Swine Processing Line Speed Evaluation Study

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List of Terms and Abbreviations

ACGIH: American Conference of Governmental Industrial Hygiene

APDF: Amplitude probability distribution function

APDF 50: mean muscle activity defined as the %MVC someone is at or below 50% of the time

APDF 90: peak muscle activity defined as the %MVC someone is at or below 90% of the time

95% CI: 95% confidence interval

BLS: Bureau of Labor Statistics

CTS: Carpal tunnel syndrome

Evisceration Line Speed: the number of hogs per hour being eviscerated, as reported by each company to the USDA

FSIS: Food Safety and Inspection Service

GAO: Government Accountability Office

HA TLV: Hand Activity Threshold Limit Value (ACGIH)

HPH: Head per hour

Job-Specific Line Speed: the number of shackles, gambrels, spikes or hoops per minute measured on an individual worker level at the time they were measured

Job-Specific Staffing Level: the number of workers performing the same job on the same line

MSD: Musculoskeletal disorder

%MVC: percent of maximum voluntary contraction

NPF: Normalized peak force defined as the %MVC normalized to a 0 to 10 scale

OR: Odds Ratio

PAA: Peracetic acid

PFI: Peak Force Index

PFI-TLV score: Peak Force Index Threshold Limit Value

Piece Rate: The number of hogs or pieces of a hog that a worker handles per minute

RSI: Revised Strain Index

TLT: Time Limited Trial

TLV: Threshold Limit Value

UCB: University of California, Berkeley

UCSF: University of California, San Francisco

ULLF: Upper Limb Localized Fatigue

USDA: United States Department of Agriculture

Executive Summary

The USDA Food Safety and Inspection Service (FSIS) contracted with a research team from the University of California, San Francisco, (UCSF) to study the impact of evisceration line speed on worker safety in swine processing establishments. The scope of work was to "assist the FSIS in assessing the relationship between evisceration line speed in young chicken and swine slaughter establishments and the scope, magnitude, and factors that influence worker safety and health risks for establishment employees impacted by the speed of the slaughter line." The study team evaluated the impact of evisceration line speed on work-related musculoskeletal disorders (MSDs) and antimicrobial-related respiratory symptoms. This report summarizes the findings for swine processing establishments.

After a series of initial visits to six New Swine Inspection System (NSIS) establishments between April and August 2023, the study team conducted the Swine Processing Line Speed Evaluation Study between July 2024 and January 2025. The study team enrolled 574 workers and conducted surveys, medical interviews, and measurements of ergonomic exposure and airborne peracetic acid (PAA) concentrations at six establishments. The establishments operated at over a range of evisceration line speeds (Head Per Hour, HPH). Data were collected from workers who performed 78 jobs in four processing areas (Front End, Main Chain, Offal, Cut Floor) while establishments operated for several days at non-Time Limited Trial (non-TLT) evisceration line speeds (i.e., 1,106 HPH) and for several days at their Time Limited Trial (TLT) evisceration line speeds (i.e., > 1,106 HPH). In this report, these evisceration line speeds will be referred to as the "non-TLT Line Speed" and the "TLT Line Speed," respectively. Since establishments operated over a range of TLT Line Speeds (up to 300 HPH greater than non-TLT Line Speed), the results are presented in units of MSD risk increase per 100 HPH increase in evisceration line speed. During each of the two data collection periods (non-TLT line speed and TLT line speed) establishments were free to change staffing levels according to the evisceration line speed at which they were operating. Therefore, piece rate, or the number of hog parts handled by a worker in units per minute (unit/min), was also quantified to provide an accurate measurement of individual workload given differences in evisceration line speeds and staffing levels. To understand the effect of changes in evisceration line speed and staffing levels, the associations between piece rate and MSD risk were also investigated.

Key Findings

- 46% of evaluated workers across all establishments were at high risk (i.e., PFI-TLV score > 1.0) for musculoskeletal disorders (MSDs).
- Piece rate, *i.e.*, the number of hog parts handled per minute by a worker, was associated with MSD risk.
- The effect of evisceration line speed increase on MSD risk varied between establishments.
- For one establishment, evisceration line speed was associated with a statistically significant *increase* in MSD risk, and for another establishment evisceration line speed was associated with a statistically significant *decrease* in MSD risk. The remaining four establishments had null associations.
- Over 42% of workers across all establishments reported moderate to severe upper extremity pain during the 12 months prior to the site visit.
- Airborne PAA concentrations were generally below the recommended ACGIH Short Term Exposure Limit of 0.4 ppm in all establishments.

Overall, 46.1% of evaluated workers were at high risk for MSDs (i.e., PFI-TLV score >1.0) in establishments operating at the TLT Line Speed (Section 5.3.).[1]

- Across establishments, between 21.8% and 64.4% of workers exceeded a PFI-TLV score of 1.0 (Table 5.4.1).

There was a larger increase in the change in PFI-TLV score from the non-TLT to TLT Line Speed among establishments operating at a TLT Line Speed ≥ 1,300 HPH compared to establishments operating at a TLT Line Speed <1,300 HPH (Table 5.3.2.C.).

The effect of TLT Line Speed on MSD risk varied across the six establishments (Section 5.4.)

- At one establishment, TLT Line Speed was associated with *greater* median MSD risk (i.e., higher PFI-TLV score) compared to the non-TLT Line Speed. Conversely, at another establishment, TLT Line Speed was associated with *lower* median MSD risk. At the four remaining establishments, TLT Line Speed was not associated with MSD risk (Table 5.4.2.A-5.4.2.B).

[1] The primary metric of upper extremity musculoskeletal disorder risk was the ACGIH TLV for Hand Activity *Peak Force Index Threshold Limit Value* (PFI-TLV score) score. A PFI-TLV score score greater than 1.0 was the threshold used to define unacceptably elevated risk (also referred to as “high risk”) of upper extremity disorders in this study. For more information about the PFI-TLV score score, see Section 3.1

- At one establishment, TLT speed was associated with a statistically significant *increase* in the odds of PFI-TLV score >1.0 compared to the non-TLT Line Speed. Conversely, at one other establishment, TLT Line Speed was associated with a statistically significant *decrease* in the odds of PFI-TLV score >1.0. Non-statistically significant increases or decreases in the odds of PFI-TLV score >1.0 were observed at the other four establishments (Table 5.4.3.A-5.4.3.B).

When comparing line speed condition (non-TLT Line Speed versus TLT Line Speed), the number of workers who changed from low MSD risk (PFI-TLV Score≤1.0) to high MSD risk (PFI-TLV score>1.0), and vice versa, varied by establishment (Table 5.4.3.C).

- At one establishment, 3% of workers experienced a *decreased* MSD risk at the TLT Line Speed while 26.9% of workers experienced an *increased* MSD risk at the TLT Line Speed, in comparison to the non-TLT Line Speed.
- In contrast, at another establishment, operating at a similar TLT Line Speed, 23.5% of workers experienced a *decreased* MSD risk at the TLT Line Speed while 8.6% of workers experienced an *increased* MSD risk at the TLT Line Speed in comparison to the non-TLT Line Speed.

Piece rate, *i.e.*, the number of hog parts handled per minute by a worker, was associated with MSD risk.

- Overall, there was a statistically significant 1% increase in PFI-TLV score per each one unit/ minute increase in piece rate (Table 5.6.2.A. - 5.6.2.B).
- Across all establishments, as piece rate increased by 1 unit per minute, there was a 7% increase in odds of being at risk for MSDs (PFI-TLV > 1.0). These odds were similar at establishments operating at a TLT Line Speed <1,300 HPH and ≥ 1,300 HPH (Tables 5.6.3.A-5.6.3.B).

43% of workers, across all establishments, reported experiencing moderate to severe upper extremity pain during the 12-month period prior to the site visit (Section 5.11).

- Across all establishments, a statistically significant increase of 31% in the odds of experiencing moderate to severe upper extremity pain per 100 HPH increase in TLT Line Speed was observed (Table 5.11.1.A.).

One-third of workers who experienced pain did not report it to their company. Among those who did report their pain, one-third received prolonged (>2 weeks) first-aid care at their establishment (Table 5.11.3).

Overall, airborne PAA concentrations were well controlled across the five establishments that used it as an antimicrobial intervention (Table 5.10.2).

Respiratory symptoms were reported by 6% of workers and were not higher when establishments operated at TLT Line Speeds (Table 5.11.6.A).

Conclusions

A key finding of this study was that the association between evisceration line speed and MSD risk varied by establishment. Increased evisceration line speed *increased* the risk of worker injury at one establishment, and importantly, increased evisceration line speed also *decreased* the risk of worker injury at a different establishment. Although simultaneously increasing line speed and reducing MSD risk was possible, it was observed at only one of six establishments. Notably, this establishment had relatively low mean MSD risk (PFI-TLV scores) and the lowest average piece rates in most processing areas. Piece rate, a measure of work pace that accounts for job-specific line speed and staffing levels, was associated with a statistically significant increase in risk of injury across *all* establishments and was a better indicator of MSD risk than evisceration line speed.

Importantly, nearly half of the swine workers evaluated were at increased risk of injury when their establishments operated at the TLT Line Speed. Of those, one-third reported that their pain made activities outside of work more challenging and nearly one-third considered changing or quitting their job because of their pain. Further, one-third of workers with pain did not report their pain to their company indicating substantial underreporting. Among those who did report their pain and received first-aid treatment, one-third received first-aid treatment for more than two weeks.

Recommendations

Swine processing establishments should mitigate MSD risk by fully implementing ergonomic program guidelines for meat packing establishments published by the US Department of Labor (US DOL, 1993; US DOL, 2013) and the National Institute of Occupational Safety and Health (NIOSH, 20204; HHE 2021-0117-3397). We also recommend continuous assessment of ergonomic and antimicrobial exposure mitigation, MSD prevention, and medical management effectiveness, coupled with ongoing program modification and improvement.

Job-specific line speed and staffing levels are important drivers of MSD risk. All establishments, regardless of current or anticipated future increased line speed, can mitigate MSD risk by increasing job-specific staffing levels, decreasing job-specific line speeds, or both, to ensure a PFI-TLV score ≤1.0. Therefore, in addition to the general guidelines published by the US DOL, we also recommend that swine processing establishments:

- Reduce the PFI-TLV score to ≤ 1.0 for all swine processing jobs.
- Implement established meat packing best practices to reduce hand exertion force to achieve a PFI-TLV score of ≤1.0.
- Implement medical management best practices, including early reporting of MSD symptoms, delivery of appropriate and timely care beyond first aid, and the use of medical monitoring to identify ongoing hazards.

Establishments should continue to monitor and maintain airborne PAA concentrations to levels below the ACGIH STEL of 0.4 ppm by reducing the use of PAA to the minimum amount necessary, enclosing sources of airborne antimicrobial, and improving ventilation.

1. Background

1.1 Request for Proposal

On October 1, 2019, the Food Safety and Inspection Service (FSIS) of the US Department of Agriculture (USDA) published the final rule, “Modernization of Swine Slaughter Inspection” (84 Fed. Reg. 52300), that established the optional New Swine Slaughter Inspection System (NSIS) for market hog establishments meeting specified criteria. The USDA rule eliminated maximum line speeds for NSIS establishments, and authorized those establishments to set their line speeds based on their ability to maintain process control to prevent fecal contamination and meet microbial performance measures for carcasses during slaughter operations. In response to a legal challenge, a court order required that all NSIS establishments operate at line speeds not greater than 1,106 head per hour (HPH) as of June 30, 2021.

The FSIS, in collaboration with the Occupational Safety and Health Administration (OSHA), subsequently allowed six establishments to operate under a “time-limited trial” (TLT) at evisceration line speeds >1,106 HPH. During the TLT, the USDA required the establishments to submit worker safety and health data including ergonomic evaluations, injury reports, and staffing levels. During this time, FSIS contracted with the study team to assess the impact of evisceration line speeds >1,106 HPH on work-related musculoskeletal disorders and antimicrobial-related respiratory symptoms.

1.2 Ergonomic Hazards and Musculoskeletal Disorders

Scientific evidence from published, peer-reviewed workplace and laboratory studies demonstrates conclusively that workplace bodily exposures to physical work factors, such as high rates of repetitive movements and exertion of high physical forces, especially while in non-neutral postures, causes musculoskeletal pain and MSDs (NRC, 2001; Hagberg et al., 2012; Bernard et al., 1997). Specifically, disorders of the hand, wrist, and forearm, such as wrist or elbow tendonitis and carpal tunnel syndrome, have been associated with work involving repeated high-force pinching or gripping, working with sustained non-neutral hand and wrist postures, working with vibrating hand tools, and working at high repetition rates (Harris-Adamson et al., 2015; Descatha et al., 2016; Bernard et al., 1997). Further, epidemiological studies have shown an exposure-response relationship between biomechanical exposures and MSDs. This means that as levels of biomechanical exposures increase, the risk of musculoskeletal pain and injury also increases. Additionally, disorders of the lower back, such as low back pain, spinal nerve impingements, and sciatica, are associated with repeated lifting of loads, especially loads that are heavy or low to the ground (Bernard et al., 1997; Heneweer et al., 2011; Kuijer et al., 2018).

