Ergonomic Evaluation of Grocery Checkstands

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INTRODUCTION

Grocery Stores are among the top twelve industries in the State of Washington for compensable non-traumatic soft tissue musculoskeletal disorders (MSDs). In one category of MSDs, upper extremity disorders, Grocery Stores had the fourth highest incident rate between 1992 and 2000 [1]. Grocery Store Front End workers (cashiers, counter and rental clerks, pharmacy technicians, retail salespersons, sales and related workers) accounted for 42% of all MSD injury claims in the industry (1994-1998), and of those, 54% were back or neck injuries and 34% were upper extremity related [2]. The causes for injuries such as these are not always known, but research suggests that there are three prominent risk factors in the work process: excessive repetitiveness, high forces, and awkward postures [3].

Concern regarding the incidence of Front End worker injuries prompted the University of Washington Field Research and Consultation Group (Field Group) to conduct a research study to analyze two potential ergonomic interventions to help reduce musculoskeletal exposures. Enlisting the help of [redacted], which utilizes various height and bi-directional (U-shaped) checkstands in some of their stores, the Field Group targeted: 1) the height of checkstands and its impact on cashier wrist posture and shoulder and back muscle activity, and 2) the alternation of the lead scanning hand (right-side vs. left-side) as a way of reducing repetitious hand and arm movements. The different height and U-shaped checkstands at [redacted] are unique in that cashiers can choose which of the two different height checkstands they prefer to work at and/or whether they prefer to scan with their right or left hand, both features which offer potential ergonomic benefits to cashiers.

A fair amount of research has been done in the grocery industry to make checkstand design recommendations intended to reduce the incidence of musculoskeletal injury. Most of these design recommendations have been incorporated into the checkstands currently in use at the [redacted]. A panel of experts [4] and numerous other researchers have concluded that certain checkstand features are more likely to be associated with musculoskeletal exposures than others. For instance, front facing checkstands, or checkstands with the scanner and scale in front of the cashier, have been recommended as a means to reduce twisting, minimize reaching, promote more neutral trunk postures, reduce wrist acceleration, and allow the use of both hands during scanning [5] [4] [6] [7].

In 1993, the National Institute of Occupational Safety and Health (NIOSH) recommended eliminating the practice of cashiers unloading customers' grocery carts. Removing groceries from the cart was found to increase the occurrence of long reaches, awkward shoulder postures, and lifting. They also recommended the installation of conveyor belts to deliver groceries to the cashier [8]. This change eliminated many of the previously identified problems with cart design and cashier cart unloading practices.

Relatively little research has been conducted on the variability of checkstand height and its influence on musculoskeletal exposure. Harber [9]found that low back bending was related to self-reported hand-wrist-lower arm and carpal tunnel syndrome symptoms, and suggested that changing checkstand heights might alleviate symptoms. In separate research, using high and low checkstands (35.5 and 31.5 inches), Harber [10] demonstrated that low back and overall arm comfort was significantly related to checkstand height ($p = 0.03$). There was a direct relationship between low-back comfort rating and subject height with a preference for the higher (35.5 inches) checkstand. Lehman and Marras [11] did a scanner study using an adjustable height checkstand, but work surface height was not a variable in their study design. Specific checkstand height suggestions were made by Wells [12], who recommended that front facing checkstands measure from 90 to 97.4cm (35 to 38 inches) and Grandjean [13], who recommended a working height of 50 to 100mm (2 to 4 inches) below elbow height. While suggestions have been made for appropriate checkstand height and worker comfort preferences have been documented, we found no studies that made use of objective assessments in analyzing the effects of checkstand height.

Much of the research in the grocery industry has involved the use of subjective measures such as employee rating scales, or semi-subjective measures such as observational analysis. Few studies have tried to objectively quantify musculoskeletal exposures in the grocery industry. Three of these studies used electrogoniometers to measure wrist motions [6] and wrist acceleration [11] [14] during scanning. With the advent of scanners in the 1980s, research focused on the repetitive hand motions associated with the increased productivity of scanning groceries compared to manually entering prices into a cash register, as well as the differences between scanner configurations [14] [11] [10] [15]. Through the use of electrogoniometry, Lehman and Marras [11] found that two-window scanners increased productivity and could reduce the risk of injury because less wrist orientation and motion were required when compared to one-window scanners. Again using electrogoniometry, Marras [6] later concluded that multiple scan beams and windows promoted more neutral wrist positions due to the cashiers' perception that they did not need to deviate their wrists while scanning. Via electrogoniometry, Madigan and Lehman [14] found that wrist accelerations were lower with bi-optic (horizontal and vertical) scanners than flat bed scanners. Electromyography (EMG) is another commonly used objective assessment tool. Through the use of EMG and electrogoniometry, bi-optic scanners were found to require less muscle activity; reduce lifting, reaching, wrist acceleration, and item manipulation; and increase productivity [16] [11]. In none of these studies incorporating the use of objective measurement tools were the findings compared to worker self-report of symptoms or comfort.

Sandsjo et al. [17] used electromyography (EMG) to look at muscle activity pattern differences between cashiers who reported neck and shoulder pain ($n=18$) and cashiers without pain ($n=6$) during 50 minutes of their normal work. They found that the cashiers without pain had more muscle rest time, and that the cashiers without pain had twice as much muscle rest in their non-dominant side as compared to the cashiers experiencing pain ($p<0.05$). It followed that the equal muscle activity on the dominant and non-dominant sides in the cashiers reporting pain was due to self imposed limitations on movement in both shoulders in order for them to avoid pain. Furthermore, as was true with other EMG pain/non-pain research, the non-pain cashiers were significantly taller [18]. In the Sandsjo study, the researchers concluded that the checkstand design was not suited for all workers and may have been a contributing factor in the development of the neck and shoulder pain [17], but the influence of specific checkstand design features was not accounted for in the study.

Similarly, Lundberg et al. [19] studied EMG trapezius activity and musculoskeletal symptoms, as well as physiological and psychological stress. Stress levels, measured through urine and saliva samples, were found to be significantly elevated at work, as evidenced by EMG, heart rate, blood pressure, and epinephrine and norepinephrine levels (indicators of mental stress and physical demands, respectively). The 70% of the 72 cashier participants whom a trained physiotherapist found to have neck and shoulder pain symptoms also had higher EMG activity at work and more muscle tension after work. While an association between these factors was shown, the authors caution that causality cannot be concluded and that other factors not measured may have contributed to the results. Specific details regarding checkstand configuration were not considered.

