answers the question… "Is this weight too heavy for the task?"

The primary product of the NIOSH equation is the **Recommended Weight Limit (RWL)**, which defines the maximum acceptable weight (load) that nearly all healthy employees could lift over the course of an 8-hour shift without increasing the risk of musculoskeletal disorders (MSD) to the lower back.

NIOSH Equation Task Variables

RWL = LC (51) x HM x VM x DM x AM x FM x CM

The NIOSH Lifting Equation always uses a load constant (LC) of 51 pounds, which represents the maximum recommended load weight to be lifted under ideal conditions. From that starting point, the equation uses several task variables expressed as coefficients or multipliers (In the equation, M = multiplier) that serve to decrease the load constant and calculate the RWL for that lifting task.

Task variables needed to calculate the RWL:

- H = Horizontal location of the object relative to the body
- V = Vertical location of the object relative to the floor
- D = Distance the object is moved vertically
- A = Asymmetry angle or twisting requirement
- F = Frequency and duration of lifting activity
- C = Coupling or quality of the workers grip on the object

Additional task variables needed to calculate LI:

- Average weight of the objects lifted
- Maximum weight of the objects lifted

Additional outputs of the NIOSH Lifting Equation:

The Frequency-Independent Recommended Weight Limit (FIRWL) and the Frequency-Independent Lifting Index (FILI) are additional outputs of the NIOSH lifting calculator.

The FIRWL is calculated by using a frequency multiplier (FI) of 1.0 along with the other task variable multipliers. This effectively removes frequency as a variable, reflecting a weight limit for a single repetition of that task and allows equal comparison to other single repetition tasks.

The Frequency-Independent Lifting Index (FILI) is calculated by dividing the weight lifted by the FIRWL. The FILI can help identify problems with infrequent lifting tasks if it exceeds the value of 1.0.

Using the NIOSH Lifting Equation

Measure and Record Task Variables

The first step is to gather the needed information and measurements for lifting task variables.

Task variable data needed:

H = Horizontal Location of the object relative to the body

V = Vertical Location of the object relative to the floor

D = Distance the object is moved vertically

A = Asymmetry Angle or twisting requirement

F = Frequency and Duration of lifting activity

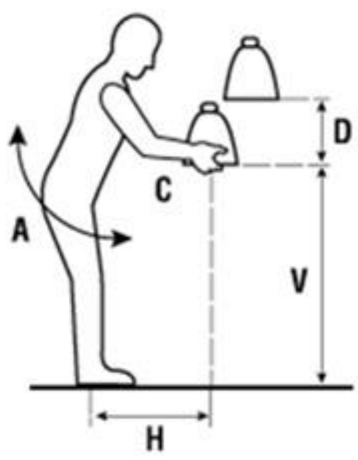
C = Coupling or quality of the workers grip on the object

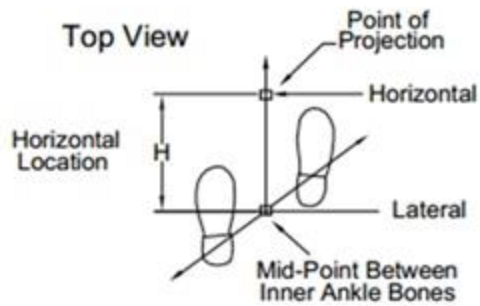
L = Average & maximum Load or weight of the object

You can use a paper worksheet to assist you with data collection as pictured above, or you may prefer to enter data directly into the calculator as variables are determined:

The following task variables are evaluated to calculate the multipliers that are used in the NIOSH equation to determine the RWL. Here are some quick explanations and guidelines that you can use to gather the needed measurements:

Horizontal Location of the Hands (H) – Measure and record the horizontal location of the hands at both the start (origin) and end (destination) of the lifting task. Measure and record the horizontal location of the hands at the end (destination) of the lifting task only if significant control is required. The horizontal location is determined by measuring the distance between the point projected on the floor directly below the mid-point of the hands grasping the object (load center), and the mid-point of a line between the inside ankle bones as pictured below:

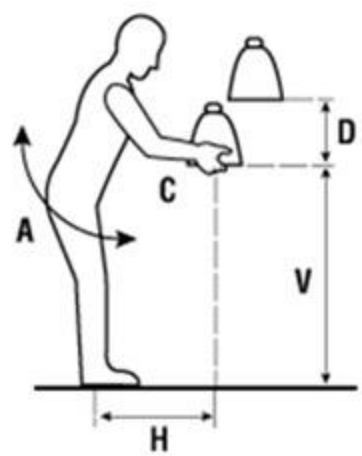




Horizontal Modifier Equation (Inches)

HM= 10/H

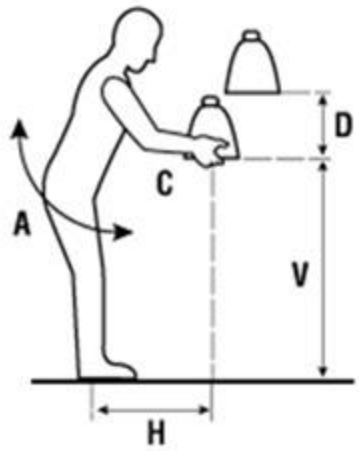
Vertical Location of the Hands (V) – Measure and record the vertical location of the hands above the floor at the start (origin) and end (destination) of the lifting task. The vertical location is measured from the floor (or standing surface) to the vertical mid-point between the hand grasps as defined by large middle knuckle (3rd MCP joint) of the hand.