Increased work pace, particularly with inadequate recovery periods, has been associated with increased localized fatigue, risk of musculoskeletal disorders, and prevalence of pain. The pace of work is defined by repetition rate and duty cycle, which is used to evaluate work-recovery cycles or patterns. A study on increased work pace and lack of recovery time, commonly experienced with “just in time” manufacturing, was associated with increased musculoskeletal symptoms (Koukoulaki et al., 2014). A study by Lin and colleagues (2012) showed that a fast work pace during a gripping task increased the average exerted grip forces, and as fatigue ensued, there was a reduction in force (i.e., reduced strength). Providing adequate rest breaks reduced the perceived exertion of the task. However, brief pauses may be insufficient to prevent pain and fatigue if the pace is too fast. A study by

Januario and colleagues (2018) found that with a quick work pace, pauses every 2 minutes did not alter muscle activity or rate of perceived exertion.

1.3 Risk Assessment for Work-Related Musculoskeletal Disorders (MSDs)

1.3.1 The ACGIH Hand Activity Threshold Limit Value (HA TLV)

The ACGIH is a North American, non-governmental, non-profit organization that promulgates voluntary limits of workplace exposures, i.e., *Threshold Limit Values* (TLVs), for chemicals and physical agents (e.g., noise and lifting) intended to protect nearly all workers from adverse health effects. According to the ACGIH, "TLVs refer to...conditions under which it is believed that nearly *all* workers may be repeatedly exposed, day after day, over a working lifetime, without adverse health effects." (ACGIH, 2022). In form, the ACGIH TLVs are analogs to OSHA Permissible Exposure Limits (PELs) (ACGIH, 2022). In fact, the original OSHA PELs promulgated in 1971 were based on then-current ACGIH TLVs. Many industries in North America have adopted ACGIH TLVs as limits for exposures for which there are no OSHA PELs.

The ACGIH *Hand Activity TLV* (HA TLV) sets an upper workplace limit of exposure to repeated hand exertions to protect most workers from distal upper extremity (finger-hand-wrist-elbow) MSDs (ACGIH, 2022). The HA TLV is based on physiological, biomechanical, and epidemiological studies. The ACGIH HA TLV was designed to protect workers from injury or persistent pain.

Because both (i) forceful exertions of the hand and (ii) how such exertions are made over time contribute to the risk of distal upper extremity MSD, the ACGIH HA TLV requires the use of both exposure characteristics to calculate the final TLV value. Specifically, the TLV uses *Normalized Peak Force* (NPF) to quantify forceful exertion applied by the hand and *Hand Activity Level* (HAL) to quantify the timing of such exertions. Increased NPF and increased HAL both contribute to increased MSD risk. To maintain a target threshold of MSD risk, increased NPF must be accompanied by decreased HAL and, conversely, increased HAL must be accompanied by decreased NPF. Stated another way, for any given HAL, there is an upper bound of permissible NPF that defines the maximum acceptable combination of hand activity and forceful exertion (i.e., the HA TLV). Given a higher HAL, the upper bound of permissible NPF is lower (and vice-versa). The operationalization of this approach leading to the calculation of the *Peak Force Index Threshold Limit Value* (PFI-TLV) score is provided in the following paragraph.

The PFI-TLV score is calculated as the ratio of a worker's observed NPF to the maximum NPF permitted by the HA TLV for that worker's observed HAL. For example, at the HA TLV, a HAL of 3.0 has a maximum permissible NPF of 3.9 (Figure 1, Page 185, ACGIH 2022). If the observed NPF were 7.8, then the Peak Force Index (PFI-TLV) score would be 2.0, meaning that the NPF exerted by a worker was two times greater than the maximum allowable NPF at a HAL of 3.0. As noted above, a PFI-TLV score of 1.0 or less poses an acceptable MSD risk, and a PFI-TLV score greater than 1.0 poses an unacceptable MSD risk (ACGIH, 2022). Although jobs should be designed to be under the PFI-AL, a score that indicates moderate risk for most workers, the PFI-TLV score represents the maximum acceptable risk[2].

The results of a recently published study help put the meaning of the observed PFI-TLV score into

[2] In addition to the PFI-TLV score, the ACGIH HA TLV also defines a more protective Peak Force Index Action Limit (PFI-AL). While all jobs should be designed to ensure exposures below the PFI-TLV score of 1.0 to minimize the risk of MSDs, protection of more susceptible workers is achieved by designing jobs to ensure exposure below the PFI-AL.

context [Yung et al., 2019]. Specifically, the study's authors explored the relationship between the PFI-TLV score and carpal tunnel syndrome (an upper extremity MSD) risk among 4,321 manufacturing workers. Workers performing tasks with a PFI-TLV score greater than 1.0 (i.e., an exposure level greater than the TLV) had twice the risk of carpal tunnel syndrome than workers in the lowest exposure strata. This means that carpal tunnel syndrome occurred twice as often among workers performing jobs with a PFI-TLV score greater than 1.0 than it did among workers in the lowest exposure strata. Additional analyses of an international cohort (that included the participants reported by Yung et al. (2019)) provide additional detail of the exposure-response associations (Table 1.3.1, Harris-Adamson, et al., paper under review).

Table 1.3.1. Exposure-response associations between PFI-TLV scores and relative risk (Hazard Ratio) of carpal tunnel syndrome

PFI-TLV score	Hazard Ratio (95%CI)	Interpretation
0.5	1.5 (0.9-2.4)	Acceptable risk - provide surveillance
1.0	2.0 (1.1-4.1)	Maximum acceptable risk
1.5	2.8 (1.6-5.1)	Unacceptable risk
2.0	3.2 (1.8-5.7)	Unacceptable risk

1.3.2. Revised NIOSH Lifting Equation (RNLE) limits

The RNLE was published in 1991 to identify safe and unsafe lifts based on lift characteristics. In this context, *safe* and *unsafe* refer to the risk of a low back MSD resulting from the lifting activity. Inputs to the equation include the locations of the hands during a lift, the coupling of the hands to the item lifted, the asymmetry (twisting of the torso) of the lift, the weight lifted, and the frequency of the lift. The lifting equation calculation produces a numerical *Lifting Index.* A Lifting Index <1.0 indicates that most workers could safely perform the lift, whereas a Lift Index >1.0 indicates some workers would be at risk for low back MSDs. The higher the LI value, the higher the risk of low back pain or injuries to workers.

For lifting tasks with varying lifting conditions, the Composite Lifting Index (CLI) was developed (Application Manual for the Revised NIOSH Lifting Equation, 2021). CLI methods are used in this report. The CLI is an approved hazard assessment method by the International Standards Organization (ISO 11228-1, 2021), and it is widely used by North American industries and safety professionals.

Table 1.3.2. Risk implications for “low back pain > 7 days or low back injury” by Lifting Index (LI and CLI) value (Fox et al., 2019)

Lifting Index Value	Risk Implications	Recommended Actions
< 1.0	Very Low	None
1.0 to 1.5	Low	Attention to low frequency/high load conditions
1.5 to 2.0	Moderate	Redesign tasks according to priorities
> 2.0	High	Changes to the task should be a high priority

The CLI calculations also output the Frequency Independent Lift Index (FILI). The FILI provides a lift index based only on the biomechanical criterion of the lifts, not on the frequency of lifts. FILI scores help evaluate the risk due solely to the hazard created by the body posture at the origin and destination of the lifts and the weight of the lifts, ignoring the frequency of the lifting activity.

1.4 Risk Assessment of MSDs in Swine Processing

Ergonomic risk factors with high rates of injuries and MSDs in meatpacking have been recognized for decades (Viikari-Juntura, 1983; Kurppa et al., 1991; Frost et al., 1998; Gorsche,1998; Marklin, 1998; Gorsche, 1999; Campbell, 1999; McGorry et al., 2003; Dempsey, 2004; Lander, 2010; Petit Le Manac'h et al., 2011; Vergara, 2012; Sundstrup, 2014; Kyeremateng-Amoah, 2014; Rowland, 2021). One of the first published studies in a U.S. pork processing plant (Moore,1994) showed a strong association between ergonomic risk factors, particularly force and awkward posture, and their research in the pork processing industry contributed to the development of ergonomic tools, such as the Strain Index, that include several measurements of speed of work, force, and awkward posture (Moore, 1995).

In 1988, the National Institute for Occupational Safety and Health (NIOSH) conducted a Health Hazard evaluation in a beef and pork processing plant to assess ergonomic risk factors for WRMSDs (NIOSH, 1989). NIOSH found high rates of WRMSD associated with jobs that were determined to have high ergonomic risk factors, including high force and repetitiveness. The departments with the highest number of WRMSDs and ergonomic risks were Hog Kill/Pork By, Ham Bone, Pork Cut, Beef Fab, and Pork Trim. NIOSH made many recommendations to improve the company's ergonomic program and reduce the job demands of high repetition, high force, and extreme postures.

OSHA published ergonomic guidelines for meatpacking plants in 1990 (updated 1993), which detailed the following key components: written program, management commitment, employee involvement, worksite analysis, prevention and control measures, medical management, and worker/supervisor/management training (OSHA, 1993). At that same time, NIOSH embarked on participatory ergonomic demonstration projects at three meatpacking plants (NIOSH, 1994). NIOSH noted that the projects with strong management commitment, employee participation, and in-house expertise were the most successful. Other essential components were ergonomic training of all staff, review of injury and illness data by all ergonomics team members, providing time for the teams to meet and function, and sharing information on results with the workforce. However, there has been no comprehensive follow-up to evaluate the incorporation of NIOSH and OSHA's recommendations in the meat processing industry's ergonomic programs.

Moore conducted one of the three participatory ergonomic projects described in the 1994 NIOSH report and explained their approach and findings in subsequent publications (Moore, 1996; Moore, 1997; Moore, 1998). In the 1997 paper, Moore described the ergonomic evaluations of three jobs: Pulling Lard, Snatching Guts, and Pulling Ribs. Several possible solutions to the ergonomic risks of these three jobs were posed by the ergonomics teams, including an automatic lard puller, a redesign of the snatching guts job to eliminate forceful grasping and lifting, and an additional worker added to the pulling rib job. Several solutions were implemented for the three jobs, but the researchers did not have supported time to evaluate the success of the ergonomic interventions. However, Moore presented an overall evaluation of the company's participatory ergonomics program through a chronologic analysis of injury and illness data and concluded that the company's ergonomic program had a positive effect in decreasing serious injuries and WRMSDs (Moore 1998).

The safety culture in meatpacking establishments has also been identified as a problem. Focus groups of Hispanic/Latino workers described a culture where companies cared more about production than people, they felt powerless in improving their situation, and where responsibility for safety was shifted to the individual workers. Workers reported many barriers to prevention and care (Ramos, 2021b; Ramos 2021b), and trust in occupational health services was low (Rowland, 2024). These findings confirm a report by the Government Accountability Office (GAO) that reviewed progress in health and safety for poultry and meatpacking workers (GAO, 2016). The GAO report concluded that underreporting of injuries by workers and employers may lead to inaccurate data on injuries, particularly MSDs. It directed the Department of Labor and OSHA to develop better data collection methods. The GAO found that, according to BLS, injury and illness rates in this industry "declined from an estimated 9.8 cases per 100 full-time workers in calendar year 2004 to 5.7 cases in 2013". However, the GAO noted that "these rates continued to be higher than rates for manufacturing overall," and meatpacking workers had higher injury and illness rates than poultry workers. GAO further noted that ergonomic risk factors, such as overexertion and repetitive motion, were the most frequent cause of serious injuries requiring days away from work. In a survey of Nebraska beef slaughterhouse workers at one establishment, the self-reported incidence rate of severe injury was more than twice the official industry estimates (Leiber, 2017).

The most recent study of MSD risk in pork processing establishments was published by NIOSH (NIOSH, 2024). At the time of the data collection in July 2022, the line on the harvesting side operated at an average speed of 1100 hogs per hour. More than half of the job tasks (61%) had hand activity levels and force at or above the ACGIH threshold limit value, and about one-third (32%) of harvesting side employees had experienced work-related symptoms of upper body musculoskeletal disorders in the prior 12 months. NIOSH provided detailed recommendations for ergonomic and medical management programs to mitigate MSD risk.

1.5. Work Organizational Stress

Extended work shifts with mandatory overtime can increase exhaustion, pain, and injuries. A study of 1834 workers found that long shifts/overtime work increased biomechanical stressors and self-reported exhaustion (Rosenblum et al., 2014; Bao et al., 2014). A systematic review of shift and long work hours found that both had a detrimental effect on safety; work shifts longer than 8 hours per day increased the risk of accidents; the risk of accidents was twice as high among those working 12 hours per day compared to those working 8 hours (Wagstaff & Sigstad, 2011).

Workplace psychosocial stress has also been associated with pain and musculoskeletal disorders (Nahit et al., 2001). A recent systematic review found strong evidence linking high job demands, high job strain, high effort/reward imbalance, and low social support to an increased risk of musculoskeletal disorders and absenteeism (Taibi et al., 2021).

1.6 Underreporting of MSD Pain and Injury may Result in an Underestimate of MSD Incidence and Prevalence

Several studies have highlighted the underreporting of injuries by workers in the meat and poultry industry to their employers (GAO, 2005; Quandt, 2006; GAO, 2016). The GAO 2016 report highlighted the challenges of gathering accurate data on injury and illness rates for meat and poultry workers due to underreporting and inadequate data collection. Factors cited by the GAO that contributed to underreporting (i) by workers included the vulnerable status of undocumented or foreign-born workers and fear of job loss and (ii) by employers included concerns about potential costs. The OSHA 300 Log, which employers use to respond to the BLS Survey of Occupational Injury and Illness, also does not specifically classify recorded injuries or illnesses as MSDs.