As a part of the same long-term project, Rissen et al. [20] studied a subgroup (n=31) of the 72 cashiers in the Lundberg study. They found a significant relationship between self-reports of negative stress and EMG activity during work. Examples of negative stress were self-reports of feelings of exhaustion, stress, and tension. No significant correlations were found between EMG activity and pain, physiological workload, or self-reports of positive reactions at work. They concluded that there may be musculoskeletal concern for workers in low-to-moderate physical work in which there are negative psychosocial factors. No consideration was given to potential contributions of checkstand design to negative stress and EMG.

In another field-based study by the same group of researchers, Rissen et al. [21]compared EMG muscle activity before and after job rotation and found a significant decrease in the muscle activity of the left trapezius and lower diastolic blood pressure as a result of shifting between cashier work and work in other departments. They found no change, however, in the prevalence of self-reported musculoskeletal pain. While workers' perceptions of stress and hurry were unchanged, job rotation was reported to be a positive experience by the workers.

Wells et al. [12] used EMG to measure muscle activity of the low back and trapezius muscles and electrogoniometry to measure the wrist motions of 24 cashiers during checking and bagging of three carts of pre-selected groceries. Low back muscle activity was converted to Newtons to allow comparison to the National Institute of Safety and Health (NIOSH) Lifting Equation [7]. The average maximum load (based on peak levels of muscle loading which was exceeded only 10% of the time) was 2033 N, well below the 3300 N Action Limit suggested by NIOSH. When the NIOSH Action Limit is exceeded, there is an increased likelihood of low back injury. Shoulder muscle activity exceeded recommended levels of activity at the static (lower muscle load or 10^{th} percentile activity) and median (the 50^{th} percentile muscle load) levels, indicating little muscle rest and heavy shoulder loads, respectively. The electrogoniometry results showed that the right wrist (dominant scanning hand) was in ulnar deviation twice the amount of time as the left wrist (66% vs. 33% respectively). Unfortunately, the analyses were not stratified by checkstand type, of which there were at least three.

Lannersten and Harms-Ringdahl [15]looked at EMG activity in five muscles of eight cashiers while performing cashier work at five checkstand configurations set up in a lab. They found static or low level muscle loads in the upper back (thoracic erector spinae) that exceeded muscle activity levels recommended by Jonsson [22], while activity in the shoulder (trapezius) and shoulder blade region (infraspinatus) was within a recommended/acceptable range, and the near-spine neck (cervical erector spinae) and side neck (levator scapulae) static muscle activity was relatively low. Median EMG levels (50^{th} percentile) were very low except in the shoulder blade region muscles during scanning. Peak (90^{th} percentile) muscle loads never exceeded the recommended limits. Additionally, muscle activity at all levels (static, median, and peak) was lower when standing than when sitting at one type (front facing with a vertical scanner) of checkstand. While checkstand configuration was a variable in this study, differences between them were related to scanner type. They reported that conventional checkstand design features were used to induce realistic work situations in this lab-based study, including right-to-left scanning direction, and a checkstand height presumed to be the industry standard of 36 inches, though this was not specified.

Only six of the previously mentioned grocery industry studies which used objective assessment equipment were conducted in the field [14] [12][19] [17] [20][21]— five using EMG and one using electrogoniometry. All six studies included at least one portion that was an assessment of actual cashiering tasks rather than simulated. None of the field-based studies used both electrogoniometry and EMG. We also found no research which looked at the objective effects of checkstand height. Furthermore, to our knowledge, little research has been done regarding the use of two-sided or U-shaped checkstands such as those in use at [redacted] Lastly, while a number of studies have solicited employee self-report of pain or other symptoms [9][23][10][24][25], few have compared objective findings with those of worker self-reports of pain or discomfort [16][21][20][17][19][12]. Within the three phases of the present study, we will conduct field-based analysis using four different objective measurement devices and worker self-report of fatigue to determine the effects of checkstand height and alternate hand scanning.

Given the prevalence of musculoskeletal injury in the grocery industry, the opportunity to study the unique design features of the U-shaped checkstands in use at [redacted] and the lack of objective research regarding the effects of checkstand height and alternate handed scanning on wrist posture and low back and shoulder muscle activity, the Field Group worked with [redacted] to conduct an investigation in these areas. It was our hypothesis that matching worker stature to the appropriate height checkstand could reduce back bending and therefore minimize the risk of cumulative back injuries. Moreover, it was also hypothesized that alternating the lead hand used for scanning would more evenly distribute the workload across both sides of the body, as measured by the electrogoniometers and EMG. The methods of conducting the research project and the results are as follows.

METHODS

This project was divided into three phases, which are presented in Table 1. This report presents only the findings of Phase 1.

Table 1. Study Phases

Phase	Assessment Device	No. of subjects	Checkstand Configurations	Time at each checkstand	Controlled items
1	Electrogoniometry Electromyography	6*	Tall right Regular height right side Regular height left side	15 minutes	yes
2	Virtual corset Actigraph	12	Tall right Regular height right side Regular height left side Half shift left side & right side	4 hours**	no
3	Electrogoniometry Electromyography Virtual corset Actigraph Borg scale	6*	Tall right Regular height right side	4 hours	no

* The same 6 cashiers participated in Phases 1 and 2 (total of 12 subjects in the study).
** Half shifts at left and right sides are 2 hours each.

Overview of Study Design

Through the use of electromyography (EMG) and electrogoniometry, this study examined the effects of two different height checkstands and alternate side lead scanning hand (right vs. left) checkstands on wrist motion and muscle activity of the low back and shoulder. The study task required the six grocery store cashiers to scan and bag groceries for fifteen minutes at each of three different checkstand configurations. The influence of height and lead hand scanning configuration on muscle activity was measured using electromyography (EMG), while the effects on wrist posture and motion were simultaneously measured using electrogoniometers. The University of Washington Human Subjects Institutional Review Board approved the study.

Study Setting and Checkstand Design

The study was conducted at the [redacted] the second largest and highest volume of [redacted] seven stores. There are three U-shaped checkstands at this store, two of which are 38.25 inches tall and one of which is 36.50 inches tall (from the floor). Since two cashiers can work back-to-back at each U-shaped stand, there are functionally six individual checkstands. The cashier on one side of the U-shaped checkstand uses his or her left hand as the lead scanning hand while the other uses the right hand to pick up and scan items (See Figure 1).