Vertical Modifier Equation (inches)

VM= 1-(.0075 |V-30|)

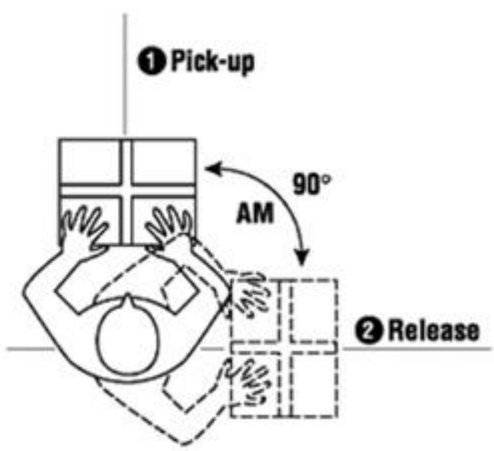
Vertical Travel Distance (D) – The vertical travel distance of a lift is determined by subtracting the vertical location (V) at the start of the lift from the vertical location (V) at the end of the lift. For a lowering task, subtract the V location at the end from the V location at the start. If you're using ErgoPlus Industrial, there's no need to worry about this one, the calculator will do this work for you.



Distance Multiplier Equation (Inches)

$$DM = .82 + 1.8/D$$

Asymmetric Angle (A) – Measure the degree to which the body is required to twist or turn during the lifting task. The asymmetric angle is the amount (in degrees) of trunk and shoulder rotation required by the lifting task. Note: Sometimes the twisting is not caused by the physical aspects of the job design, but rather by the employee using poor body mechanics. If this is the case, no twisting (0 degrees) is required by the job. If twisting is required by the design of the job, determine the number of degrees the back and body trunk must twist or rotate to accomplish the lift. (i.e. 90° as pictured below)



Asymmetric Multiplier Equation

$$AM = 1 - (.0032A)$$

Coupling (C) – Determine the classification of the quality of the coupling between the worker's hands and the object as good, fair, or poor (1, 2, or 3). A good coupling will reduce the maximum grasp forces required and increase the acceptable weight for lifting, while a poor coupling will generally require higher maximum grasp forces and decrease the acceptable weight for lifting.

- **1 = Good** – Optimal design containers with handles of optimal design, or irregular objects where the hand can be easily wrapped around the object.
- **2 = Fair** – Optimal design containers with handles of less than optimal design, optimal design containers with no handles or cut-outs, or irregular objects where the hand can be flexed about 90°.
- **3 = Poor** – Less than optimal design container with no handles or cut-outs, or irregular objects that are hard to handle and/or bulky (e.g. bags that sag in the middle).

Table 7
Coupling Multiplier

Coupling Type	Coupling Multiplier	
	V< 30 inches (75 cm)	V $\geq$ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Frequency (F) – Determine the average number of lifts per minute of the lifting task being evaluated, this is the lifting frequency. This information can often be verified by asking for average production rates from a group leader, supervisor, or production manager. You can also accomplish this by determining the number of lifts per minute during a short sampling period. NIOSH recommends a 15-minute sampling or observation period. The Frequency (F) value will be between 0.2 lifts/minute and 15 lifts/minute. For lifting tasks with a frequency less than .2 lifts per minute (>1 lift every 5 minutes), you will use the minimum frequency of .2 lifts/minute.

Duration (Dur) – Determine the lifting duration as classified into one of three categories: Enter 1 for short-duration, 2 for moderate-duration and 8 for long-duration as follows:

- **1 = Short** – lifting ≤ 1 hour with recovery time ≥ 1.2 X work time
- **2 = Moderate** – lifting between 1 and 2 hours with recovery time ≥ 0.3 X lifting time
- **8 = Long** – lifting between 2 and 8 hours with standard industrial rest allowances

Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	≤ 1 Hour		>1 but ≤ 2 Hours		>2 but ≤ 8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

APPENDIX E: SUMMARY TABLES OF USABILITY STUDY

Table E. 4:Ease of Use Summary Statistics for NIOSH LIFTING EQUATION- SNOOK AND CIRELLO

Mean	*-0.906*
Std Dev	2.267
StdErr Mean	0.231
Upper 95% Mean	-0.447
Lower 95% Mean	-1.366
N	96

Table E. 5:Ease of Use Summary Statistics for NIOSH LIFTING EQUATION – ACRES

Mean	-2.778
Std Dev	2.716
StdErr Mean	0.453
Upper 95% Mean	-1.859
Lower 95% Mean	-3.697
N	36