1.7 Mitigation of Risk of MSDs from Biomechanical Exposures

The hazards of manually intensive work can be mitigated by implementing engineering interventions guided by ergonomic design principles. *Ergonomics,* sometimes also called *human factors engineering,* is the study of the physical and cognitive demands of work to ensure a safe and productive workplace for employees (Harris-Adamson & Rempel, 2021). In contrast to the industrial engineering approach that measures time and motion t0 optimize and maintain worker productivity, ergonomics measures the physical demands of work to assess the risk of MSDs. Based on these measurements, ergonomics focuses on the design of the work environment, tools and equipment to reduce stress on the muscle, nerves, tendons and joints of workers. In fact, the risk of upper extremity MSDs due to excessive repetition and force at work has been known for more than three decades (Armstrong, 1987; Silverstein, 1987; Silverstein, 1991).

The first step in identifying interventions to protect workers from hazardous work is to conduct an ergonomic hazard evaluation. The ergonomic hazard evaluation characterizes interactions between workers and the work environment so that modifications to workstations, tools, equipment, and procedures performed by workers can be designed and implemented to mitigate hazardous exposures. The mitigation of hazardous exposures is the foundation of all occupational safety and health programs and is necessary for protecting the health and safety of working people.

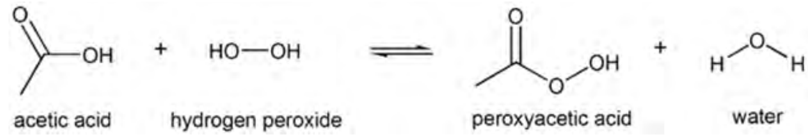
Workplace safety and health programs rely on ergonomics and established public health principles to reduce the risk and severity of work-related MSDs. Such programs typically involve (i) a review of existing injury data to identify tasks that place workers at high risk of injury, (ii) an ergonomic hazard evaluation of the high-risk tasks to identify the specific contributors (e.g., weights of items lifted, rate of lifting) to the hazard, and (iii) a redesign of the task, workstation, or tools to reduce the hazards. Successful safety and health programs require management support, training supervisors and employees on ergonomic principles, and assigning responsibilities for hazard analysis, engineering redesign, and intervention implementation to qualified ergonomists and engineers.

The *hierarchy of controls* is the guiding framework of nearly all modern hazard mitigation activities in the industry. According to the National Institute for Occupational Safety and Health (NIOSH) of the US Centers for Disease Control, "The hierarchy of controls is a way of determining which actions will best control exposures [to hazards in the workplace]. Implementing this hierarchy of controls can lower worker exposure and reduce the risk of illness or injury. The preferred order of action based on general effectiveness is (i) hazard elimination, (ii) substitution of a safer product or activity, (iii) engineering to reduce worker contact with the hazard, (iv) administrative controls (e.g., changes in the duration of time that a worker is exposed to the hazard), and (v) personal protective equipment." (NIOSH, 2022)

The National Safety Council states that the hierarchy of controls "is used to determine the most effective and protective ways to prevent exposure risks and places a higher priority on more protective engineering controls such as hazard ventilation, isolation, elimination, or substitution than administrative controls. Engineering controls are the first line of defense against workplace hazards whenever feasible. Such built-in protection, inherent in the design of a process, is preferable to a method that depends on continual human implementation or intervention." (NSC, 2021, p579).

1.8 Antimicrobial hazards and Pulmonary Symptoms in Swine Processing

Peracetic Acid (PAA) is a powerful oxidizing agent used as an antimicrobial processing aid in poultry and swine processing establishments. PAA is an organic peroxide that is flammable above 40.5°C (105°F) and has an explosion point of explosion point of 43.3°C (110°F). PAA formulations for antimicrobial intervention are an equilibrium mixture of PAA, hydrogen peroxide, and acetic acid.



The latest version of FSIS Directive 7120.1, "Safe and Suitable Ingredients Used in the Production of Meat, Poultry, and Egg Products," contains a list of PAA-containing substances and the concentrations that may be used for specific purposes in meat, poultry, and egg product establishments. PAA solutions are currently approved for use in PAA concentrations ranging from 50 to 2000 parts per million (ppm).

Vapor and aerosol PAA exposure has been associated with multiple adverse health outcomes in human populations, including lacrimation, mild to severe discomfort of mucous and nasal membranes, and irritation of mucous and nasal membranes (Pechacek, 2015). PAA exposure has also been associated with upper and lower respiratory tract symptoms, including wheezing, coughing, shortness of breath, and chest tightness (Blackley, 2023). Several case studies have found exposure to PAA may result in the development of occupational asthma (Cristofari-Marquand et al., 2007; Hawley et al., 2018; Walters et al., 2019).

OSHA has no specific standards for PAA. The National Institute for Occupational Safety and Health (NIOSH) proposed an Immediately Dangerous to Life and Health (IDLH) airborne concentration for PAA of 0.55 ppm in 2015. The American Conference of Governmental Hygienists (ACGIH) recommends a Threshold Limit Value (TLV) of 0.4 ppm as a 15-minute Short Term Exposure Limit (STEL). The California Occupational Safety and Health Administration (Cal/OSHA) has proposed a 15-minute STEL of 0.4 ppm and an 8-hour PEL of 0.15 ppm. The National Research Council Acute Exposure Guideline Levels (AEGL) for Hazardous Substances recommend an AEGL-1 of 0.17 ppm for non-disabling irritation and an AEGL-2 of 0.5 ppm for disabling irritation. The AEGLs represent a threshold level of effect after 10 minutes of exposure.

2. Study Planning

When the FSIS granted line speed waivers, establishments were not required to assess "baseline" ergonomic or PAA exposures before implementing higher evisceration line speeds. To our knowledge, no establishments have made such data available to the FSIS, making a "pre/post TLT" analysis impossible. Therefore, the Study team proposed to use a within-plant study design with the six TLT establishments evaluated on two occasions – once while running at a slower evisceration line speed (1,106 HPH) and once while running at a faster evisceration line speed (>1,106 HPH). This Phase 2 study was conducted between July and October 2024. At three of the establishments, employees had a collective bargaining agreement with the establishment designating the UFCW as their representative. Before each establishment visit, the PULSE team held separate video meetings with company corporate representatives, establishment managers, and UFCW representatives to explain the study and finalize logistical details. At each establishment, data collection occurred over three days each week, led by a senior occupational medicine professional, a senior ergonomist professional, and a senior industrial hygienist professional, and assisted by students and occupational medicine residents.

3. Specific Aims

The overall objective of this study was to evaluate the association between evisceration line speed and the risk of adverse health effects for swine processing workers. The study team addressed the following specific aims in this report, including:

Aim 1: Estimate the effect of evisceration line speed and piece rate on the *ACGIH Threshold Limit Value for Hand Activity PFI-TLV* score among workers in six establishments operating over a range of evisceration line speeds.

Aim 2: Estimate the effect of evisceration line speed and piece rate on the prevalence of moderate to severe *upper extremity* pain while controlling for covariates in six establishments operating over a range of evisceration line speeds.

Aim 3. Estimate the effect of evisceration line speed and exposure type on antimicrobial measurements in establishments operating over a range of evisceration line speeds.

Aim 4. Estimate the prevalence of respiratory symptoms among workers in six establishments operating at different evisceration line speeds.

Aim 5: Describe the reporting, first response, and medical management of work-related pain and injuries, including their impact on job performance and outside activities in evaluated establishments operating over a range of evisceration line speeds.

4. Methods

4.1. Study Design

This was a studyof swine processing workers employed by six swine slaughter TLT establishments and operating at > 1,106 HPH. Data were collected using cross-sectional observational methods and cross-over experimental methods. All establishments allowed the study team to enter the establishment for seven days (four days during Week 1 and three days during Week 2) and provided additional information on operations and injury prevention and management programs as requested by the investigators. Enrolled establishments operated at 1,106 during the non-TLT Line Speed week and, depending on the establishment, up to 350 HPH faster during the TLT Line Speed week. Establishment management was requested to maintain typical staffing levels during the non-TLT Line Speed and TLT Line Speed weeks. The order of the weeks was randomized at each establishment.

4.2. Job and Participant Selection

Because differential effects of line speed by job on (i) injury risk measures and (ii) symptom outcomes were possible, it was necessary to sample workers at each establishment by job performed. A job was defined as one or more standard tasks typically performed by an individual worker across a standard work shift. Jobs were chosen for evaluation based on biomechanical hazards observed during the Phase 1 establishment visits and the initial walk-through during Phase 2 establishment visits (see Appendix 1); a mix of jobs throughout the production process was included to fully evaluate the impact of evisceration line speed on processes upstream and downstream of evisceration. Jobs from shackling to the cut floor through packing were selected for inclusion in the study. Ultimately, jobs were categorized into four groups by area (Table 4.2.1). Packing and palletizing were evaluated at only one establishment that was observed to have a potentially high MSD risk for the low back; other establishments had engineering controls that eliminated or reduced MSD risk from lifting while palletizing.

Workers over 18 years of age who performed one of the selected jobs during the establishment visits were chosen to participate in the study. Workers in training (as indicated by the company) were excluded from the study. Workers on both day and swing shifts were included if a swing shift existed. Workers were provided with paid time off the line to participate in the study. The goal was to evaluate 100 workers at each establishment with a Work and Health Survey and an ergonomic assessment. Additionally, up to ten workers at each establishment were interviewed by a study team physician, the selection of which was triggered by the Work and Health Survey. Given a large number of jobs, approximately five workers per job were the maximum target for inclusion. If there were more than five workers in a particular job, workers were selected using a random number generator. Participants who rotated between two or more jobs were designated a “primary” job for data collection and a “secondary” job. Some participants were measured while performing their primary and secondary jobs, particularly if few people performed the secondary job.

After being pulled from the line, each worker met with a study team member who explained the study in detail before obtaining informed consent. Workers had a choice of not consenting at all, consenting to part of the study, or consenting to all parts of the study. For example, those who did not consent to be videotaped did not receive an ergonomic assessment and were exclusively surveyed. The participation proportion (participation rate) was calculated as the number of workers who agreed to participate in one or more data collection activities divided by the number of workers who were asked (recruited) to participate in the study. The Institutional Review Board approved this study at UCSF.

Table 4.2.1. Definition of line speed, piece rate, and staffing collected using video analysis by task

Job	Task	Line Speed	Piece Rate	Staffing
Front End (n=4)	Shackle Hog	Number of shackles on one line that pass by a fixed point, per minute	Number of hogs hung on shackles by one worker, per minute	Number of staff shackling/rolling/cutting/hanging on the same line
	Roll Hog	N/A (hogs transported on conveyer)	Number of hogs passing by one worker, per minute	
	Cut Tendon Gam Hog		Number of hogs cut/hung by one worker, per minute	
Main Chain (n=36)	Shave Hog Remove Stick Holes Mouth Wash Midsection Skinner Mark Hams Neck Break Drop Heads Cut Mouth Head Transfer Brisket Saw Bung Gun Open Hog C-Hook Pull Bung Gutter Steam VAC Split Aitch Backup Split Saw Kidney Pop Remove Kidney Middle Higher Trim Remove Tail Gallbladder Leaf Lard Gun Lard Puller Scrape Lard Remove Spinal Cord Hanging Tender Trim Neck Push Hogs	Number of hogs/hog-portions/trays on one line that pass by a fixed point, per minute	Number of hogs or hog-portions processed (i.e., pushed, shaved, cut, trimmed, popped, pulled, removed, etc.) by one worker, per minute	Number of staff performing the same job, working along the same the line
Offal Head (n=8)	Head Spike Mark Lips Round Head Temple Marker Mark Snouts Chisler	Number of spikes/rings on one line that pass by a fixed point, per minute	Number of hog-head-portions (e.g., head, jaw, pair of ears/cheeks, snout, tongue, etc.) processed (i.e., spiked, cut, trimmed, removed, etc.) by one worker, per minute	Number of staff performing the same job along the same line, or sharing the same flow of conveyed/binned product
	Remove Tongue Tongue Trim Trim Ears Remove Pate Meat Jaw Pull	N/A (product transported on a conveyer or in a bin)		

	Save Cheek Meat Trim Back Head			
	Trim Cheek Meat		Number of single cheeks trimmed by one worker, per minute	
	Hearts Feed Stomach Machine	Number of hooks/trays on one line that pass by a fixed point, per minute		
Viscera (n=11)	Stomach Opener Pepsin Pull Pancreas Save & Separate Rectum Separate Intestines Liver Hanger Remove Stomach Save Thyroid Casing Wheel Knife	N/A (product transported by conveyer/shoot/bin)	Number of hog-viscera-portions (e.g., heart, stomach, rectum, liver, etc.) processed (i.e., cut, removed, hung, etc.) by one worker, per minute	
Cut Floor Trim (n=11)	Ham Chop Saw Shoulder Chop Saw Remove Aitch Bone Remove Back Bone Neckbone Lifter Body Bone Pull Ribs Bone Butts Trim Butts Picnic Whiz Loin	N/A (product is delivered to worker via conveyor)	Number of portions (e.g., leg, rack of ribs, loin, etc.) processed (i.e., cut, trimmed, deboned, etc.) by one worker, per minute	Number of staff performing the same job while sharing the same flow of conveyed product
Package (n=4)	Bagger Cryovac Box Meat Palletizer	N/A (product is delivered to worker via conveyor)	Number of products (e.g., loin, rack of ribs, full box, etc.) handled (i.e., bagged, lifted, etc.) by one worker, per minute	

* For reporting purposes, one shackle or gambrel holds one hog

4.3. Work and Health Survey ("survey")

A survey was administered to participants by a trained study team member in a private room during work hours. The survey instrument was a structured electronic questionnaire designed to collect information about health outcomes and ergonomics hazards among swine processing workers. The survey included questions on demographics (age, gender, tenure at the establishment, and job title), work-related ergonomic hazards (perceived hand force), work organization (work schedule, overtime, line staffing, rotation), and discomfort and pain (self-reported musculoskeletal pain in various body regions, the severity of which was rated by the worker on a ten-point Likert scale). Work-related pain was defined as any pain or discomfort experienced during the past 12 months that was worse at work and lasted for more than one day. *Moderate to severe* work-related pain was defined as work-related pain that was assigned a pain severity rating of four or greater (on a ten-point scale). Feedback on survey content was solicited from multiple stakeholders, including union members and USDA staff prior to use in the study. The Work and Health Survey (see Appendix 2) was administered in the worker's language of choice by a study team member (USDA telephonic interpretation service).