Figure 1. Right-side checkstand Left-side checkstand

Each of the checkstands was the front-facing type, which was designed so that the cashier faces the customer, the cash register is at a 90 degree orientation relative to the belt, and a keypad is located on a height-adjustable platform above the scanner. With this type of checkstand, customers unload their groceries from the cart or basket onto a conveyor belt that transports the groceries to the edge of the scanner. The cashier passes the groceries over/past the horizontal/vertical scanner. If the scanner does not automatically register the price, items are re-scanned a maximum of three times, if unsuccessful, then the code is manually entered on the keypad. Produce and bulk foods are weighed on the combination scanner/scale and the code is manually entered on the keypad. Items are then manually moved (pushed or carried) to the adjacent bagging area.

For larger orders, another employee may bag the groceries at a bagging station at the end of the checkstand. For smaller orders, the cashiers may bag the groceries themselves using the "bagging well" located in front of them. A "slide board" spans and covers the gap created by the bagging well and bridges the space between the scanner surface and the bagging area. To use the bagging well, the slide board is removed and bags are placed inside the well. The bagging well contains plastic bags suspended on a height adjustable rack that holds the bags open while items are placed inside. The cashier then lifts the loaded bags to the bagging area or into the customer's cart.

In order to maximize the height difference between the 36.50 and 38.25 inch checkstands, a specified number and height of floor pads were used for each checkstand configuration. By using three floor pads at a regular height checkstand, the height of the checkstand (the vertical distance from the top of the pads to the working surface of the checkstand) was reduced to 35.25 inches, and by using only one floor pad at the tall checkstand, the distance was limited to 38.125 inches. The height difference between the regular and the tall checkstands was thereby increased to 2.875 inches. The keypad height was standardized for each study participant at 12.5 inches (from the scanner surface to the middle row of the keyboard) on the regular height checkstands, and 11.25 inches on the tall checkstand.

Since the standard checkstand height in the grocery industry in the U.S. is 36 inches, and use of floor pads is customary, the 35.25 inch checkstand is referred to as "regular" height and the 38.125 inch checkstand is referred to as "tall." Both sides (left and right) of each U-shaped checkstand are the same height. The order in which the subjects worked at each of the checkstands was randomized.

Each subject worked for 15 minutes at each of the three configurations of checkstands:

- Regular height, right hand scanning configuration (RR)
- Regular height, left hand scanning configuration (RL)
- Tall height, right hand scanning configuration (TR)

Site and Subject Selection

Subjects were recruited for the study via an informational flyer posted in the [redacted] break room. To address the effect of checkstand height on the biomechanics of cashiers, subjects were selected by height to represent short, medium, and tall persons. Nine participants volunteered but only six subjects were tested. The study was limited to six cahiers at the request of [redacted]. One participant was excluded due to a previous diagnosis of a musculoskeletal disorder and two other participants were excluded due to being outside of the desired height range. Four females and two males participated in the study (See Table 2). The median age was 36, ranging from 21 to 59 years of age and all were right handed. The height distribution included two females in the 25th percentile, two females in the 50th percentile, and two males in the 95th percentile.

Table 2. Subject demographics

Subject #	**Gender (Male or Female)**	**Age (years)**	**Height (inches)**	**Weight (pounds)**	**Height percentile by gender (%)**
1	M	21	75.5	170	95 M
2	F	37	65	140	50 F
3	F	23	63	120	25 F
4	F	41	66	149	50 F
5	F	59	62.5	110	25 F
6	M	35	75	200	95 M

Study Equipment

On the day of each individual's scheduled work time and prior to data collection, 12 mm diameter Ag/AgCl disposable EMG electrodes (Model N-00-S; Medicotest; Ballerup, Denmark) were attached over the participant's left and right trapezius muscles (above the shoulder blades) and to the left and right lumbar erector spinae (low back) muscles. The EMG electrodes were applied to the middle of each shoulder as recommended by Jensen et al. [26] and in the lumbar region 3 cm. lateral to the spinal column at the level of the 3rd vertebrae as recommended in the literature [16] [27]. An electrogoniometer (Model

XM-65; Biometrics; Blackwood Ltd, United Kingdom) was attached to each wrist. Careful measurements of each individual were taken to ensure that the EMG and electrogoniometer placements were the same for all participants.

The electrogoniometers were used to measure the wrist angle in extension/flexion (up and down in a waving motion) and radial/ulnar deviation (up and down in a handshake motion) (See Figure 2). Each electrogoniometer was made up of two plastic, rectangular-shaped plates (about 2"x 0.5") connected by a spring coil and biaxial cables. The device was attached by tape above and below the wrist, with one of the plastic plates on the back of the hand and the other on the back of the forearm. A cable from each goniometer ran up the arm and was secured with a clip near the subject's shoulder. The angular signals were recorded on four channels of an 8-channel, portable, battery-powered logger (Model MP-3000P-8; Mega Electronics Ltd; Kuopio, Finland) worn around the participant's waist.

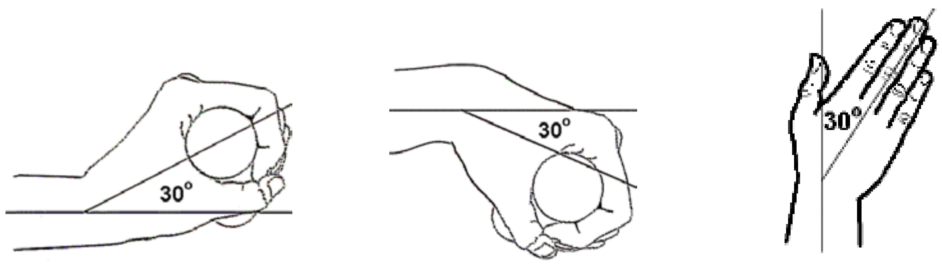

Figure 2. Wrist in extension, flexion, and ulnar deviation.

The other 4 channels of the logger were used to measure muscle activity in the trapezius and lumbar erector spinae muscles. A small optical cable connected the logger to the serial port of a portable computer (Latitude C-800; Dell; Round Rock, TX), which was situated to the side of the checkstand. The data were sampled at a frequency of 1000 Hz and stored on the hard disc of the computer. A digital video camera (Sony DCR-PC101 NTSC) simultaneously recorded the subjects to allow researchers to later compare electrogoniometer data to the events captured on the videotape. A cash register printout of the number of grocery items scanned by each participant allowed researchers to make comparisons between the workloads of the cashiers.