Table E. 6:Ease of Use Summary Statistics for REBA-QEC

Mean	-0.391
Std Dev	1.900
StdErr Mean	0.194
Upper 95% Mean	-0.006
Lower 95% Mean	-0.776
N	96

Table E. 7:Ease of Use Summary Statistics for REBA- ACRES

Mean	-1.417
Std Dev	2.523
StdErr Mean	0.420
Upper 95% Mean	-0.563
Lower 95% Mean	-2.270
N	36

Table E. 8:Ease of Use Summary Statistics for NIOSH LIFTING EQUATION- SNOOK AND CIRELLO for Blue Collar work

Mean	-0.906
Std Dev	2.291
StdErr Mean	0.405
Upper 95% Mean	-0.080
Lower 95% Mean	-1.732
N	32

Table E. 9:Ease of Use Summary Statistics for NIOSH LIFTING EQUATION – ACRES-Lifting for Blue Collar Work

Mean	-2.917
Std Dev	2.875
StdErr Mean	0.830
Upper 95% Mean	-1.09
Lower 95% Mean	-4.743
N	12

Table E. 10:Ease of Use Summary Statistics for Agriculture Work

Mean	-0.906
Std Dev	2.291
StdErr Mean	0.405
Upper 95% Mean	-0.080
Lower 95% Mean	-1.732
N	32

Table E. 11:Ease of Use Summary Statistics for Agriculture Work

Mean	-2.833
Std Dev	2.725
StdErr Mean	0.787
Upper 95% Mean	-1.102
Lower 95% Mean	-4.565
N	12

Table E. 12:Ease of Use Summary Statistics for White Collar work

Mean	-0.906
Std Dev	2.291
StdErr Mean	0.405
Upper 95% Mean	-0.080
Lower 95% Mean	-1.732
N	32

Table E. 13:Ease of Use Summary Statistics for White Collar work

Mean	-2.583
Std Dev	2.778
StdErr Mean	0.802
Upper 95% Mean	-0.818
Lower 95% Mean	-4.349
N	12

Table E. 14:Ease of Use Summary Statistics for REBA-QEC for Blue Collar

Mean	-0.391
Std Dev	1.921
StdErr Mean	0.340
Upper 95% Mean	0.302
Lower 95% Mean	-1.083
N	32

Table E. 15:Ease of Use Summary Statistics for REBA-ATLAS for Blue Collar Work

Mean	-1.083
Std Dev	2.746
StdErr Mean	0.793
Upper 95% Mean	0.661
Lower 95% Mean	-2.828
N	12

Table E. 16:Ease of Use Summary Statistics for REBA-QEC for Agriculture Work

Mean	-0.391
Std Dev	1.921
StdErr Mean	0.340
Upper 95% Mean	0.302
Lower 95% Mean	-1.083
N	32

Table E. 17:Ease of Use Summary Statistics for REBA- ATLAS for Agriculture Work

Mean	-1.25
Std Dev	2.598
StdErr Mean	0.75
Upper 95% Mean	0.401
Lower 95% Mean	-2.901
N	12

Table E. 18:Ease of Use Summary Statistics for REBA-QEC for White Collar work

Mean	-0.391
Std Dev	1.921
StdErr Mean	0.340
Upper 95% Mean	0.302
Lower 95% Mean	-1.083
N	32

Table E. 19:Ease of Use Summary Statistics for REBA- ATLAS for White Collar work

Mean	-1.917
Std Dev	2.353
StdErr Mean	0.679
Upper 95% Mean	-0.421
Lower 95% Mean	-3.412
N	12

Table E. 20:Appropriateness Score Summary Statistics for NIOSH- Snook and Cirello Tables

Mean	1.229
Std Dev	2.070
StdErr Mean	0.211
Upper 95% Mean	1.649
Lower 95% Mean	0.8098009
N	96

Table E. 21:Appropriateness Score Summary Statistics for NIOSH LIFTING EQUATION ACRES-Lifting

Mean	0.5
Std Dev	1.698739
StdErr Mean	0.2831232
Upper 95% Mean	1.07477
Lower 95% Mean	-0.07477
N	36

Table E. 22:Appropriateness Score Summary Statistics for REBA-QEC

Mean	0.271
Std Dev	1.762
StdErr Mean	0.180
Upper 95% Mean	0.628
Lower 95% Mean	-0.086
N	96

Table E. 23:Appropriateness Score Summary Statistics for REBA- ATLAS

Mean	0.028
Std Dev	2.478
StdErr Mean	0.413
Upper 95% Mean	0.866
Lower 95% Mean	-0.811
N	36

Table E. 24:Appropriateness Score Summary Statistics for NIOSH- Snook and Cirello Tables blocked by Blue Collar work

Mean	1.25
Std Dev	2.079
StdErr Mean	0.368
Upper 95% Mean	2.000
Lower 95% Mean	0.500
N	32

Table E. 25:Appropriateness Score Summary Statistics for NIOSH LIFTING EQUATION-ACRES-Lifting blocked by Blue Collar work

Mean	0.083
Std Dev	1.929
StdErr Mean	0.557
Upper 95% Mean	1.309
Lower 95% Mean	-1.142
N	12