4.4. Medical Interviews

To evaluate the impact of musculoskeletal pain and respiratory symptoms on work and non-work activities and to assess establishment responses to work-related pain and injury, standard questions were administered using a separate survey (the supplemental medical survey) to assess pain during the past 12 months, details of medical treatment of pain (first aid and/or medical), and impact on job and activities outside of work. The supplemental medical interview was administered by study team physicians.

4.5. Manager and Union Representative Interviews

Managers were interviewed to collect information about establishment operations and the injury prevention and treatment program. Interviews were conducted among (when available) establishment managers, operations managers, superintendents, line supervisors, safety program managers/coordinators, training program managers/coordinators, ergonomics program managers/coordinators, occupational health nurses, and other personnel involved with injury mitigation strategies (such as maintenance, knife sharpening). Union representatives were interviewed and worker safety agreements were reviewed, if applicable.

4.6. Ergonomic Assessment

After completing the survey, the study team placed wearable devices on one arm and videotaped while the worker performed their typical job for 10 minutes. Biomechanical exposure measurements included force, repetition, duty cycle, and wrist kinematics (posture and velocity). Exposures and risk for MSDs were evaluated at both TLT Line Speeds, and the differences within the person were assessed for statistical significance.

Piece rate, the number of hogs or pieces of a hog that a worker handles per minute (see Table 4.2.1), was also included as the exposure variable of interest in statistical models. Piece rate incorporates job-specific line speed and job-specific staffing levels and is an individual measure of workload. Since the piece rate varies for each job, and there were many jobs with fewer workers per job, the impact of changes in piece rate on PFI-TLV scores was performed for a small number of jobs where the mean PFI-TLV score was >1.0, and there were more than 15 workers across the six establishments.

4.2.1. Exposure measurement

Hand exertion force was estimated by measuring forearm muscle activity using surface electromyography (Mindrove, Kft., Győr, Hungary) and summarized by median and peak values calculated as the 50^{th} and 90^{th} percentiles on an amplitude probability distribution function (APDF). Wrist posture and motion (kinematics) were measured using a twin-axis electronic goniometer (Biometrics, Ltd., Cwmfelinfach, Wales) and summarized by median wrist angle in the sagittal plane. Specifically, median wrist flexion and extension angles were used to generate a Revised Strain Index (see Appendix 3). Median and peak sagittal plane velocity values were calculated as the 50^{th} and 90^{th} percentiles on an amplitude probability distribution function (APDF 50 and APDF 90). Repetition rate (frequency of exertions per minute) and duty cycle (percent time in hand exertion) were quantified from video analysis by categorizing each frame of video into hand exertion categories of interest using Multimedia Video Task Analysis software (MVTA, University of Wisconsin, Madison). A complete description of exposure measurement methods is provided in Appendix 3.

4.6.2. MSD risk assessment scores

Exposure measurements were interpreted using validated MSD risk assessment tools. The primary upper extremity MSD risk assessment tool was the ACGIH Threshold Limit Value for Hand Activity (HA TLV). The HA TLV results in a Peak Force Index Threshold Limit Value score (PFI-TLV score) derived from the HAL (Hand Activity Level) and the NPF (Normalized Peak Force), which are based on force, repetition rate, and duty cycle exposure measures.

HAL values range from 0 (i.e., "hands idle") to 10 (i.e., "rapid motions, difficult to keep up") and are based on the frequency (number of hand exertions per work time) and duty cycle (percentage of time hands are exerting a force) of hand exertions. It can be (i) estimated by a trained observer, (ii) found in a table published by ACGIH (ACGIH, 2022), or (iii) calculated using an equation (ACGIH, 2022). In this study, the equation method was used to calculate the HAL from hand exertion frequency and duty cycle measurements (duty cycle=work time/(work time + "rest" time)). Work time accrued when the hands exerted more than 10% of the specific strength of a population, and rest time accrued when the hands exerted a force less than 10% of the particular strength of a population. For the HAL equation, the exertion frequency (exertion frequency=exertions/second) (exertion frequency is expressed in units of Hz) was based on hand exertions that occurred only during work time, so the HAL exertion frequency will almost always be greater than the hand exertion repetition rate measured across the sample period (hand exertion repetition rate=number of hand exertions/(work time + rest time)). An individual (worker-level) HAL score was calculated for all workers who were videotaped.

NPF values range from 0 (no force exerted) to 10 (maximum voluntary force or strength). NPF can be estimated using a variety of approaches (ACGIH, 2022), such as worker or analyst ratings using the Borg CR10 scale, both of which can be prone to potential bias from worker or analyst judgment. Another approach is a biomechanical model based on the weight of items handled and population strengths. A biomechanical model may be less accurate when measuring forces exerted using tools such as knives, dynamic loads (such as handling live animals), or when handling items with reduced friction (such as slippery carcasses). For this investigation, the 90^{th} percentile of the force (i.e., the "peak force") applied was based on surface electromyographic (EMG) measurements of the forearm muscles of the dominant arm of a worker relative to their maximal muscle activity (or maximum strength) normalized to a 0 to 10 scale. In this way, information from each worker evaluated with EMG was used to estimate the NPF required for each task. For the workers who were not evaluated using EMG but were videotaped only (and thus had an individual HAL score but no NPF), single imputation based on establishment and job-specific EMG averages, accounting for age and sex, was used to estimate the NPF value.

A PFI-TLV score of one or less was used to define acceptable risk jobs (PFI-TLV score≤1) and unacceptable risk jobs (PFI-TLV score>1) (Kapellusch et al., 2014; Yung et al., 2019). Recent large multi-country prospective studies support the ACGIH TLV for hand activity, so it was used as the primary risk assessment score. A complete description of risk assessment calculations is presented in Appendix 3.

For one job (Palletizing), the Revised NIOSH Lift Equation (RNLE) was used as the risk assessment approach because the primary activity was lifting. Based on a systematic review of prospective and cross-sectional studies, a composite lift index (CLI) score was calculated and compared to a limit of 1.5 (Fox et al., 2019). Inputs for the RNLE were determined from video analysis, direct measurements, and known box weights. Vertical hand location was calculated based on collected measurements of the conveyer, pallet, and box sizes. Horizontal reach distances were conservatively estimated based on the box size and position of the box on the pallet. Hand coupling was considered ‘good’ if boxes had handles and ‘fair’ if not. The lifting frequency was calculated based on video analysis, and the work duration was based on worker self-report of duration. The CLI was calculated based on the binning of the vertical hand location at the destination of the lift (low, mid, high). For each subject, the average lifting frequency was split equally in the vertical height bins.

Video and electromyography data provided validated and unbiased measures of individual biomechanical workload.

4.6.3. Statistical analysis

Descriptive Statistics. Summary statistics were generated for all workers included in the study and summarized by non-TLT Line Speed (1,106 HPH) and TLT Line Speed (>1,106 HPH). The prevalence of workers at high risk of MSDs (PFI-TLV score>1.0) was calculated during the non-TLT and TLT Line Speeds. Additionally, the prevalence of workers who changed or maintained their PFI-TLV score to above or below 1.0 when working at the non-TLT and TLT Line Speeds was calculated.

Effect Heterogeneity. To allow for the possible heterogeneity of relationships between line speed or piece rate with health outcomes or PFI-TLV scores according to establishment-level or job-level characteristics, the statistical analyses estimated subgroup-specific associations, as described below. The analysis plan considered the following subgroups: TLT Line Speed group (<1,300HPH and ≥1,300HPH based on having an equal number of establishments in each group), establishment (six establishments), and processing area (i.e., Front End, Main Chain, Offal, Cut Floor). Seventy-eight unique jobs were evaluated across the six establishments and then collapsed into four categories based on the area (Table 4.2.1).

Standardized Unit of Increase. Since the six establishments operated at a range of TLT Line Speeds, for statistical analysis, the evisceration line speed was centered such that a line speed of 1,106 was “zero increase in line speed" then scaled to per-100 increase in HPH. PFI-TLV score was a skewed variable, with repeated measures within-person, therefore, an analysis approach that accommodated those features of the data was applied.

Overview of Statistical Approach. Several statistical models were used to answer study questions. One set of models (i.e., the median ratio models, median score difference models, and matched-change-score models) was used to compare PFI-TLV score as a *continuous measure* across evisceration line speed or piece rate category. A second set of models (i.e., conditional logistic regression models) was used to compare the odds of PFI-TLV score as a *categorical measure* (specifically, PFI-TLV score >1.0) across evisceration line speed or piece rate category. Within those two sets, models either (i) included all available results for participating workers (i.e., those who contributed results from one measurement week only and those who contributed results from both measurement weeks) and were adjusted for potential confounders or (ii) were restricted to only those participants who contributed results collected during both measurement weeks (i.e., within-person matched pair data). A complete description of each model is provided below.

Median Ratio Models. To estimate the relative increase in PFI-TLV score per 100 HPH increase in evisceration line speed (i.e., median ratio), conditional on random and fixed effects, mixed-effects parametric quantile regression models (Crowther, 2019) were fitted with a random intercept for person and with fixed effects for age (continuous linear), sex (binary: male, female), language (binary: English, non-English), and duration of tenure in the job (categorical: 90 days, ≥ 90 days but < 1 year, ≥ 1 year but < 5 years, ≥ 5 years but < 10 years, or ≥10 years). Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) procedures were used to compare the model fit for a null model (with person random intercept only) to decide between lognormal, Weibull, or gamma distributional assumptions for PFI-TLV score conditional on random effects – the best fit was a Weibull distribution. Effect heterogeneity was considered for the relationship of line speed to PFI-TLV score according to TLT Line Speed group (establishments with TLT speed <1,300 HPH vs. ≥1,300 HPH), according to the establishment, and according to the area (Front End, Main Chain, Offal, Cut Floor). First, a regression model was fitted with interaction terms between line speed and the putative effect modifier (i.e., TLT Line Speed group, establishment, processing area), in addition to the other fixed and random effects. Then, the significance of the set of all interaction terms in that model was determined by a χ^2 test to obtain an overall p-value for interaction. Next, stratified models were fitted according to the variable inspected for effect heterogeneity in the interaction-term models. The test for the significance of individual fixed-effect regression coefficients in the mixed-effect parametric quantile regression models was a Z-test. To illustrate the impact of line speed on PFI-TLV score under these mixed-effect parametric quantile regression models, the predicted marginal means of PFI-TLV score at hypothetical values of line speed (+100, +200, +300 HPH) were calculated post-estimation.

Median PFI-TLV score Difference Models. To estimate the difference in median PFI-TLV score per 100 HPH increase in line speed, nonparametric quantile regression models were fitted with fixed effects for age, sex, language, and tenure. Robust standard errors were used to account for dependent observations (i.e., some persons contributed more than one visit to the analysis). Effect heterogeneity was evaluated for the relationship of line speed to PFI-TLV score according to TLT Line Speed group (establishments with TLT Line Speed <1,300 HPH vs. ≥1,300 HPH), establishment, and area (Front End, Main Chain, Offal, Cut Floor). First, a regression model was fitted with interaction terms between line speed and the putative effect modifier (i.e., TLT Line Speed group, establishment, processing area). Then, the significance of the set of all interaction terms in the model was determined by a χ^2 test to obtain an overall p-value for interaction. Stratified models were fitted according to the variable inspected for effect heterogeneity in the interaction-term models. The test for the significance of individual fixed-effect regression coefficients in the nonparametric quantile regression models with robust standard errors was a *t*-test.

Within-Person-Matched Change Score Linear Regression Model. To leverage the within-person-matched study design, change score linear regression approach was used to estimate the within-person-matched association of PFI-TLV score with an increase in line speed (i.e., the difference in mean PFI-TLV score per +100 HPH) for a person's primary job. Each study participant observed at non-TLT and TLT Line Speeds had their change in PFI-TLV score between the TLT vs. non-TLT Line Speed calculated as an outcome, and the increase in line speed between those observations calculated as the exposure. As this change score linear regression model only included one observation per person, a bootstrap procedure was implemented assuming independent observations, and used to calculate bias-corrected and accelerated (BCa) confidence intervals based on 1,000 bootstrap replicates to allow for possible non-normality of residuals. In addition to the overall model, these models were also fitted stratified by TLT Line Speed group (establishments with TLT Line Speed <1,300 HPH vs. ≥1,300 HPH) and by area (Front End, Main Chain, Offal, Cut Floor). These change score models could not be stratified by the establishment because all persons in the same establishment had the same change in line speed between visits.