Figure 3. Study equipment: Photo 1 - data logger, trapezius EMG; Photo 2 - left electrogoniometer; Photo 3 - data logger connected by cable to laptop computer

Study Procedure

With the electrogoniometers and EMG electrodes in place, calibration values and reference levels were recorded in order to normalize and compare each participant's results. For the electrogoniometer calibration, three 5 second periods of neutral posture were recorded during which the participants held their wrists straight, in a position of zero degrees flexion/extension and neutral radial/ulnar. This was repeated after each checkstand configuration to assure that the instrumentation recording was consistent. For the trapezius EMG calibration, the participant held a two-pound dumbbell in each hand with the arms outstretched to the side at a ninety-degree angle (like airplane wings). This calibration was performed three times for fifteen seconds. For the erector spinae EMG calibration, a harness was placed around the participant's upper body and an electronic force gauge with a digital display (Chatillon, Model DFIS, Greensboro, NC) was attached to the harness. The participants were asked to resist against an opposition pull force of 22.5 lbs created by one of the researchers. This procedure was repeated three times. Some participants pulled against forces of 11.5, 22.0 and 33.5 lbs. These calibration readings were recorded with a computer program (MegaWin Version 1.21, Mega Electronics, Kuopio, Finland) and were later used as the reference values for the subsequently collected EMG. Cashier muscle activity (EMG) was compared to these calibration values and is presented as a percentage of this reference voluntary electrical activity (RVE) [28].

The video camera, data collection computer program, and the participant's grocery scanning activity were started simultaneously with a verbal cue. The data collection period at each checkstand was tracked with the computer clock and a stopwatch. The time period at each checkstand was briefly extended on a number of occasions to make up for time lost due to interruptions in data collection. For example, a number of times the signal from the electrogoniometer was visibly disrupted, presumably due to a loose connection. To make up for the few minutes it took to check the connections, the data collection was extended by a few minutes beyond the standard data collection period.

Cashiers scanned and bagged thirty-four items that were pre-selected to represent a range of weights, package shapes and sizes, as well as scanability (due to size, weight, or non-rigidity of the package). Six of the items were produce, which needed to be weighed and the code for the item entered into the cash register via the keypad. The groceries were loaded onto the conveyor belt by the researchers. Two grocery carts of identical items were rotated as many times as needed during the allotted time at each checkstand. Cashiers were instructed to work at their normal pace and in their usual fashion. They scanned and bagged the items, and placed the bags in a grocery cart as they would ordinarily do with a customer; however, there was no monetary exchange.

Data and Statistical Analysis

The EMG data were high-pass filtered with a 2nd order dual-pass Butterworth filter with a low frequency cutoff of 0.05 Hz to remove any DC offset in the EMG data. The data were then rectified and averaged using a 100 millisecond window and smoothed at 1 second moving window.

With three of the six subjects, the electrogoniometer signal was disrupted, corrupting small portions of collected data. The signal disruption was generally found to be associated with the cable becoming disconnected from the logger due to tugging on the cables from subject's clothing or the cable pulling tight from movement. As a result, the corrupt portions were excluded from the data analysis. Due to equipment malfunction, data from one of the tall subjects were missing for two checkstands (RR and TR).

Electrogoniometry

The wrist positions recorded with the electrogoniometer were analyzed in two planes for each hand: flexion/extension and radial/ulnar. The mean, minimum, and maximum values were calculated for wrist position, velocity, range of motion, and repetitiveness. The mean wrist position was the average angle (in degrees) the wrist was in over the course of the data collection period. In the flexion/extension plane, negative values indicate flexion; in the radial/ulnar plane, negative values indicate radial deviation. Velocity of wrist movement measured the speed of wrist movement in degrees per second. The range of motion (ROM), the range in degrees over which the hand moved, was calculated by subtracting the 5th percentile angle values from the 95th percentile angle values. Repetitiveness, measured in cycles per second (Hertz), reflects the level of recurring wrist movement.

EMG

With the rectified, averaged, and smoothed EMG data, an amplitude probability distribution function (APDF) was computed and the 10th, 50th, and 90th percentile values were obtained to reflect the static, median, and peak muscle activity values respectively. These values were calculated for each checkstand configuration and were averaged over all subjects. Static activity, or the static load on the muscles, is defined by the percentage of activity at < 10% of RVE [29] [30][31] [32] median activity is at the 50th percentile, and dynamic activity refers to the 90th percentile relative to the RVE.

Two types of analyses were performed on the trapezius muscle EMG data to provide an indication of how much time the muscles were being loaded and the amount of time spent in muscular rest. One type of analysis, proposed by Veiersted, et al. [33], was a gap analysis that measured brief periods of muscle inactivity, called gaps. Gaps are the periods of "silence" or rest defined in this study as activity below 5.0% of RVE and lasting for periods between 0.2 and 3 seconds. Gap analysis captures the frequency of gaps per minute as well as the percentage of total time spent in gaps. A complementary measure of muscular rest was the percentage of time the muscle was allowed to rest. This was measured as the percentage of total time spent below 3% RVE (%MR).

Using JMP statistical software (Version 4.0; JMP; Cary, SC), repeated measures analysis of variance methods (RANOVA) were used to compare the results between the right and left hand checkstand configurations. Due to missing data from one subject when working at the tall checkstand, the PROC MIXED procedure in SAS (Version 8.1; SAS Institute; Cary, SC) was used to account for the missing measures when calculating certain RANOVAs.

Statistical comparisons were made between these checkstand configurations:

- the *regular* height *right* hand scan configuration (RR) and the *regular* height *left* hand scan configuration side (RL)
- the *regular* height *right* hand scan configuration (RR) and the *tall* height *right* hand scan configuration (TR)

P-values were calculated for each of the comparisons. P-values less than or equal to 0.05 were considered to be statistically significant.

RESULTS

Comparisons regarding the effects of checkstand height were made between the regular height and tall checkstands, and comparisons regarding the effects of alternating the dominant scanning hand were made between the regular height left-side and regular height right-side checkstands. Dependent variables for electrogoniometry were wrist posture, velocity of wrist movement, and repetitiveness of wrist motion; dependent variables for EMG were muscle activity, muscular rest, and EMG gaps. Differences between the different height checkstands were analyzed by worker height, but no notable differences were found. Therefore, these results reflect the findings of all the subjects treated as one group. Left-side vs. right-side analyses included data from all six subjects; regular height vs. tall checkstand analyses included only five subjects (data from one of the tall subjects was missing).

Regular Height Checkstand vs. Tall Checkstand

Electrogoniometry

The differences between the tall checkstand and a regular height checkstand are shown in Appendix A. The height difference between the two checkstands was 2.875 inches, with the tall checkstand at 38.125 inches and the regular height checkstand at 35.25 inches.