Table E. 26:Appropriateness Score Summary Statistics for NIOSH- Snook and Cirello Tables blocked by Agricultural Work

Mean	1.188
Std Dev	2.117
StdErr Mean	0.374
Upper 95% Mean	1.951
Lower 95% Mean	0.424
N	32

Table E. 27:Appropriateness Score Summary Statistics for NIOSH LIFTING EQUATION-ACRES-Lifting blocked by Agricultural Work

Mean	0.75
Std Dev	1.603
StdErr Mean	0.463
Upper 95% Mean	1.768
Lower 95% Mean	-0.268
N	12

Table E. 28:Appropriateness Score Summary Statistics for NIOSH- Snook and Cirello Tables blocked by White Collar work

Mean	1.25
Std Dev	2.080
StdErr Mean	0.368
Upper 95% Mean	2.000
Lower 95% Mean	0.500
N	32

Table E. 29:Appropriateness Score Summary Statistics for NIOSH LIFTING EQUATION-ACRES-Lifting blocked by White Collar work

Mean	0.667
Std Dev	1.614
StdErr Mean	0.466
Upper 95% Mean	1.692
Lower 95% Mean	-0.359
N	12

Table E. 30:Appropriateness Score Summary Statistics for REBA-QEC blocked by Blue Collar work

Mean	0.344
Std Dev	1.6773515
StdErr Mean	0.2965167
Upper 95% Mean	0.9484997
Lower 95% Mean	-0.261
N	32

Table E. 31:Appropriateness Score Summary Statistics for REBA-ATLAS blocked by Blue Collar work

Mean	0.167
Std Dev	2.691
StdErr Mean	0.777
Upper 95% Mean	1.877
Lower 95% Mean	-1.543
N	12

Table E. 32:Appropriateness Score Summary Statistics for REBA-QEC blocked by Agriculture Work

Mean	0.375
Std Dev	1.680
StdErr Mean	0.297
Upper 95% Mean	0.981
Lower 95% Mean	-0.231
N	32

Table E. 33:Appropriateness Score Summary Statistics for REBA-ATLAS blocked by Agricultural work

Mean	0.583
Std Dev	2.234
StdErr Mean	0.645
Upper 95% Mean	2.003
Lower 95% Mean	-0.836
N	12

Table E. 34:Appropriateness Score Summary Statistics for REBA-QEC blocked by White Collar work

Mean	0.0938
Std Dev	1.957
StdErr Mean	0.346
Upper 95% Mean	0.799
Lower 95% Mean	-0.612
N	32

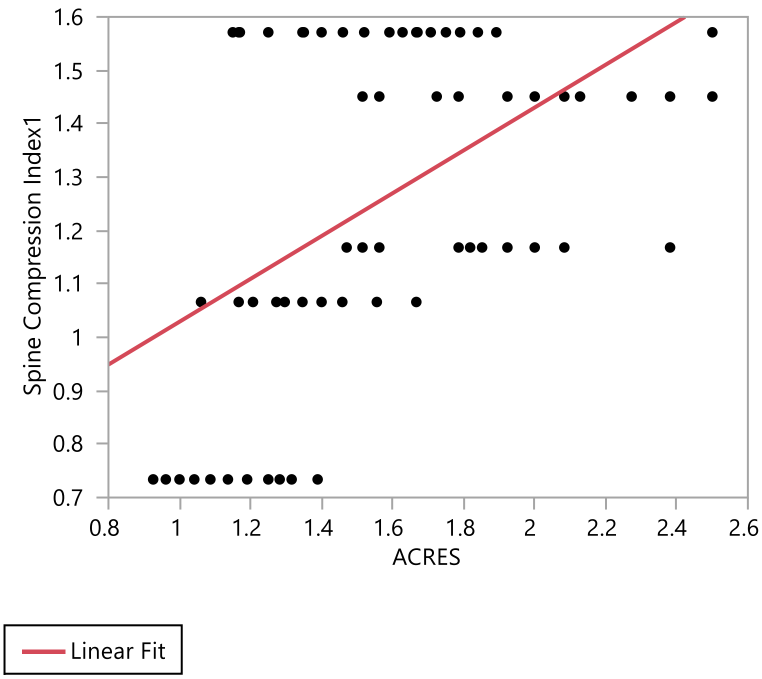
Table E. 35:Appropriateness Score Summary Statistics for REBA-ATLAS blocked by White Collar work

Mean	-0.667
Std Dev	2.535
StdErr Mean	0.732
Upper 95% Mean	0.944
Lower 95% Mean	-2.278
N	12

APPENDIX F: JMP Analysis Report of ATLAS Validation Study

Fit Group

Bivariate Fit of Spine Compression Index1 By ACRES



Summary Statistics

	Value	Lower 95%	Upper 95%	Signif. Prob
Correlation	0.485775	0.333666	0.613231	<.0001*
Covariance	0.053974			
Count	117			

Variable	Mean	Std Dev
ACRES	1.584806	0.366802
Spine Compression Index1	1.263771	0.302911