Conditional Logistic Regression Models. In addition to analyses considering continuous PFI-TLV score as an outcome, analyses were also conducted for the binary outcome of PFI-TLV score > 1.0 since that threshold reflects the score where the doubling of MSD risk, which describes the point at which there is more certainty than not, that an injury is due to work-related exposures. Simply put, a PFI-TLV score >1.0 indicates the maximum threshold limit value for upper extremity intensive work.

To estimate the odds ratios for PFI-TLV score > 1.0 per +100 HPH, conditional on random and fixed effects, mixed-effects logistic models were fitted with a random intercept for person and with fixed effects for age and sex. Language and tenure were omitted from these models to avoid estimation problems. Possible effect heterogeneity was evaluated for the relationship of line speed to PFI-TLV score according to TLT Line Speed group (establishments with TLT speed <1,300 HPH vs. ≥1,300 HPH), establishment, and area (Front End, Main Chain, Offal, Cut Floor). First, a regression model was fitted with interaction terms between line speed and the putative effect modifier (i.e., TLT Line Speed group, establishment, processing area). Then, the significance of the set of all interaction terms in the model was determined by a χ^2 test to obtain an overall p-value for interaction. Stratified models were fitted according to the variable inspected for effect heterogeneity in the interaction-term models. The test for statistical significance of individual fixed-effect regression coefficients in the mixed-effect logistic regression models was a Z-test.

Within-Person Matched Conditional Logistic Regression Models. To leverage the within-person-matched study design, conditional logistic regression models were fitted to estimate the within-person-matched associations (i.e., conditional odds ratios) of PFI-TLV score > 1.0 per +100 HPH at the person's primary job. While this approach controls for both measured and unmeasured within-person time-invariant confounders through matching, these models are limited by sample size, as only persons in the sample who had changes in their PFI-TLV score > 1.0 status between the TLT and non-TLT Line Speed conditions contribute information to this analysis. Models were fitted overall, and stratified by TLT Line Speed group, by establishment, and by area. The test for statistical significance of the line-speed exposure in the conditional logistic regression models was a Z-test.

Piece Rate Models. Since piece rate is very closely related to individual job tasks, all statistical analyses for piece rate were conditioned on job. Mixed-effect models (i.e., mixed-effect parametric quantile regression and mixed-effect logistic regression) incorporated a second random effect for job, in addition to the fixed effects (with piece rate substituted for line speed) and person-level random intercept described above, assuming nested random effects (visits from persons in jobs). The within-person-matched analyses (i.e., change score and conditional logistic regression analyses) was conditioned on job as a time-invariant personal characteristic by restricting the estimation sample to primary job observations only. The nonparametric quantile regression analysis was not used for piece rate analysis since it could not condition on job.

Respiratory Symptoms and Upper Extremity Pain Health Outcome Analyses. The respiratory symptoms analysis and the upper extremity pain analysis followed the same procedures. Analyses included data surveyed for each worker's primary job performed at the TLT Line Speed (>1,106 HPH). χ^2 tests were used to test the independence of categorical variables in a contingency table analysis, first with respect to the independence of the health outcome and job code; then to test the independence of health outcome and TLT Line Speed group (establishments with TLT speed <1,300 HPH vs. ≥1,300 HPH); then to test the independence of health outcome and establishment; and last to test the independence of health outcome and area (Front End, Main Chain, Offal, Cut Floor). Then, logistic regression models were used to estimate the prevalence odds ratios of having had respiratory symptoms per +100 HPH line speed at non-TLT Line Speed, first unadjusted and then adjusted for age, sex, language, and job tenure. Secondary analyses considered heterogeneity in the relationships of line speed to these outcomes according to TLT Line Speed group (establishments with TLT speed <1,300 HPH vs. ≥1,300 HPH), establishment, and area. Additional models were fitted without line speed to evaluate the independent associations of TLT Line Speed group, establishment, and area with these health outcomes, both unadjusted and adjusting for age, sex, language, and job tenure.

We conducted analyses to assess the effect of evisceration line speed on MSD risk. Each establishment operated at the non-TLT Line Speed of 1,106 HPH and, at a separate time, at a TLT Line Speed >1,106 HPH. Since establishments had varied TLT Line Speeds, the results are presented per 100 HPH increase (+100 HPH).

4.7. Antimicrobial Hazard Assessment

4.7.1 PAA Exposure measurement instruments

To measure airborne concentrations of PAA, we used the ChemDAQ SafeSide™ Portable Monitoring Envirocell Sensor Module (ChemDAQ, Pittsburg, PA, USA). The ChemDAQ system is comprised of a passive electrochemical sensor that is sensitive to PAA. Before reaching the sensor, the PAA diffuses through a chemical-coated filter that reduces the cross-sensitivity of the sensor to hydrogen peroxide by chemically reacting with any hydrogen peroxide vapor that is present and preventing it from passing into the detection chamber. The instrument uses a tablet to log the PAA concentration data. The ChemDAQ SafeSide™ PAA sensor has a range of detection of 0.01 to 3.00 ppm and an accuracy of 0.20 ppm (or 5% of the signal, whichever is greater). The ChemDAQ SafeSide™ User's Manual states that the sensor cannot get wet because condensation or water on the sensor's membrane will absorb PAA vapor. Additionally, a beard net was wrapped around the sensor to protect the membrane from exposure to water droplets.

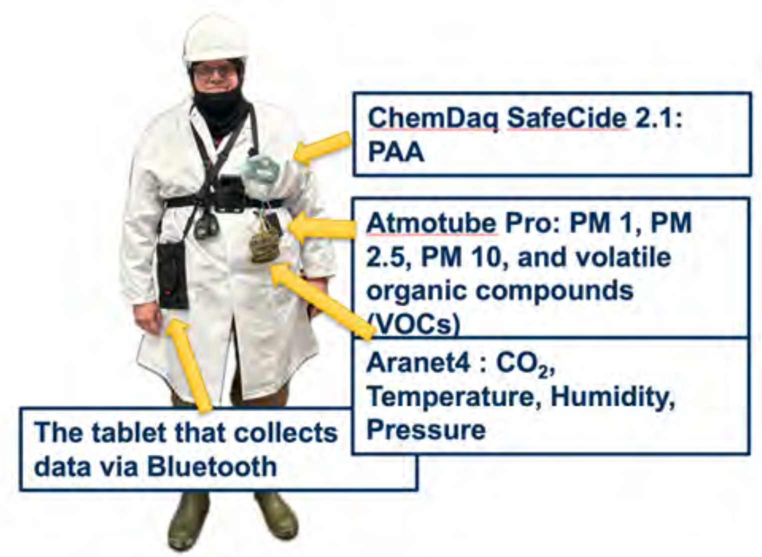
We used an Atmotube Pro (ATMOTECH Inc., San Francisco, CA, USA) to collect additional information on temperature, relative humidity (%), and atmospheric pressure. We also used an Aranet4 (SAF Tehnika, Riga, Latvia) to measure CO_2 concentrations to characterize ventilation conditions. The Atmotube Pro and Aranet4 all log data at 5-minute or shorter intervals. The ChemDAQ records a value each time the measured PAA levels change. A Go-Pro video camera was used to record sampling locations while measuring air contaminant concentrations to ensure the accuracy of sampling locations from week 1 to week 2.

4.7.2. Sample collection method

The aim of this study was to examine if airborne concentrations of PAA differed with line speed changes. To explore this difference, pair samples were collected at each line speed. During the first week of the study at each establishment, the industrial hygienist would select 5 to 10 sampling locations at or near antimicrobial application sources for PAA. Once the locations were selected, the industrial hygienist would collect 5-minute samples at each location and repeat this procedure 10 times. The goal was to collect ten five-minute samples at each location across different times throughout the day to represent the range of exposures that may occur at each application point due to typical production fluctuations. The sampling locations were selected based on distance from the antimicrobial application source, not necessarily on proximity to workers due to the limited number of application points. The industrial hygienist would wear a chest harness and attach the ChemDAQ SafeSide™, the Atmotube, and the Aranet 4 at breathing zone height to represent worker exposure if they stood at each sampling location. Locations were also selected to measure levels of PAA at sampling locations progressively further away from the application source. This was conducted to determine the exposure range to PAA across the work area surrounding the sampling locations near the antimicrobial intervention cabinets, of which there was one at each establishment.

During week two, the sampling protocol was repeated, collecting ten additional 5-minute samples at each sampling location to create match pairs for analysis. An illustration of an industrial hygienist wearing the instruments is shown in Figure 4.7.1. Please note that because his height was much taller than most employees, we positioned the sensors at a height that represented the employees working at that establishment. When possible, we recorded video during PAA sampling. These videos confirmed field sheet notes and assigned proximity metrics to a subset of samples (e.g., identifying the distance from the sample to the antimicrobial intervention application point).

Figure 4.7.2. Sampling instrument setup



All sampling locations were selected to not interfere with the employee work processes or workflow but to allow for a representative sample of airborne concentrations of PAA in the various locations throughout an establishment where PAA is applied. Using paper field sheets, we recorded each sample interval's time, location, and any observations or activity occurring at the locations (e.g., drains being clogged and water pooling on the floor). Except for the first week of sampling at the first establishment, where there were issues with the sensor not recording values for all the repetitions of the sampling locations, all other locations had match pairs for all sampling intervals.

4.7.3 Sampling location determination

Sampling locations were selected to focus on two main application points: the antimicrobial intervention cabinets or enclosures for treating the whole hog and the antimicrobial interventions along the cut floor conveyor belts, where conveyor belts carrying cut meat were sprayed with PAA. Table 4.7.1 includes detailed descriptions of these sampling locations.

Table 4.7.3 Descriptions of sampling locations and approximate distance from PAA application source

Detailed Description of Sampling Locations	Sampling Locations Across All Establishments	Approximate Distance from PAA Source (in feet)
Antimicrobial Intervention Cabinet (Whole Hog) Sampling Locations		
Intake of Antimicrobial Intervention Cabinet (CHAD or IST)	3	≤4’
Output of Antimicrobial Intervention Cabinet/ Enclosure for Whole Hog (CHAD, IST, or Hallway)	5	≤4’
5-9’ from Intake Side of Antimicrobial Intervention Cabinet (CHAD or IST)	3	5-9’
5-9’ from Output Side of Antimicrobial Intervention Cabinet (CHAD or IST)	4	5-9’
Production floor in vicinity of Antimicrobial Intervention Cabinet (CHAD or IST)	1	≤4’
≥10’ from Intake Side of Antimicrobial Intervention Cabinet (CHAD or IST)	2	≥ 10’
≥10’ from Output Side of Antimicrobial Intervention Cabinet (CHAD or IST)	4	≥ 10’
Antimicrobial Intervention (Parts Wash) on the Cut Floor Production Area		
Spray Application of PAA onto Saw Blade	3	≤4’
Spray Application (Spray Nozzles with No Enclosure) over the cut floor processing line conveyor belts	2	≤4’
Spray Application (Spray Nozzles with Partial Enclosure over the Spray Bars) on the cut floor processing line conveyor belts	8	≤4’

4.7.4. PAA Exposure Sampling Data Analysis

Following sampling, all data files for the sampling were downloaded from the instruments and applications. Data from the different instrument output files were cleaned and assembled into a dataset using the timestamps from field notes, output files, and GoPro videos to assign values to each sampling location and cycle. Due to the ChemDaq sensor only recording a value each time the levels of PAA changed, for each sampling location and cycle, the data files were expanded to create a reading for each second of the 5-minute sampling periods, and the recorded value of PAA was then replicated for each second it remained at that value. This created a file of 300 readings to represent the 300 seconds in a 5-minute sample, allowing for an accurate PAA time-weighted average (TWA) for each sample. All negative values for PAA were set to 0.00 ppm. Data management was done using Microsoft Excel 360 (Seattle, WA), and statistical analysis was performed using IBM SPSS Version 30.0 (Armonk, NY).

Each 5-minute sample was assigned the corresponding sampling location, establishment, and if it was collected during the non-TLT Line Speed week or the TLT Line Speed week. Samples collected at the same location and establishment were paired together, and descriptive statistics were utilized to determine the normality of the dataset. Results for each and all sampling locations combined were not normally distributed, so non-parametric statistics were selected to analyze all data. Wilcoxon signed ranks test was selected as the statistical analysis to use to compare TLT versus non-TLT pairs sets by various groupings to determine if there is a statistical difference between PAA exposure by line speed, including i) by TLT Line Speed groupings (establishments operating at TLT Line Speed <1,300 HPH and those running ≥1,300 HPH), ii) by establishment, and iii) by area of the plant, and by type of PAA application.

4.7.5. Respiratory Symptoms

As part of the Work and Health Survey ("survey") described in section 4.3, workers were asked to describe their respiratory symptoms over the past year and rate them by frequency and severity. For frequency, they were asked to answer if they experienced symptoms: yes, often; yes, sometimes; no; other; or decline to state. For severity of symptoms, they were asked to rate their symptoms at one of five levels of severity: very mild, mild, moderate, moderate-severe, or severe.