Wrist Posture

The mean wrist positions were closer to the neutral position at the tall checkstand compared to the regular height checkstand in the radial/ulnar and flexion/extension planes for the left wrist and in the flexion/extension plane for the right wrist. However, these differences were small (1.0 to 2.5 degrees).

For both wrists at both the tall and regular height checkstands, the mean wrist position was one of extension and ulnar deviation (vs. flexion and radial deviation). When comparing hands, in both the tall and regular height checkstands a statistically significant difference ($p = 0.03$) was found in the mean flexion/extension angle between the left and right wrist. The average left wrist position was extended 4.5 degrees greater than the right wrist.

The wrist range of motion (ROM) was greater at the tall checkstand compared to the regular height checkstand for both wrists in both the radial/ulnar and flexion/extension plane. The differences between ROM at the tall and regular height checkstands for both wrists and in both planes were as small as 1 degree and as great as 4 degrees.

Velocity of Wrist Movement

As shown in Appendix A, wrist movement velocities were similar between the tall and regular height checkstands as well as between the right and left wrists. There was a slightly increased velocity at the tall checkstands compared to the regular height checkstands, though it did not reach statistical significance. Only radial/ulnar wrist movement differences proved to be statistically significant. The left wrist moved 3 degrees per second faster when working at the tall checkstand compared to working at the regular height checkstand ($p = 0.03$). Also, the interaction between the left and right wrists and the tall and regular height checkstands was statistically significant ($p = 0.04$), with the left wrist slower than the right wrist at the regular height checkstand, but faster than the right wrist at the tall checkstand (See Figure 4).

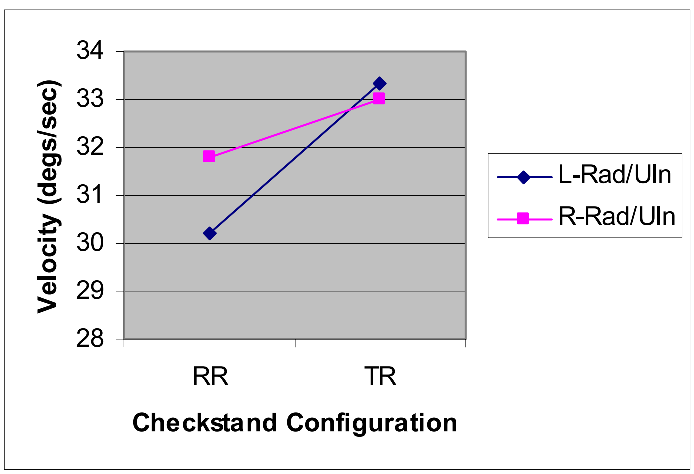

Figure 4. Mean Radial/Ulnar Wrist Velocity at *Tall* Right Side Checkstand (TR) vs. *Regular* Height Right Side Checkstand (RR)

Repetitiveness of Wrist Motion

There was little to no difference in wrist motion repetitiveness between the tall and regular height checkstands or between the left and right wrists. Repetitiveness ranged from 0.53 to 0.60 Hz, or an average of one wrist movement every 1.5 to 2 seconds.

Electromyography

Trapezius Activity

As shown in Appendix B, both left and right trapezius muscle activity was significantly higher in the tall checkstands compared to the regular height checkstands at the 10^{th} percentile ($p = 0.05$ right; $p = 0.01$ left) and the 50^{th} percentile EMG activity ($p = 0.01$ right; $p = 0.05$ left). The 10^{th} and 50^{th} percentile are representative of the static and median loads respectively. At the 90^{th} percentile, which is representative of peak loads, there were less pronounced differences.

Erector Spinae Activity

There were no significant differences in any of the EMG parameters of the left and right erector spinae muscles between the tall and regular height checkstands.

Gaps / Muscular Rest

The percent time of muscular rest and number of EMG gaps per minute in the trapezius muscle were low with no differences between checkstands.

Regular Height Right Side vs. Regular Height Left Side

Electrogoniometry

Appendix C shows the differences and respective p-values for the comparison of the wrist movements between the checkstands where the incoming groceries approached on the cashier's right side ("right side") and a checkstand where the incoming groceries approached on the cashier's left side ("left side"). Both checkstands were of regular height.

Wrist Posture

As shown in Appendix C, the range of motion was greater for the left-side checkstand than the right-side checkstand for both wrists in both planes. The difference between the two checkstands was significant ($p = 0.03$) for the left wrist in the ulnar/radial plane, with three degrees more range of motion at the left-side checkstand .

Velocity of Wrist Movement

There was little difference in the velocity of wrist movement between the right- and left-side checkstands in both planes.

Repetitiveness of Wrist Motion

There was little difference in the repetitiveness of wrist motion between the right- and left-side checkstands in both planes.

Electromyography

Trapezius Activity

As shown in Appendix D, there were no significant differences in right and left trapezius muscle activity between the right- and left-side checkstands.

Erector Spinae Activity

There were no significant differences in right and left ES muscle activity between the right- and left-side checkstands.

Gaps / Muscular Rest

The percent time of muscular rest and number of EMG gaps per minute in the trapezius muscle were low with no differences in left and right trapezius muscle activity between the right- and left-side checkstands.

DISCUSSION

This study focused on the effect that tall and regular height checkstands had on the erector spinae muscles and the effect that right- and left-hand scan checkstands had on wrist motion and trapezius muscle activity. It was hypothesized that matching the checkstand height to the cashier's height would reduce musculoskeletal exposures to the low back (erector spinae) muscles and that alternating work between right- and left-hand scan checkstands would balance repetitive wrist motions and trapezius muscle activity between the lead and non-lead scanning side of the body. While the data did not conclusively support these hypotheses, some differences were observed between the regular height and tall checkstands and between the right and left-hand scan checkstands. Since only six subjects were studied, some of these differences may have been difficult to detect due to a lack of statistical power.

Comparison of Tall vs. Regular Height Checkstands

It was postulated that checkstand height would primarily influence the erector spinae (ES) muscle activity and have little to no influence on wrist motions and trapezius muscle activity. We thought that there would be more ES activity at the lower (regular height) checkstands due to more back bending in order to accommodate the lower height of the checkstands, particularly for taller workers. As shown in Appendix B, the overall ES activity for all workers did not appreciably change between the regular height and tall checkstands. However, as seen in Appendix B, differences in trapezius muscle activity were observed, with trapezius activity on both sides significantly higher at the tall checkstands, regardless of worker height. There was little difference in wrist position or wrist motion between the tall and regular height checkstands. It appears that the upper arm and the resultant trapezius muscle may have compensated for differences in checkstand height.