Linear Fit

Spine Compression Index1 = 0.6280092 + 0.4011607*ACRES

Summary of Fit

RSquare	0.235977
RSquare Adj	0.229334
Root Mean Square Error	0.265918
Mean of Response	1.263771
Observations (or Sum Wgts)	117

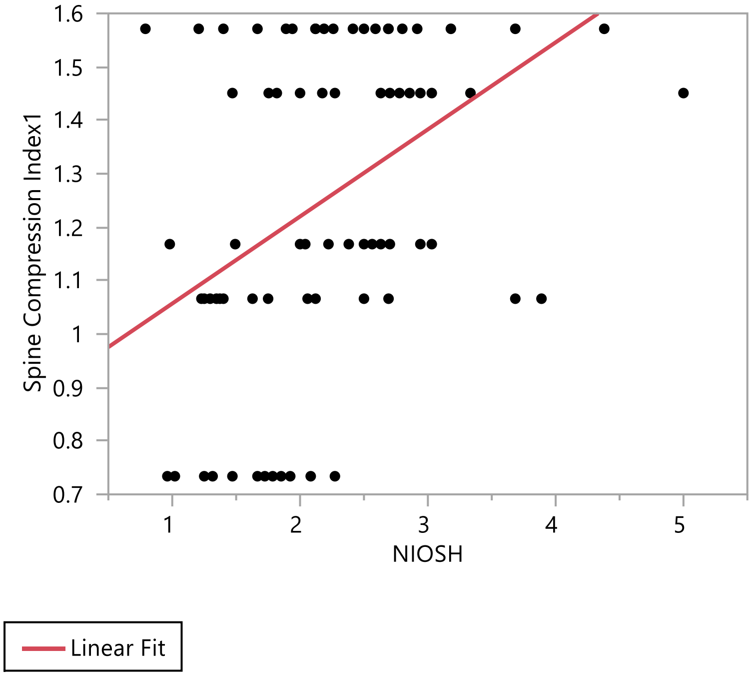
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2.511641	2.51164	35.5191
Error	115	8.131922	0.07071	**Prob > F**
C. Total	116	10.643563		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.6280092	0.109471	5.74	<.0001*
ACRES	0.4011607	0.067311	5.96	<.0001*

Bivariate Fit of Spine Compression Index1 By NIOSH



Summary Statistics

	Value	Lower 95%	Upper 95%	Signif. Prob
Correlation	0.397103	0.232317	0.539729	<.0001*
Covariance	0.088807			
Count	117			

Variable	Mean	Std Dev
NIOSH	2.268762	0.738291
Spine Compression Index1	1.263771	0.302911

Linear Fit

Spine Compression Index1 = 0.8941311 + 0.1629259*NIOSH

Summary of Fit

RSquare	0.157691
RSquare Adj	0.150367
Root Mean Square Error	0.27921
Mean of Response	1.263771
Observations (or Sum Wgts)	117

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1.678393	1.67839	21.5295
Error	115	8.965170	0.07796	**Prob > F**

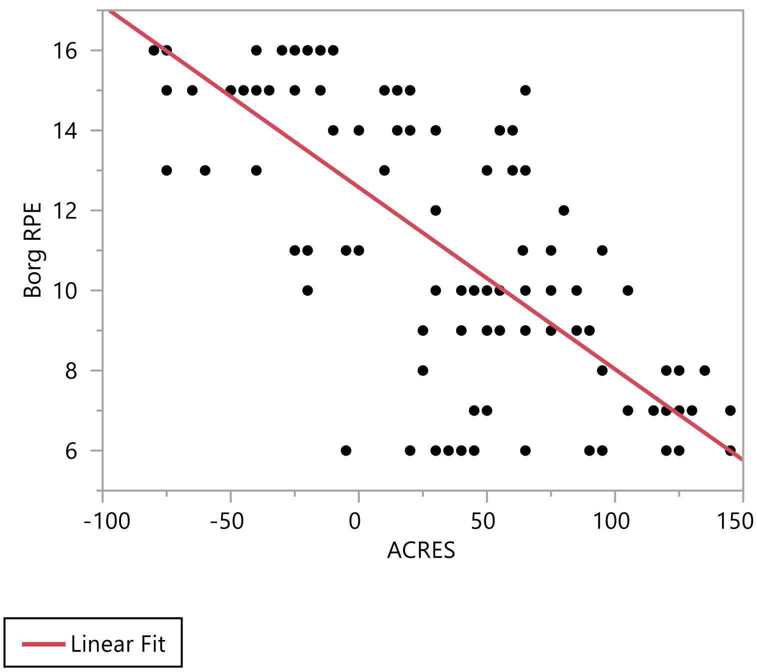
Source	DF	Sum of Squares	Mean Square	F Ratio
C. Total	116	10.643563		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8941311	0.083742	10.68	<.0001*
NIOSH	0.1629259	0.035113	4.64	<.0001*