5. Results

5.1. Establishment Line Speed Summary

Six establishments participated in the study. Each establishment reported their average evisceration line speeds to the USDA for the two data collection periods (Table 5.1). Individual establishment TLT Line Speeds are not shown to protect confidential business information. For the purposes of this report, assume the difference in line speed between the non-TLT and the TLT Line Speed data collection periods was up to 400 HPH (data not shown). The average hot carcass weight across the six establishments, as provided by the establishments, was 211.9 (3.7) lbs.

Table 5.1. Hog weight, evisceration line speed, and turnover rate of the two TLT line speed groups

Establishment	TLT Line Speed group[1]	Hog Weight[2] (lbs) Mean (SD)	Non-TLT Line Speed (HPH)	TLT Line Speed[2] (HPH) Mean (SD)	2023 Turnover Rate[2] Mean (SD)
A	<1,300 HPH	211.3 (2.9)	1,106	1,232.0 (66.0)	47.1% (11.6%)
B			1,106		
C			1,106		
D	≥1,300 HPH	212.5 (4.9)	1,106	1,362.7 (38.5)	54.6%
E			1,106		
F			1,106		

1 TLT Line Speed group is based on establishment-specific TLT Line Speed
2 Average of establishment-specific data as provided by the USDA (and reported by companies)

5.2. Participant Overview

5.2.1. Data collected

The worker survey was completed by 574 participants across the six establishments ("survey data" in Table 5.2.1.); of those, 275 were in establishments operating at a TLT Line Speed of <1,300 HPH and 299 were in establishments operating at a TLT Line Speed of ≥1,300 HPH. Thirty-six study participants also completed a medical interview. Four hundred ninety-eight workers were videotaped to analyze body movements ("video data") and wore devices to collect electromyography (EMG) and goniometer measurements ("wearable data") when their establishments operated at the non-TLT line speed (<1,106HPH) and 519 had video and wearable data collected when their establishments operated at a TLT Line Speed ≥1,300 HPH. Of those, 472 participants had "within-person-matched" data that included video and wearable data collected on two occasions (i.e., when their establishments operated at the non-TLT Line Speed and when their establishments operated at the TLT Line Speeds).

Table 5.2.1. Data collected by week and TLT Line Speed group

	TLT Line Speed <1,300 HPH (N)	TLT Line Speed ≥1,300 HPH (N)	All Establishments(N)
Survey Data	275	299	574
Medical Interviews	20	16	36
Video and Wearable Data			
Non-TLT Line Speed (1,106 HPH)	236	262	498
TLT Line Speed (>1,106 HPH)	255	264	519
Paired Data[1]	227	245	472

1 The number of workers with survey, video, and wearable data collected during both the Non-TLT and TLT weeks

5.2.2. Demographics

The mean age of the 574 study participants was 39.6 (11.3) years, with little difference across establishments in the < 1,300HPH versus ≥1,300HPH TLT Line Speed groups (Table 5.2.2). Approximately three-quarters of the study participants were male (75.4%), with slightly more men (5.2%) at the establishments in the ≥1,300HPH TLT Line Speed group. Over two-thirds (69.1%) of the workers identified as Hispanic, 11.7% identified as Black, 5.6% identified as White, and 13.6% identified as another race. Only 8.2% spoke English as their primary language; the majority spoke another language, such as Spanish. Most of the workers (81%) were born outside of the United States; a larger proportion of study participants in the ≥1,300HPH TLT Line Speed group reported being born outside of the United States (24.4% versus 13.8%). Four out of five study participants had been employed in their respective processing establishments for one or more years. More workers had a job tenure of more than five years employed in the <1,300 HPH TLT Line Speed establishments compared to those in the ≥1,300 HPH TLT Line Speed establishments.

Study participants reported working an average of 9.1 hours per day and 5.0 days per week (data not shown). Study participants in the ≥1,300 HPH TLT Line Speed group reported working an average of 1.15 hours less per day and 0.1 days less per week than participants in the <1,300 HPH TLT Line Speed group. Ninety-four percent of study participants reported working the day shift, with the remainder reporting working night, swing, evening, or other shifts. There was a slight difference (6%)

in the number of day shift workers; in the <1,300HPH TLT Line Speed group, 91.6% of participants worked on the day shift compared to 97.7% of participants in the ≥1,300HPH TLT Line Speed establishments. Ninety-two percent of workers in the <1,300 HPH Line Speed establishments reported "typically" working mandatory or voluntary overtime (i.e., more than 40 hours per week), whereas 78.6% of workers in the ≥1,300 HPH TLT Line Speed establishments reported "typically" working mandatory or voluntary overtime.

Table 5.2.2. Demographic characteristics of study participants

	TLT Line Speed Group		
	<1,300 HPH N(%)	≥1,300 HPH N(%)	All Establishments N(%)
Age	N= 268	N= 278	N= 546
Mean (SD)	41.8 (11.4)	37.6 (10.9)	39.6 (11.3)
Gender	N= 275	N = 299	N= 574
Male	200 (72.7%)	233 (77.9%)	433 (75.4%)
Female	75 (27.3%)	66 (22.1%)	141 (24.6%)
Race/Ethnicity	N= 275	N= 297	N= 572
Black	34 (12.4%)	33 (11.1%)	67 (11.7%)
White/Caucasian	18 (6.5%)	14 (4.7%)	32 (5.6%)
Hispanic	174 (63.3%)	221 (74.4%)	395 (69.1%)
Other	49 (17.9%)	29 (9.7%)	78 (13.6%)
Primary Language Spoken	N= 275	N= 299	N= 574
English	28 (10.2%)	19 (6.4%)	47 (8.2%)
Other	247 (89.8%)	280 (93.6%)	527 (91.8%)
Born outside the US	N= 275	N= 295	N= 570
Yes	237 (86.2%)	223 (75.6%)	460 (80.7%)
No	38 (13.8%)	72 (24.4%)	110 (19.3%)
Work Tenure	N= 274	N= 297	N= 571
< 90 days	8 (2.9%)	8 (2.7%)	16 (2.8%)
≥ 90 days but < 1 year	41 (15.0%)	69 (23.2%)	110 (19.3%)
≥ 1 year but < 5 years	103 (37.6%)	148 (49.8%)	251 (43.4%)
≥ 5 years but < 10 years	53 (19.3%)	36 (12.1%)	89 (15.6%)
≥ 10 years	69 (25.2%)	36 (12.1%)	105 (18.4%)

HPH = hogs per hour

75.4% of workers were male and 69.1% identified as Hispanic. 91.8% reported a language other than English as their primary language and 80.7% were born outside of the United States.

5.3. Associations between PFI-TLV scores and Evisceration Line Speed across all establishments and by TLT Line Speed group

5.3.1. Estimated PFI-TLV scores across all establishments and by TLT Line Speed group

Overall, 44.7% (N=222) of workers evaluated in this study exceeded a PFI-TLV score of 1.0 when their establishments operated at the non-TLT Line Speed, and 46.1% (N=239) exceeded a PFI-TLV score of 1.0 when their establishments operated at the TLT Line Speed (Table 5.3.1).

The distribution of PFI-TLV scores for establishments operating at the non-TLT and TLT Line Speeds, stratified by TLT Line Speed group are shown in Figure 5.3.1.A. The scatter plots (Figure 5.3.1.B) show the PFI-TLV scores when establishments operated at non-TLT and TLT Line Speeds, stratified by TLT Line Speed group. These plots show the contributions of exposures (NPF and HAL) that result in the PFI-TLV score. Points above the red line have a PFI-TLV score>1.0 indicating increased MSD risk.

Table 5.3.1. Comparison of median PFI-TLV score and prevalence of workers exceeding the TLV (PFI-TLV score >1.0) by non-TLT line speed and TLT line speed across all establishments and by TLT Line Speed group

	Non-TLT Line Speed			TLT Line Speed		
	N	PFI-TLV score Median (IQR)	PFI-TLV score > 1.0 N (%)	N	PFI-TLV score Median (IQR)	PFI-TLV score >1.0 N (%)
All Establishments	497	0.93 (0.64 to 1.27)	222 (44.7%)	518	0.94 (0.63 to 1.4)	239 (46.1%)
TLT Line Speed group						
<1,300 HPH	236	0.94 (0.70 to 1.26)	105 (44.5%)	255	1.00 (0.67 to 1.43)	128 (49.8%)
≥1,300 HPH	260	0.91 (0.61 to 1.30)	116 (44.6%)	263	0.89 (0.61 to 1.29)	111 (42.2%)

Nearly half of workers in this study exceeded safe levels of biomechanical exposure (i.e., they had a PFI-TLV score greater than 1.0).

Figure 5.3.1.A. Distribution of PFI-TLV scores at non-TLT and TLT Line Speeds and by TLT Line Speed group

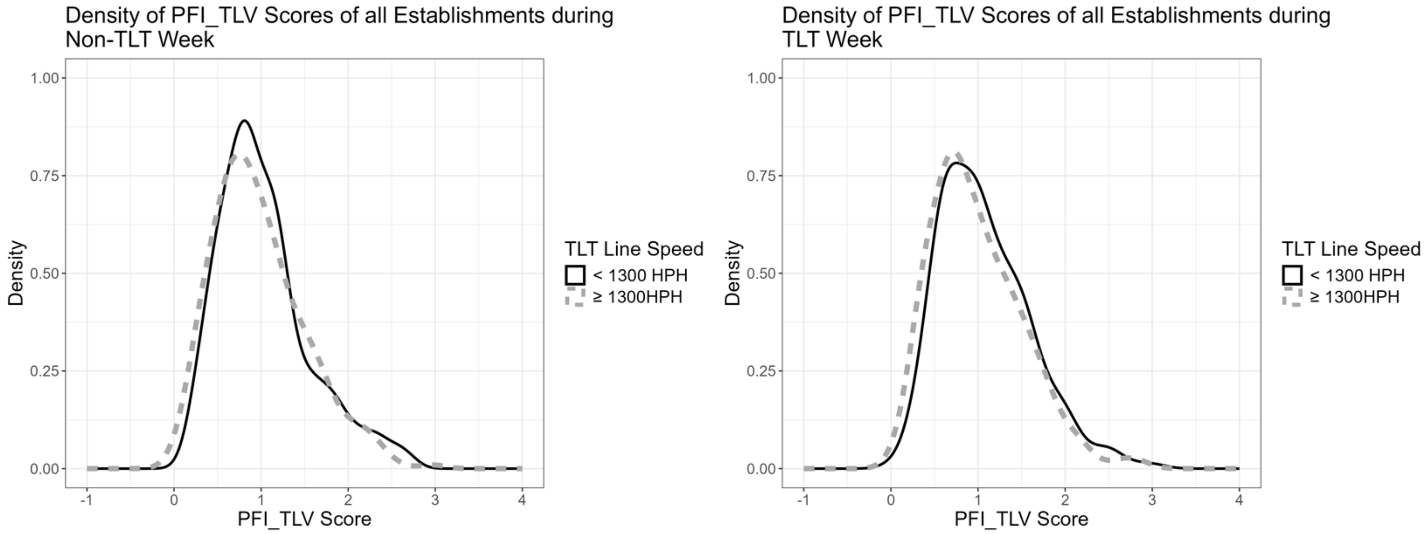
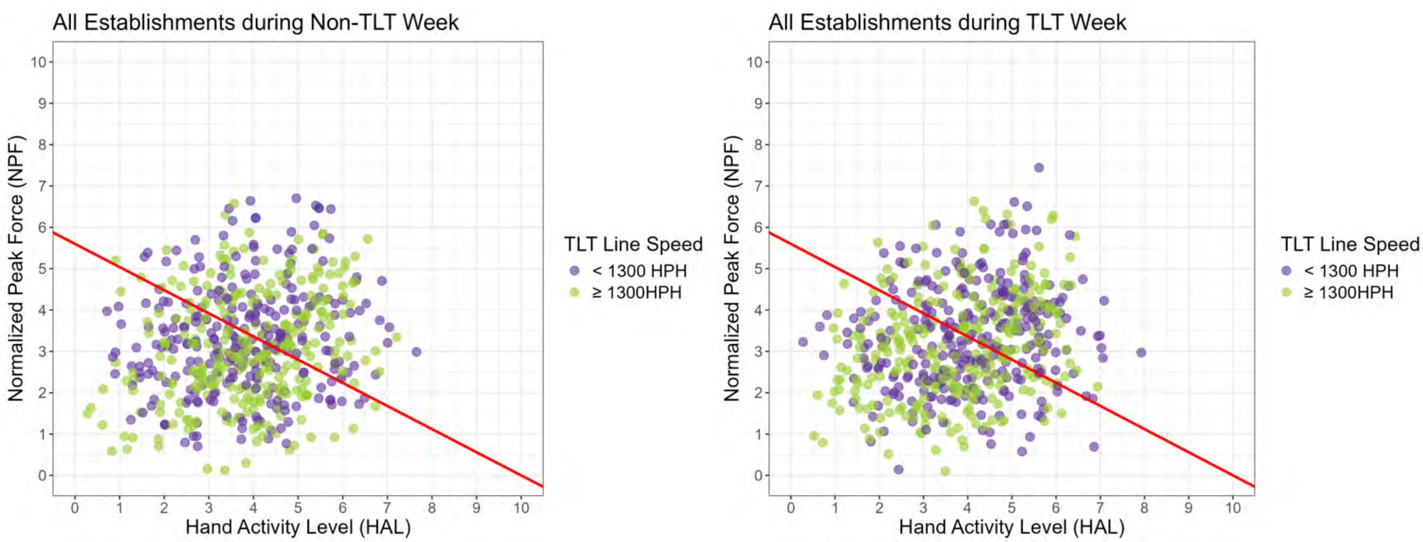


Figure 5.3.1.B. Scatter plots of PFI-TLV scores when establishments operated at non-TLT and TLT Line Speeds, stratified by TLT Line Speed group. Points above the red line have a PFI-TLV score>1.0 indicating increased MSD risk[1]



1 The NPF value is calculated from the 90th percentile of the amplitude probability distribution function of a worker's EMG data, and the HAL value is calculated from the repetition rate and duty cycle calculated from the video analysis of each worker's video. See section 4.6.2. for additional detail.