A regression analysis was used to examine the interaction between cashier height and the height of the checkstands. The only potential trend that was found was that the mean velocity for flexion/extension in the dominant scanning hand decreased across all conditions (tall and regular height and right- and left-sides of the checkstand) as cashier height increased. However, a larger sample size will be needed in order to draw more definitive conclusions about this and other relationships of interest. Additionally, a larger difference between the tall and regular height checkstands than the 2.9 inch difference observed in this study may foster more noteworthy effects.

Comparison of Right-side vs. Left-side Checkstands

It was postulated that the hand/side used to grasp and scan the groceries would show greater wrist motion and trapezius muscle activity than the hand/side that placed the scanned groceries on the bagging platform; with the reverse effects occurring when the other checkstand configuration was used. Our data indicated that grocery scanning was a very bi-manual activity. As shown in Appendices C and D respectively, there were virtually no differences in wrist motion or trapezius activity between the hand/side of the body grasping and scanning the groceries and the hand/side of the body used to place the scanned items on the bagging platform. Viewing the videotapes confirmed the bi-manual nature of the task. Most of the cashiers used one hand to bring a grocery item to the scanner and the other hand to move it to the bagging area; and for scanning large, heavy, or flimsy items, most cashiers used both hands.

It was also postulated that there would be differences in erector spinae muscle activity between the right- and left-hand scan checkstands due to upper body twisting. However, as shown in Appendix D, our data indicated there were only small changes in right and left erector spinae activity between the right- and left-side scan configurations.

There were some methodological explanations for why the observed differences between the right- and left-hand scan checkstands may have been smaller than anticipated. First, with the data collected in this study, the subject did both the scanning and bagging. In ordinary practice, for large grocery orders, a separate worker would do the bagging. Had the data collection included only scanning and money exchange, as is more likely in typical cashiering work, there may have been a greater difference between the left- and right-sides. It appears that including the bagging tended to balance out some of the expected differences, which was confirmed when the videotapes were reviewed. Though cashiers used both hands to bag, there was a tendency to use the left hand more than the right while at the right-hand scan checkstand because of the location of the bagging well in relation to the bagging platform. While right-side checkstands may facilitate greater use of the right arm for scanning, the location of the bagging well promotes greater use of the left arm. Therefore, while the data do not seem to indicate respite for the left arm while working at a right-side checkstand, evidence of the effects of that respite may have been overshadowed by the bagging activity. Given that on average, bagging accounted for 60% of the total cashiering time, actions during bagging could have counterbalanced the opposing hand scanning activity.

In addition, some of the expected differences could have been washed out due to differences between cashier height. The two tall cashiers used only one hand to bag regardless of being at the right- or left-side checkstand. One of them consistently held the bag with his left hand while filling it with his right hand, and the other cashier did the opposite. Neither of the tall cashiers used the bagging well at any of the checkstands, but placed the bag on the bagging platform itself, presumably to avoid the back bending that would result from lowering groceries to the bagging well. Because of their reversed arm movement and the consistency of the use of that one arm across all conditions by both subjects, the effects on the overall data would counterbalance and mask the differences seen in the other subjects.

In future studies, it may be beneficial to partition the task into subtasks so that each segment can be analyzed in relation to the research question, or data collection should focus solely on the activity of interest. In addition, sampling a larger number of subjects in each height category would be beneficial to either confirm or refute the trends seen in the two taller subjects we studied.

Comparisons with Other Occupations

Muscular activity and Muscular Rest

Our findings indicated that the mean number of gaps per minute below 5.0% of the reference voluntary electrical activity (RVE) for all subjects in this study was 1.0 gap/minute (0 to 7.6). Comparatively, office workers were found to have 7.2 (0.5 to 17) gaps/minute and office-building cleaners had 1.5 (0.2 to 13) gaps/minute in the trapezius muscle. Moreover, the percentage of time in muscular rest (< 3 % of RVE) while scanning, bagging, and doing cash register entries (with no breaks for money changing) was just 0.15% (0 – 6.8%). Comparatively, office workers were found to have 12.0% (0.0 to 32%) muscular rest and office-building cleaners 1.5 % (0.2 to 13%) muscular rest [34]. Other comparisons in the literature include the job tasks of metal can inspection and stacking at 1.0% (0.2 – 8.9) and CAD-workers at 2.9% (0.0 – 18.1)[35], and elderly subjects performing mouse tasks at 12.6% (0.0 – 43.4) muscular rest for the right trapezius and young subjects at 40.3% (9.8 – 78.0) ($p < 0.05$) for the same [36], although muscular rest in these tasks was defined as that which was below 0.5% EMG_{max}.

Overall, the results of the EMG gap analysis and percentage of muscular rest indicate that there is little muscular rest when performing grocery-checking duties (as performed in this study). This lack of gaps and muscular rest may be one explanation behind the documented high incidence of reported grocery store WMSDs in the state of Washington [1].

Two aspects of how our study was conducted may complicate comparisons between our results and the results from other studies: 1) our short data collection time (1 hour vs. ~7 hours) and, 2) the fact the work we measured was simulated work rather than actual work. Our short collection periods may not have accurately captured rest periods. The simulated work measurements probably typify a busy period for the cashiers when there are no breaks between customers.

Velocity of Wrist Movement

Velocity of wrist movement measured in this study is commensurate with wrist velocity values associated with work performed by groups identified as being at high risk for developing cumulative trauma disorders [3] [37][38] [6]. In a 1993 study, Marras and Schoenmarklin used OSHA 200 logs and worker medical records to study workers who were in low and high risk occupations for developing cumulative trauma disorders. They defined high risk jobs as jobs where injuries had a median incidence rate of 111.5 days per 200,000 worker-hours and an average of 18.4 lost workdays per injury. In comparison, low risk jobs had no injuries or lost workdays. In Marras and Schoenmarklin's 1993 study, the average wrist velocity for the high risk group was 25.9 and 42.4 degrees of wrist movement per second, in the radial/ulnar and flexion/extension planes respectively [38]. As seen in Figure 5, average wrist velocities in our study exceeded these levels. The mean wrist velocities for the combined left- and right-side checkstands were 31.1 and 50.9 degrees per second, in the radial/ulnar and flexion/extension planes respectively. The mean velocities for the tall and regular height checkstands were 32.1 and 53.3 degrees per second, in the radial/ulnar and flexion/extension planes respectively. A measure similar to velocity, the repetitiveness of wrist movement or the number of wrist posture changes per second (Hertz), was found in our study to be comparable to the cashier levels measured by Wells [12](Wells - mean of 2233 changes per hour; [redacted] – mean of 1854 changes per hour).