APPENDIX E: JMP ANALYSIS REPORT OF ACRES POSTURE VALIDATION STUDY

Fit Group
Bivariate Fit of Borg RPE By ACRES



Summary Statistics

	Value	Lower 95%	Upper 95%	Signif. Prob
Correlation	-0.76293	-0.82371	-0.68482	<.0001*
Covariance	-149.636			
Count	144			

Variable	Mean	Std Dev
ACRES	44.09589	57.44579
Borg RPE	10.50249	3.696112

Linear Fit

Borg RPE = 12.576081 - 0.0454328*ACRES

Summary of Fit

RSquare	0.582061
RSquare Adj	0.579118
Root Mean Square Error	2.217171
Mean of Response	10.61111
Observations (or Sum Wgts)	144

Analysis of Variance

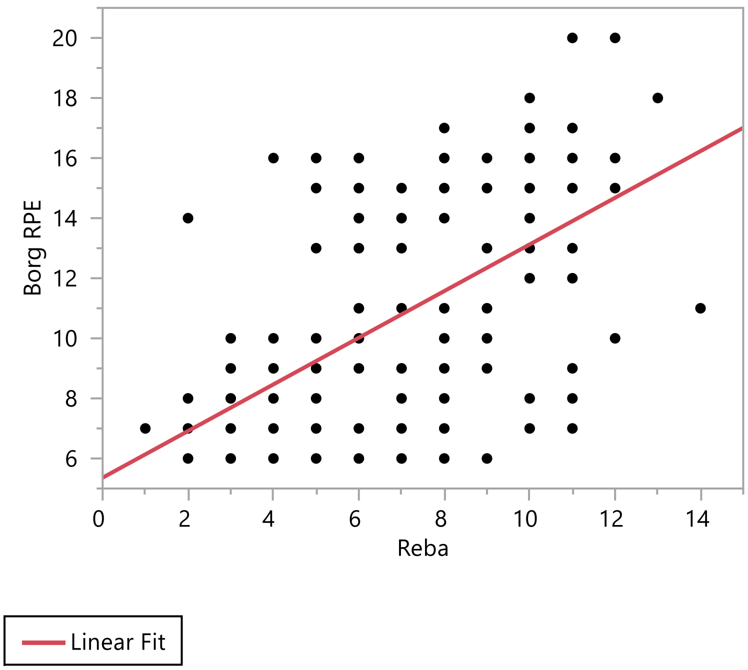
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	972.1717	972.172	197.7627

Source	DF	Sum of Squares	Mean Square	F Ratio
Error	142	698.0505	4.916	Prob > F
C. Total	143	1670.2222		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	12.576081	0.23165	54.29	<.0001*
ACRES	-0.045433	0.003231	-14.06	<.0001*

Bivariate Fit of Borg RPE By Reba



Summary Statistics

	Value	Lower 95%	Upper 95%	Signif. Prob
Correlation	0.63331	0.54246	0.709517	<.0001*
Covariance	7.055945			
Count	201			

Variable	Mean	Std Dev
Reba	6.576355	3.034102
Borg RPE	10.50249	3.696112

Linear Fit

Borg RPE = 5.3602842 + 0.7765461*Reba

Summary of Fit

RSquare	0.401081
RSquare Adj	0.398071
Root Mean Square Error	2.867593
Mean of Response	10.50249
Observations (or Sum Wgts)	201

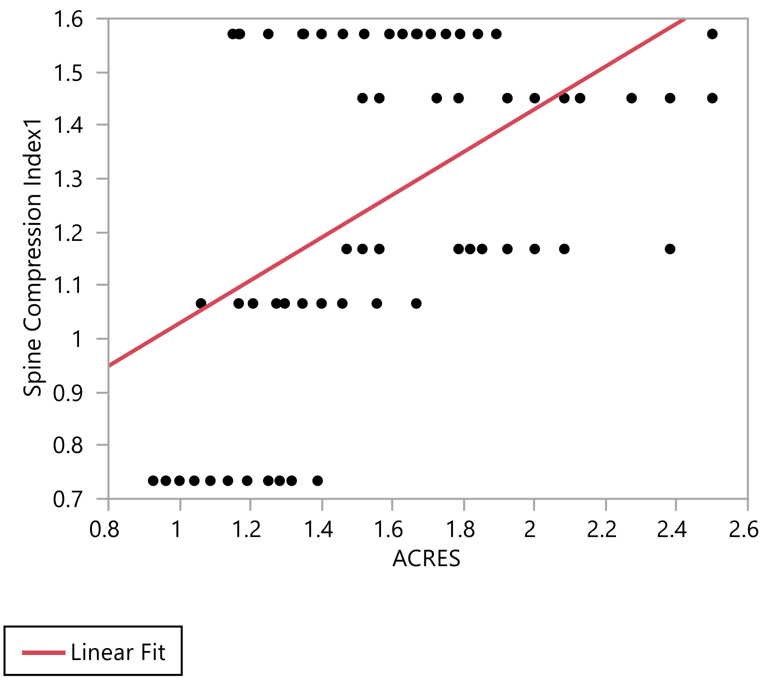
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1095.8534	1095.85	133.2654
Error	199	1636.3954	8.22	**Prob > F**
C. Total	200	2732.2488		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.3602842	0.489213	10.96	<.0001*
Reba	0.7765461	0.067268	11.54	<.0001*