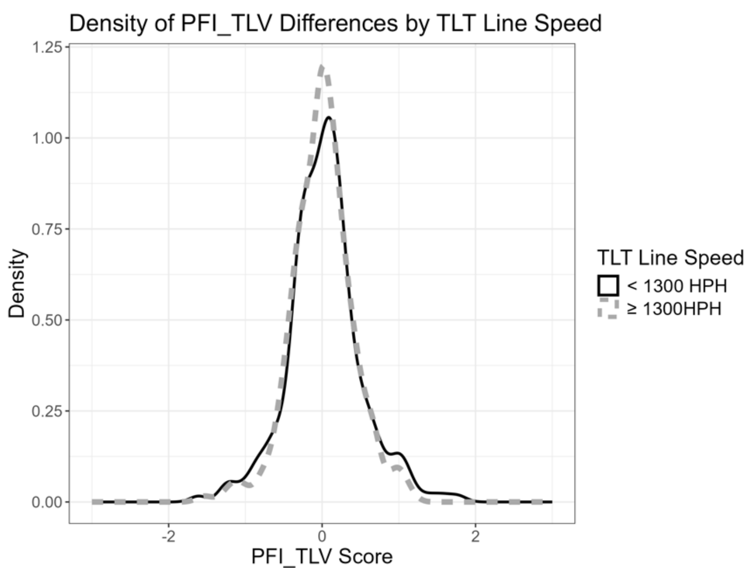
5.3.2. Unstratified and stratified linear regression models of the change in median PFI-TLV score per +100 HPH by TLT Line Speed group

The distributions of within-person change in median PFI-TLV scores between the non-TLT and TLT Line Speeds, according to the processing areas are shown in Figure 5.3.2.

Median Ratio Models. The results of the mixed-effect parametric quantile regression models are provided in Table 5.3.2.A. The ratios of the median PFI-TLV score per +100 HPH line speed, adjusted for the fixed effects of age, sex, language, and tenure, and conditional on the person-level random intercepts, were not statistically different than 1.0, meaning that no association was observed in either the unstratified model nor the model stratified by TLT Line Speed.

Median PFI-TLV score Difference Models. The results of the non-parametric quantile regression models are provided in Table 5.3.2.B. The differences in the median PFI-TLV score per +100 HPH line speed, adjusted for age, sex, primary language, and job tenure, were not statistically different than 0.00, meaning that no statistically significant associations were observed in either the unstratified model nor the model stratified by TLT Line speed.

Figure 5.3.2. Distribution of *change* in PFI-TLV scores by TLT Line Speed group[1]



1 Change in PFI-TLV score = PFI-TLV score when the establishment is operating at the TLT Line Speed minus PFI-TLV score when the establishment is operating at the non-TLT Line Speed

Table 5.3.2.A. Adjusted PFI-TLV score median ratio per +100 HPH increase in evisceration line speed from mixed-effects parametric quantile regression models assuming Weibull distributions

	Observations N	Individuals N	Median Ratio[1] (95% CI)	p-value
All Establishments	1,118	547	1.01 (0.99 to 1.03)	0.26
TLT Line Speed group				
<1,300 HPH	547	262	1.02 (0.98 to 1.07)	0.25
≥1,300 HPH	571	285	1.01 (0.99 to 1.03)	0.44

1 Models adjusted for age, sex, primary language, and job tenure with a random intercept for person

Table 5.3.2.B. Adjusted difference in median PFI-TLV score per +100 HPH increase in evisceration line speed from non-parametric quantile regressions

	Obs. (N)	Difference in median PFI-TLV score per +100 HPH[1] (robust 95% CI)	p-value
All Establishments	1,118	-0.01 (-0.04 to 0.03)	0.71
TLT Line Speed group			
<1,300 HPH	547	-0.005 (-0.07 to 0.06)	0.89
≥1,300 HPH	571	0.003 (-0.03 to 0.04)	0.87

1 Models adjusted for age, sex, primary language, and job tenure

In both, unstratified analyses and analyses stratified by TLT Line Speed group, no statistically significant associations were observed between evisceration line speed and MSD risk.

Within-Person-Matched Change Score Linear Regression Models. The results of the linear regression change score analysis using data matched by person are presented in Table 5.3.2.C. In the unstratified model, there was no change in mean PFI-TLV score per +100 HPH increase in line speed. In the stratified models a statistically significant change in mean PFI-TLV score per +100 HPH was observed among establishments operating at TLT Line Speed ≥1,300HPH (0.15 PFI-TLV score change per +100 HPH, 95%CI=0.01 to 0.31) but not among establishments operating at TLT Line Speed <1,300 HPH.

Table 5.3.2.C. Change in mean PFI-TLV score per +100 HPH increase in evisceration line speed from a linear regression change score analysis using data matched by person

	Jobs N	Individuals N	Change in mean PFI-TLV score per +100 HPH (95% CI[1])
All Establishments	73	460	0.004 (-0.05 to 0.06)
TLT Line Speed Group			
<1,300 HPH	52	223	0.03 (-0.08 to 0.15)
≥1,300 HPH	55	237	0.15 (0.01 to 0.31)

1 bias-corrected and accelerated confidence intervals from 1000 bootstrap replicates

In the analysis stratified by TLT Line Speed group, establishments that operated at a TLT Line Speed ≥1,300 HPH had a statistically significant increase in MSD risk (per +100 HPH), whereas no such association was observed among establishments that operated at line speeds <1,300 HPH. In the unstratified analysis, there was no statistically significant association between evisceration line speed and MSD risk.

5.3.3. Unstratified and stratified conditional logistic regression models of PFI-TLV score>1.0 per +100 HPH by TLT Line Speed group

Mixed-Effect Conditional Logistic Regression Models. The results of the mixed-effect logistic regression models are presented in Table 5.3.3.A. In both, the unstratified models and the models stratified by TLT Line Speed group, associations between evisceration line speed and a PFI-TLV score >1.0, conditional on the person-level random effect and adjusted for age, sex, language, and job tenure across all establishments, were not statistically significant.

Within-Person Matched Conditional Logistic Regression Models. The results of the conditional logistic regression matching on person and stratified by establishment are presented in Table 5.3.3.B. Only persons who transitioned from a PFI-TLV score ≤1.0 to a PFI-TLV score >1.0, or vice versa, contributed information to the models. In both, the unstratified model and the models stratified by TLT Line Speed, associations between evisceration line speed and a PFI-TLV score >1.0 were not statistically significant.

Change in PFI-TLV Category. The sample size informing the conditional logistic regression analysis (Table 5.3.3.B.) is shown in Table 5.3.3.C. The proportion of workers who changed category of PFI-TLV score <1.0 to ≥1.0, or vice versa, between observations was similar across TLT Line Speed groups. Most persons in the study stayed consistently below or above a PFI-TLV score of 1.0 (Table 5.3.3.C).

Table 5.3.3.A. Conditional odds ratio of having a PFI-TLV score >1.0 per +100 HPH increase in evisceration line speed from mixed-effects logistic regression models

	Individuals N	Observations N	Odds Ratio[1] (95% CI)	p-value
All Establishments	615	1,118	1.04 (0.90 to 1.21)	0.61
TLT Line Speed group				
<1,300 HPH	547	262	1.14 (0.83 to 1.57)	0.42
≥1,300 HPH	571	285	1.03 (0.87 to 1.23)	0.71

1 Models adjusted for age, sex, primary language, and job tenure with a random intercept for person

Table 5.3.3.B. Conditional odds of a PFI-TLV score >1.0 per +100 HPH of evisceration line speed from conditional logistic regression models using data matched by person

	Jobs N	Individuals[1] N	Observations N	Odds Ratio (95% CI)	p-value
All Establishments	45	128	256	1.02 (0.87 to 1.21)	0.78
TLT Line Speed group					
<1,300 HPH	33	65	130	1.14 (0.81 to 1.62)	0.45
≥1,300 HPH	33	63	126	0.99 (0.82 to 1.20)	0.91

1 Includes individuals with complete PFI-TLV score pairs recorded at non-TLT and TLT line speeds

Table 5.3.3.C. Individual change in ACGIH TLV for Hand Activity category (PFI-TLV score ≤1.0 versus PFI-TLV score >1.0) by TLT Line Speed group using data matched by person

	Categories of PFI-TLV score change from non-TLT Line Speed to TLT Speed[1]				
	N	≤1.0 to ≤1.0 N (%)	>1.0 to ≤1.0 N (%)	≤1.0 to >1.0 N (%)	>1.0 to >1.0 N (%)
All Establishments	471	192 (40.7%)	62 (13.1%)	68 (14.4%)	149 (31.6%)
TLT Line Speed Group					
<1,300 HPH	227	86 (37.9%)	28 (12.3%)	38 (16.7%)	75 (33.0%)
≥1,300 HPH	244	106 (43.4%)	34 (13.9%)	30 (12.3%)	74 (30.3%)

1 Includes individuals with complete PFI-TLV score pairs recorded at non-TLT and TLT Line Speeds

In both, unstratified analyses and analyses stratified by TLT Line Speed group, there were no statistically significant associations between TLT Line Speed and the odds of a PFI-TLV score>1.0.

5.4. Associations between PFI-TLV scores and Evisceration Line Speed by Establishment

5.4.1. Estimated PFI-TLV scores by establishment

The median PFI-TLV score and the proportion of workers who exceeded a PFI-TLV score of 1.0 varied widely across establishments (Table 5.4.1). The median PFI-TLV scores ranged between 0.78 and 1.13 when establishments operated at the non-TLT Line Speed and between 0.70 and 1.23 when establishments operated at the TLT Line Speeds.

The proportion of workers whose PFI-TLV scores exceeded 1.0 varied across establishments. At the non-TLT Line Speed, between 34.6% (Establishment E) and 58.0% (Establishment A) of workers had PFI-TLV scores that exceeded 1.0. At the TLT Line Speed, between 21.8% (Establishment C) and 65.3% (Establishment A) of workers had PFI-TLV scores that exceeded 1.0.

The distribution of PFI-TLV scores for each establishment at both the non-TLT and the TLT Line Speeds are shown in Figure 5.4.1.A. Establishments C and E had a higher proportion of workers with PFI-TLV scores ≤1.0, whereas Establishments A, B, and F had a higher proportion of workers with PFI-TLV scores >1.0.

Scatter plots of PFI-TLV scores when establishments operated at non-TLT and TLT Line Speeds, stratified by establishment are shown in Figure 5.4.1.B. These plots show the contributions of exposures (NPF and HAL) that result in the PFI-TLV scores. Points above the red line have a PFI-TLV score of greater than 1.0, indicating an increased MSD risk.

Table 5.4.1. Comparison of median PFI-TLV score and prevalence of workers exceeding the TLV (PFI-TLV score>1.0) by establishment and evisceration line speed

By Establishment	Non-TLT Line Speed N	Non-TLT Line Speed PFI-TLV score Median (IQR)	Non-TLT Line Speed PFI-TLV score>1.0 N (%)	TLT Line Speed N	TLT Line Speed PFI-TLV score Median (IQR)	TLT Line Speed PFI-TLV score>1.0 N (%)
Establishment A	81	1.13 (0.85 to 1.49)	47 (58.0%)	95	1.13 (0.87 to 1.54)	62 (65.3%)
Establishment B	71	0.89 (0.69 to 1.25)	27 (38.0%)	73	1.23 (0.82 to 1.61)	47 (64.4%)
Establishment C	84	0.85 (0.60 to 1.13)	31 (36.9%)	87	0.70 (0.55 to 0.98)	19 (21.8%)
Establishment D	92	1.00 (0.66 to 1.41)	49 (53.3%)	93	0.96 (0.64 to 1.32)	44 (47.3%)
Establishment E	78	0.78 (0.52 to 1.08)	27 (34.6%)	78	0.75 (0.47 to 1.10)	22 (28.2%)
Establishment F	91	0.93 (0.61 to 1.40)	41 (45.1%)	92	0.97 (0.62 to 1.35)	45 (48.9%)

Figure 5.4.1.A. Distribution of PFI-TLV scores at non-TLT and TLT Line Speeds by establishment