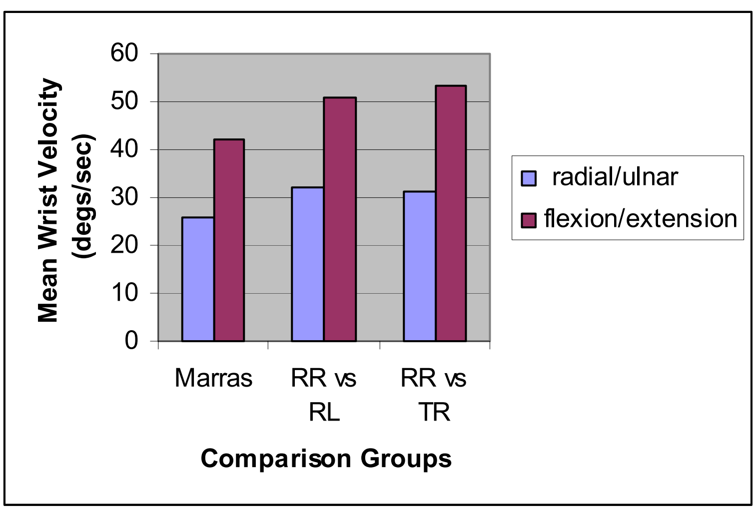

Figure 5. Mean Wrist Velocity in Comparison to Marras's High Risk Group

CONCLUSIONS

With right- and left-hand scan checkstands instituted to vary worker tasks and presumably to disperse muscle stress and repetitive movements, we found that scanning and bagging tasks are a very bi-manual activity with little difference in exposures between the right and left wrists (regardless of primary scanning hand), the right and left shoulder muscles, and the checkstand designs. Unlike this study where the checkers did both the scanning and bagging, greater differences between checkstand designs may be observed if there is a dedicated bagger. This is due to the bagging task having a counterbalancing effect with respect to activity of the dominant scanning hand. We continue to hypothesize that alternating the dominant scanning hand would be beneficial, which we hope to demonstrate in Phases 2 and 3 of this study.

With respect to the comparison between regular height and tall checkstands, rather than accommodating height differences with alterations in low back muscle activity as was expected, it appears that height accommodations were made in the upper arm and shoulder area by altering upper arm/shoulder position. Therefore, the taller checkstands appear to affect the loads in the upper arms and shoulders rather than the back.

Finally, grocery checking is an activity that does subject the checkers to high levels of musculoskeletal exposure. The wrist velocities measured in this study put the workers in a high risk category for developing musculoskeletal disorders and the amount of muscular rest measured in the shoulder muscles was low in comparison to other occupations.

In Phases 2 and 3, rather than using low back EMG activity, we plan on obtaining more accurate and detailed measurements of low back postures using inclinometers (Virtual Corset; MicroStrain, Inc.; Burlington, VT). These measurements could be expanded to the upper arm/shoulder as well. In addition, we plan on performing multi-hour measurements of cashiers to obtain a better idea of the distribution of the patterns of activity and inactivity occurring over the workday. We will also obtain self-reported measures of fatigue in order to quantify worker input regarding the potential benefits of alternating the dominant scanning hand. Furthermore, Phases 2 and 3 will be take place during actual cashiering tasks rather than simulated tasks.

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Appendix A. Comparison of wrist measurements from electrogoniometers between regular and tall (both right-side) checkstand designs.*

Wrist	Measure	Parameter	Checkstand Design Regular	Tall	Difference	p-value
Right	Flexion/ Extension	Position (°)	4.9 (0.5 to 11.8)	2.4 (-0.9 to 7.4)	2.5	0.16
		ROM (°)	58.4 (43.9 to 68.9)	62.4 (52.5 to 68.9)	-4.0	0.21
		Velocity (°/s)	51.6 (34.9 to 60.2)	54.0 (39.9 to 62.6)	-2.4	0.11
		Repetitiveness (Hz)	0.60 (0.54 to 0.69)	0.59 (0.47 to 0.65)	0.01	0.73
	Radial/Ulnar Deviation	Position (°)	3.3 (7.6 to -2.2)	3.3 (10.9 to -1.9)	0.0	0.98
		ROM (°)	37.6 (28.6 to 47.9)	38.7 (28.7 to 46.8)	-1.1	0.34
		Velocity (°/s)	31.8 (21.5 to 41.6)	33.0 (24.4 to 41.1)	-1.2	0.12
		Repetitiveness (Hz)	0.56 (0.45 to 0.64)	0.55 (0.41 to 0.60)	0.01	0.85
Left	Flexion/ Extension	Position (°)	9.1 (5.2 to 13.4)	7.4 (-0.9 to 16.0)	1.7	0.61
		ROM (°)	66.6 (49.2 to 78.6)	67.8 (58.1 to 83.7)	-1.2	0.67
		Velocity (°/s)	52.2 (36.8 to 65.7)	55.3 (47.6 to 66.7)	-3.1	0.18
		Repetitiveness (Hz)	0.55 (0.45 to 0.62)	0.55 (0.49 to 0.60)	0.0	0.91
	Radial/Ulnar Deviation	Position (°)	4.1 (8.7 to -2.8)	3.1 (10.8 to -1.9)	1.0	0.72
		ROM (°)	38.7 (26.9 to 47.5)	40.4 (29.1 to 49.6)	-1.7	0.09
		Velocity (°/s)	30.2 (24.8 to 36.8)	33.3 (26.7 to 38.7)	-3.1	0.03
		Repetitiveness (Hz)	0.53 (0.43 to 0.61)	0.55 (0.48 to 0.60)	-0.02	0.39

* Mean values, ranges in parentheses, differences, and significance of the differences (p-values). Positive flexion/extension and radial/ulnar deviation values indicate extension and ulnar deviation respectively. [n = 5]

Appendix B. Comparison of muscle activity levels grouped by muscle between regular height and tall checkstand designs.*