Fit Group
Bivariate Fit of Spine Compression Index1 By ACRES



Summary Statistics

	Value	Lower 95%	Upper 95%	Signif. Prob
Correlation	0.485775	0.333666	0.613231	<.0001*
Covariance	0.053974			
Count	117			

Variable	Mean	Std Dev
ACRES	1.584806	0.366802
Spine Compression Index1	1.263771	0.302911

Linear Fit
Spine Compression Index1 = 0.6280092 + 0.4011607*ACRES

Summary of Fit

RSquare	0.235977
RSquare Adj	0.229334

Root Mean Square Error	0.265918
Mean of Response	1.263771
Observations (or Sum Wgts)	117

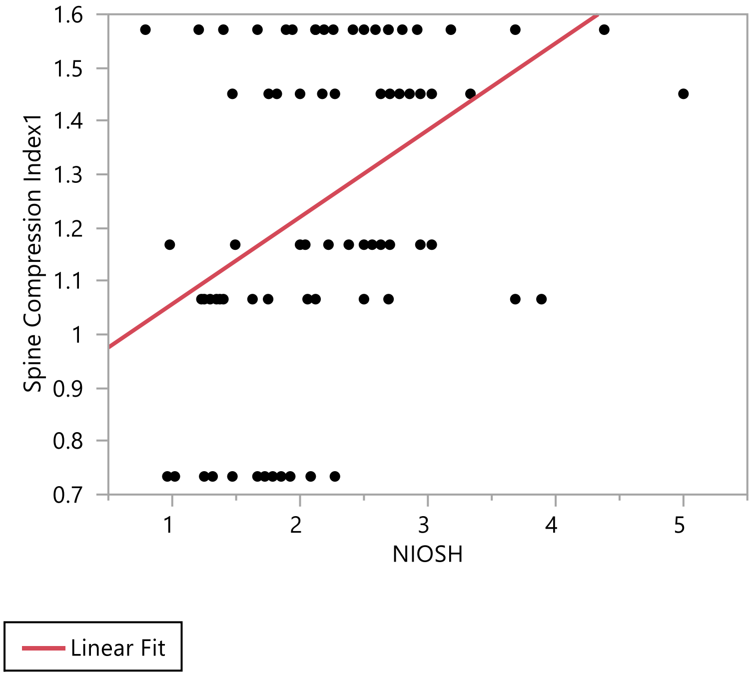
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2.511641	2.51164	35.5191
Error	115	8.131922	0.07071	**Prob > F**
C. Total	116	10.643563		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.6280092	0.109471	5.74	<.0001*
ACRES	0.4011607	0.067311	5.96	<.0001*

Bivariate Fit of Spine Compression Index1 By NIOSH



Summary Statistics

	Value	Lower 95%	Upper 95%	Signif. Prob
Correlation	0.397103	0.232317	0.539729	<.0001*
Covariance	0.088807			
Count	117			

Variable	Mean	Std Dev
NIOSH	2.268762	0.738291
Spine Compression Index1	1.263771	0.302911

Linear Fit

Spine Compression Index1 = 0.8941311 + 0.1629259*NIOSH

Summary of Fit

RSquare	0.157691
RSquare Adj	0.150367
Root Mean Square Error	0.27921
Mean of Response	1.263771
Observations (or Sum Wgts)	117

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1.678393	1.67839	21.5295
Error	115	8.965170	0.07796	**Prob > F**
C. Total	116	10.643563		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8941311	0.083742	10.68	<.0001*
NIOSH	0.1629259	0.035113	4.64	<.0001*

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 8/15/2017

To: Colton Fales
425 Beach Ave.
Ames, IA 50014

CC: Dr. Richard T Stone
3004 Black Engineering

From: Office for Responsible Research

Title: ATLAS: A study on the effects of dynamic acceleration on manual material Handling

IRB ID: 17-055

Approval Date: 8/15/2017

Date for Continuing Review: 8/14/2019

Submission Type: New

Review Type: Expedited

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

- **Use only the approved study materials** in your research, **including the recruitment materials and informed consent documents that have the IRB approval stamp.**
- **Retain signed informed consent documents for 3 years after the close of the study**, when documented consent is required.
- **Obtain IRB approval prior to implementing any changes** to the study by submitting a Modification Form for Non-Exempt Research or Amendment for Personnel Changes form, as necessary.
- **Immediately inform the IRB of (1) all serious and/or unexpected adverse experiences** involving risks to subjects or others; and (2) **any other unanticipated problems involving risks** to subjects or others.
- **Stop all research activity if IRB approval lapses**, unless continuation is necessary to prevent harm to research participants. Research activity can resume once IRB approval is reestablished.
- **Complete a new continuing review form** at least three to four weeks prior to the **date for continuing review** as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

Please be aware that IRB approval means that you have met the requirements of federal regulations and ISU policies governing human subjects research. **Approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **IRB approval in no way implies or guarantees that permission from these other entities will be granted.**

Upon completion of the project, please submit a Project Closure Form to the Office for Responsible Research, 202 Kingland, to officially close the project.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 3/12/2018

To: Colton Fales
425 Beach Ave.
Ames, IA 50014

CC: Dr. Richard T Stone
3004 Black Engineering

From: Office for Responsible Research

Title: Red, White, and Blue Collars: A survey of the demands across different work classes

IRB ID: 17-197

Study Review Date: 3/12/2018

The project referenced above has been declared exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b) because it meets the following federal requirements for exemption:

- (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey or interview procedures with adults or observation of public behavior where
  - Information obtained is recorded in such a manner that human subjects cannot be identified directly or through identifiers linked to the subjects; or
  - Any disclosure of the human subjects' responses outside the research could not reasonably place the subject at risk of criminal or civil liability or be damaging to their financial standing, employability, or reputation.

The determination of exemption means that:

- **You do not need to submit an application for annual continuing review.**

- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any modifications to the research procedures (e.g., method of data collection, nature or scope of information to be collected, changes in confidentiality measures, etc.), modifications that result in the inclusion of participants from vulnerable populations, and/or any change that may increase the risk or discomfort to participants. Changes to key personnel must also be approved. The purpose of review is to determine if the project still meets the federal criteria for exemption.

  Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

  Detailed information about requirements for submission of modifications can be found on the Exempt Study Modification Form. A Personnel Change Form may be submitted when the only modification involves changes in study staff. If it is determined that exemption is no longer warranted, then an Application for Approval of Research Involving Humans Form will need to be submitted and approved before proceeding with data collection.

Please note that you must submit all research involving human participants for review. **Only the IRB or designees may make the determination of exemption**, even if you conduct a study in the future that is exactly like this study.

Please be aware that **approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted.**

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office of Research Ethics
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 02/26/2021

To: Colten Fales Richard T Stone

From: Office of Research Ethics

Title: **Acceleration of Trunk Lifting Assessment System Inter-Individual Variability Validation Study**

IRB ID: **21-092**

Submission Type: Initial Submission **Exemption Date:** 02/26/2021

The project referenced above has been declared exempt from most requirements of the human subject protections regulations as described in 45 CFR 46.104 or 21 CFR 56.104 because it meets the following federal requirements for exemption:

2018 - 2 (i): Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) when the information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects.
2018 - 3 (i.A): Research involving benign behavioral interventions in conjunction with the collection of information from an adult subject through verbal or written responses or audiovisual recording when the subject prospectively agrees to the intervention and information collection and the information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects. - 3 (ii) If research involves deception, it is prospectively authorized by the subject.

The determination of exemption means that:

- **You do not need to submit an application for continuing review. Instead, you will receive a request for a brief status update every three years. The status update is intended to verify that the study is still ongoing.**
- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any *modifications to the research procedures* (e.g., method of data collection, nature or scope of information to be collected, nature or duration of behavioral interventions, use of deception, etc.), any change in *privacy or confidentiality protections*, modifications that result in the *inclusion of participants from vulnerable populations*, removing plans for informing participants about the study, any *change that may increase the risk or discomfort to participants, and/or* any change such

that the revised procedures do not fall into one or more of the regulatory exemption categories. The purpose of review is to determine if the project still meets the federal criteria for exemption.

- All ***changes to key personnel*** must receive prior approval.

- **Promptly inform the IRB of any addition of or change in federal funding for this study.** Approval of the protocol referenced above applies only to funding sources that are specifically identified in the corresponding IRB application.

  Detailed information about requirements for submitting modifications for exempt research can be found on our website. For modifications that require prior approval, an amendment to the most recent IRB application must be submitted in IRBManager. A determination of exemption or approval from the IRB must be granted before implementing the proposed changes.

  Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

Additionally:

- All research involving human participants must be submitted for IRB review. **Only the IRB or its designees may make the determination of exemption**, even if you conduct a study in the future that is exactly like this study.

- **Please inform the IRB if the Principal Investigator and/or Supervising Investigator end their role or involvement with the project** with sufficient time to allow an alternate PI/Supervising Investigator to assume oversight responsibility. Projects must have an eligible PI to remain open.

- **Immediately inform the IRB of** (1) **all serious and/or unexpected adverse experiences** involving risks to subjects or others; and (2) **any other unanticipated problems involving risks** to subjects or others.

- **Approval from other entities may also be needed**. For example, access to data from private records (e.g., student, medical, or employment records, etc.) that are protected by FERPA, HIPAA or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted**.

- Your research study may be subject to **post-approval monitoring by Iowa State University's Office for Responsible Research**. In some cases, it may also be subject to formal audit or inspection by federal agencies and study sponsors.

- Upon completion of the project, transfer of IRB oversight to another IRB, or departure of the PI and/or Supervising Investigator, please initiate a Project Closure in IRBManager to officially close the project. For information on instances when a study may be closed, please refer to the IRB Study Closure Policy.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.