Muscle	Side	Parameter	Checkstand Design (%RVE) Regular	Tall	Difference (%RVE)	p-value
Trapezius	Left	10th Percentile	20.3 (12.4 to 36.1)	23.8 (16.5 to 39.4)	-3.5	0.06
		50th Percentile	42.1 (33.9 to 62.9)	46.9 (33.7 to 66.6)	-4.8	0.05
		90th Percentile	80.1 (61.4 to 110.5)	85.4 (63.5 to 109.8)	-4.4	0.23
		% Muscular Rest	0.1 (0 - 0.3)	0 (0 – 0)	0.1	0.18
		Gaps per minute	0.8 (0 to 1.9)	0.5 (0 to1.8)	0.3	0.20
	Right	10th Percentile	17.9 (4.6 to 35.2)	24.7 (7.0 to 47.8)	-6.8	0.02
		50th Percentile	37.2 (15.1 to 65.7)	46.9 (17.3 to 77.5)	-9.7	0.01
		90th Percentile	83.9 (32.4 to 126.2)	84.2 (35.0 to 125.3)	-0.3	0.86
		% Muscular Rest	1.5 (0 to 6.8)	0.4 (0 to 1.7)	1.1	0.33
		Gaps per minute	1.8 (0 to 5.9)	1.0 (0.1 to 3.9)	0.8	0.22
Erector Spinae	Left	10th Percentile	34.1 (22.2 to 55.7)	33.9 (22.6 to 55.5)	0.2	0.94
		50th Percentile	63.3 (37.2 to 85.1)	61.1 (35.5 to 87.4)	2.2	0.51
		90th Percentile	120.0 (58.1 to 166.4)	110.0 (53.4 to 155.2)	10.0	0.08
	Right	10th Percentile	43.3 (15.3 to 58.4)	46.3 (30.0 to 68.3)	-3.0	0.55
		50th Percentile	79.1 (46.7 to 102.8)	78.6 (56.5 to 99.3)	0.5	0.91
		90th Percentile	148.4 (90.9 to 216.2)	143.4 (80.1 to 188.4)	5.0	0.57

* Mean values, ranges in parentheses, differences, and significance of the differences (p-values) are presented; 10th, 50th, and 90th percentiles are %RVE. [n = 5]

Appendix C. Comparison of wrist measurements from electrogoniometers between right- and left-side (both regular height) checkstand designs.*

Wrist	Measure	Parameter	Checkstand Design		Difference	p-value
			Right	**Left**		
Right	**Flexion/ Extension**	**Position (°)**	4.9 (0.5 to 11.8)	7.1 (3.9 to 12.2)	-2.1	0.36
		ROM (°)	58.4 (43.8 to 68.9)	61.4 (53.9 to 67.6)	-3.0	0.51
		Velocity (°/s)	51.6 (34.9 to 60.2)	50.5 (35.3 to 56.4)	1.1	0.17
		Repetitiveness (Hz)	0.60 (0.54 to 0.69)	0.56 (0.46 to 0.61)	0.04	0.14
	Radial/Ulnar Deviation	**Position (°)**	3.3 (7.6 to -2.2)	2.2 (8.7 to -4.4)	1.1	0.06
		ROM (°)	37.6 (28.6 to 47.9)	40.8 (34.6 to 46.4)	-3.2	0.19
		Velocity (°/s)	31.8 (21.5 to 41.6)	32.0 (22.9 to 37.2)	-0.2	0.78
		Repetitiveness (Hz)	0.56 (0.45 to 0.64)	0.53 (0.45 to 0.60)	0.03	0.30
Left	**Flexion/ Extension**	**Position (°)**	9.1 (5.2 to 13.4)	7.0 (0.4 to 13.3)	2.1	0.25
		ROM (°)	66.6 (49.2 to 78.6)	66.8 (51.2 to 79.0)	-0.2	0.20
		Velocity (°/s)	52.2 (36.8 to 65.7)	49.3 (33.9 to 63.2)	2.9	0.91
		Repetitiveness (Hz)	0.55 (0.45 to 0.62)	0.49 (0.42 - 0.57)	0.06	0.09
	Radial/Ulnar Deviation	**Position (°)**	4.1 (8.7 to -2.8)	6.3 (13.6 to -3.2)	-2.2	0.58
		ROM (°)	38.7 (26.9 to 47.6)	41.8 (33.9 to1.7)	-3.1	0.03
		Velocity (°/s)	30.2 (24.8 to 36.8)	30.7 (23.8 to8.1)	-0.5	0.39
		Repetitiveness (Hz)	0.53 (0.43 to 0.61)	0.48 (0.41 to 0.56)	0.05	0.22

* Mean values, ranges in parentheses, differences and significance of the differences (p-values). Positive flexion/extension and radial/ulnar deviation values indicate extension and ulnar deviation respectively. [n = 6]

Appendix D. Comparison of muscle activity levels grouped by muscle between right- and left-side checkstand designs.*

Muscle	Side	Parameter	Checkstand Design (%RVE) Right	Checkstand Design (%RVE) Left	Difference (%RVE)	p-value
Trapezius	Left	**10th Percentile**	20.3 (12.4 to 36.1)	22.1 (10.2 to 46.6)	-1.8	0.47
		50th Percentile	42.1 (33.9 to 62.9)	42.4 (30.6 to 65.9)	-.3	0.40
		90th Percentile	80.1 (61.4 to 110.5)	75.7 (58.9 to 93.8)	4.4	0.28
		% Muscular Rest	0.1 (0 to 0.3)	0.3 (0 to 1.2)	-0.2	0.23
		Gaps per minute	0.8 (0 to 1.9)	0.9 (0.1 to 1.8)	-0.1	0.52
	Right	**10th Percentile**	17.9 (4.6 to 35.2)	19.2 (8.4 to 32.6)	-1.3	0.46
		50th Percentile	37.2 (15.1 to 65.7)	42.8 (19.5 to 63.3)	-5.6	0.29
		90th Percentile	83.9 (32.4 to 126.2)	87.8 (38.0 to 118.6)	-3.9	0.69
		% Muscular Rest	1.5 (0 to 6.8)	0.8 (0.187 to 2.8)	0.7	0.45
		Gaps per minute	1.8 (0 to 5.9)	1.1 (0.3 to 2.7)	0.7	0.45
Erector Spinae	Left	**10th Percentile**	34.1 (22.2 to 55.7)	33.7 (19.5 to 51.7)	0.4	0.55
		50th Percentile	63.3 (37.2 to 85.1)	65.0 (43.4 to 81.8)	-1.7	0.26
		90th Percentile	120.0 (58.1 to 166.4)	126.3 (74.0 to 159.6)	-6.3	0.09
	Right	**10th Percentile**	43.3 (15.3 to 58.4)	44.3 (20.2 to 67.0)	-1.0	0.32
		50th Percentile	79.1 (46.7 to 102.8)	78.7 (55.1 to 104.4)	0.4	0.08
		90th Percentile	148.4 (90.9 to 216.2)	133.6 (90.2 to 176.3)	14.8	0.23

*Mean values, ranges in parentheses, differences, and significance of the differences (p-values) are presented; 10th, 50th, and 90th percentiles are %RVE. [n = 6]