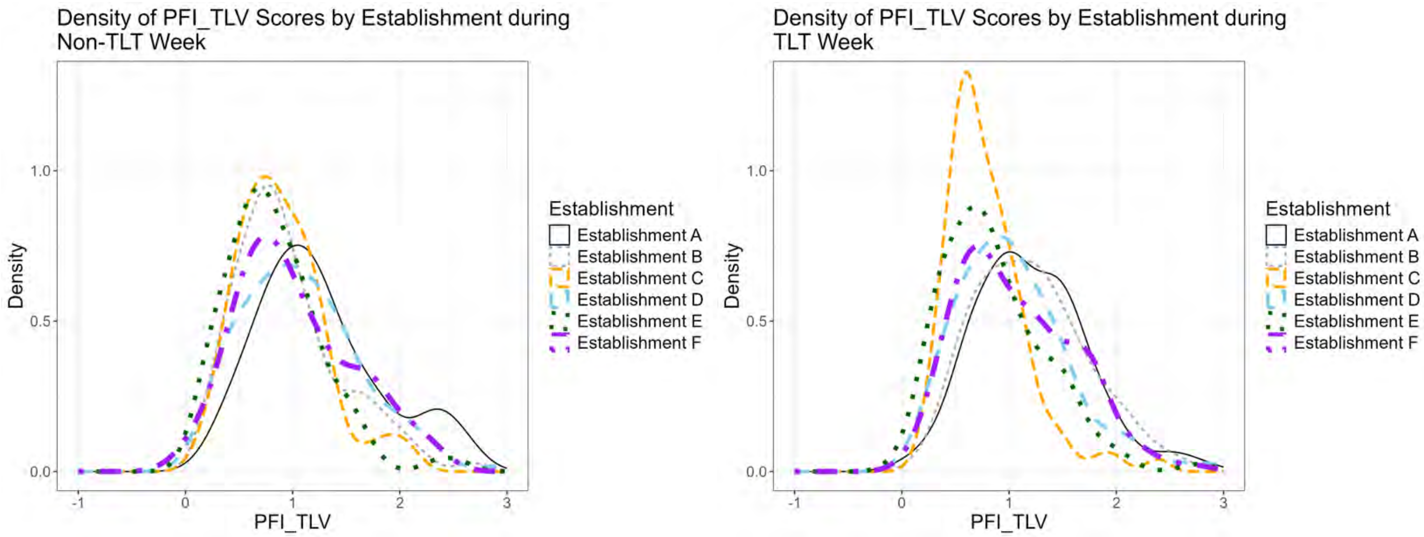
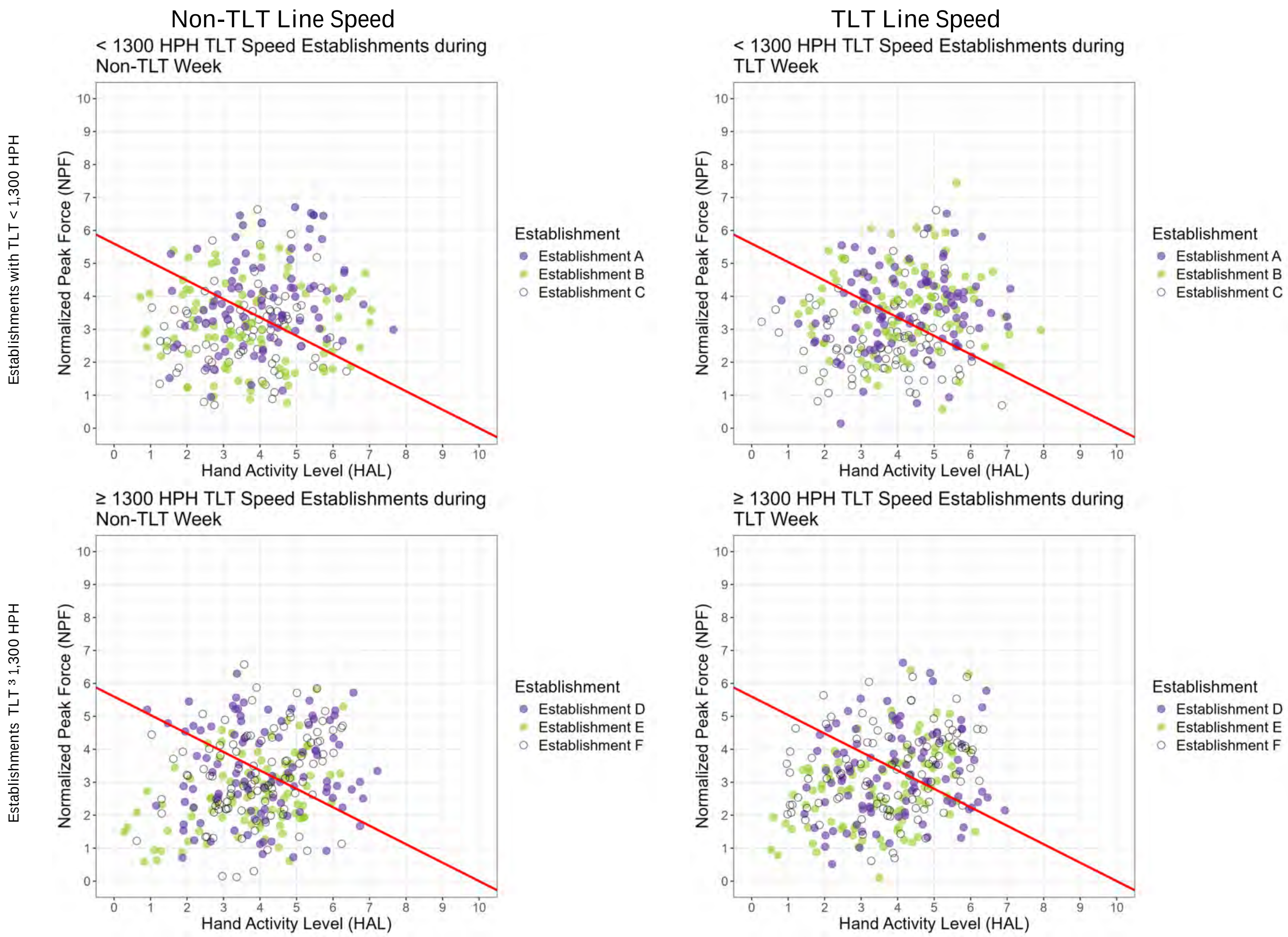


Figure 5.4.1.B. Scatter plots of PFI-TLV scores when establishments operated at non-TLT and TLT Line Speeds, stratified by establishment. Points above the red line have a PFI-TLV score>1.0 indicating increased MSD risk[1]



1 The NPF value is calculated from the 90th percentile of the amplitude probability distribution function of a worker's EMG data, and the HAL value is calculated from the repetition rate and duty cycle calculated from the video analysis of each worker's video. See section 4.6.2. for additional detail.

The median PFI-TLV score varied by establishment, as did the proportion of workers with a PFI-TLV score >1.0. At TLT Line Speeds, the proportion of workers with a PFI-TLV score >1.0 ranged from 21.8% to 65.3%

5.4.2. Unstratified and stratified linear regression models of the change in median PFI-TLV score per +100 HPH by establishment

The distributions of within-person differences in PFI-TLV score between the non-TLT and TLT evisceration line speeds for all establishments are shown in Figure 5.4.2. These person-level changes in PFI-TLV scores are neither normally distributed variables nor unimodal distributions. Some worker's PFI-TLV scores decreased by up to one unit, while other worker's PFI-TLV scores increased by up to two units.

Median Ratio Models. The results of the mixed-effect parametric quantile regression analysis are provided in Table 5.4.2. The ratios of the median PFI-TLV score per +100 HPH line speed, adjusted for the fixed effects of age, sex, language, and tenure, and conditional on the person-level random intercepts, varied by establishment. Establishment C had had a 7% reduction in median PFI-TLV score per +100 HPH increase in evisceration line speed that was statistically significant. Establishment B, had a +15% increase in the median PFI-TLV score per +100 HPH increase in evisceration line speed, which was also statistically significant. The interaction of line speed with individual establishments was significant (p=0.0001), conditional on the fixed and random effects.

Median PFI-TLV score Difference Models. The results of the non-parametric quantile regression analysis are provided in Table 5.4.2.B. Establishment C, had a 0.08 *decrease* in median PFI-TLV score with increasing evisceration line speed. Establishment B had a 0.20 *increase* in median PFI-TLV score with increasing evisceration line speed adjusted for age, sex, language, and job tenure. The interaction between line speed (+100 HPH) and establishment was statistically significant (p= 0.0001) in the nonparametric quantile regression model adjusted for age, sex, language, and job tenure. Thus, similar to the parametric quantile regression results, there was apparent heterogeneity in the direction of the line-speed effect across establishments.

Figure 5.4.2. Distribution of *change* in PFI-TLV scores by establishment

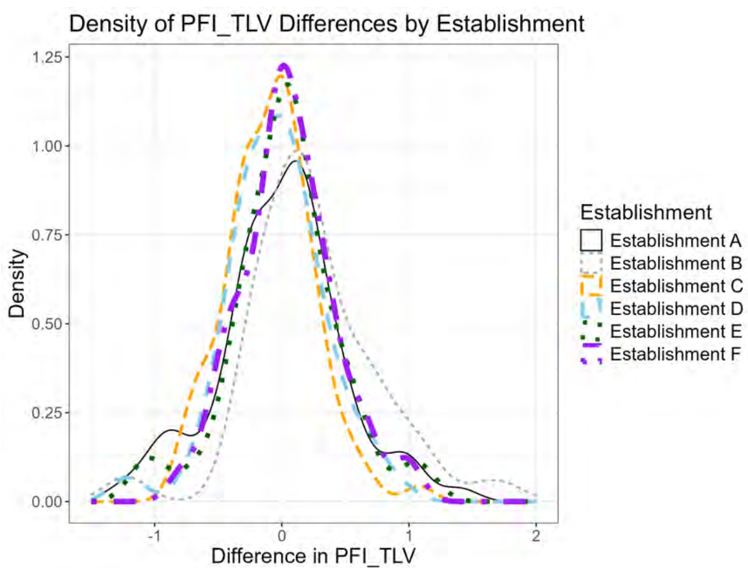


Table 5.4.2.A. Adjusted PFI-TLV score median ratio per +100 HPH increase in evisceration line speed from mixed-effects parametric quantile regression models assuming Weibull distributions

	Observations N	Individuals N	Median Ratio[1] (95% CI)	p-value
By Establishment				
Establishment A	188	97	0.95 (0.79 to 1.13)	0.55
Establishment B	185	76	1.17 (1.10 to 1.25)	<0.01
Establishment C	174	89	0.93 (0.88 to 0.98)	0.004
Establishment D	199	96	0.98 (0.94 to 1.02)	0.27
Establishment E	181	87	1.02 (0.97 to 1.06)	0.52
Establishment F	191	102	1.02 (0.99 to 1.06)	0.15

1 Models adjusted for age, sex, primary language, and job tenure with a random intercept for person

Table 5.4.2.B. Adjusted difference in median PFI-TLV scores per +100 HPH increase in evisceration line speed from non-parametric quantile regressions

	Obs. N	Change in median PFI-TLV score per +100 HPH[1] (robust 95% CI)	p-value
By Establishment			
Establishment A	188	0.02 (-0.28 to 0.32)	0.90
Establishment B	185	0.19 (0.10 to 0.28)	<0.01
Establishment C	174	-0.07 (-0.14 to 0.01)	0.07
Establishment D	199	-0.03 (-0.10 to 0.05)	0.53
Establishment E	181	-0.01 (-0.07 to 0.04)	0.62
Establishment F	191	0.05 (-0.02 to 0.11)	0.17

1 Models adjusted for age, sex, primary language, and job tenure with robust standard errors to account for repeated data

Within-Person-Matched Change Score Linear Regression Model. Of note, the change in mean PFI-TLV score per +100 HPH increase in evisceration line speed using a linear regression change score analysis using data matched by person and stratified by establishment could not be performed since all workers had the same non-TLT and TLT Line Speeds (i.e., there was no exposure variation).

Both, the median PFI-TLV ratios and the median PFI-TLV change scores, varied by establishment. Specifically, for both, MSD risk was statistically significantly ***higher*** per +100 HPH in Establishment B, whereas MSD risk was statistically significantly ***lower*** in Establishment C. No statistically significant associations were observed for the other four establishments.

5.4.3. Unstratified and stratified conditional logistic regression models of PFI-TLV score>1.0 per +100 HPH by establishment

Mixed-Effect Conditional Logistic Regression Models. The results of the mixed-effect logistic regression models are presented in Table 5.4.3.A. In both, the unstratified models and the models stratified by TLT Line Speed group, associations between evisceration line speed and a PFI-TLV score >1.0, conditional on the person-level random effect and adjusted for age and sex, were not statistically significant. Job tenure and primary language were removed from the model to increase parameter stabilization. There was a 3.5-fold increase in the odds of a PFI-TLV score >1.0 per +100 HPH increase in line speed, conditional on the fixed and random effects at Establishment B. There were lower odds of a PFI-TLV score >1.0 per +100 HPH line speed, conditional on the fixed and random effects, at Establishment C. The association at Establishment F was suggestive of a nearly 30% increase in the odds of a PFI-TLV score >1.0 per +100 HPH increase in line speed, conditional on fixed and random effects, but was not statistically significant. The test for interaction between evisceration line speed and establishment, conditional on fixed and random effects, was statistically significant (p=0.0001).

Within-Person Matched Conditional Logistic Regression Models. The results of the conditional logistic regression matching on person and stratified by establishment are presented in Table 5.4.3.B. Persons who transitioned from a PFI-TLV score ≤1.0 to a PFI-TLV score > 1.0, or vice versa, contributed information to the model. The within-person association of evisceration line speed with the odds of having a PFI-TLV score > 1.0 per +100 HPH was highest at Establishment B (OR= 3.98; 95% CI: 1.59 to 9.98) and protective at Establishment C (OR=0.54; 95% CI: 0.33 to 0.92). Establishment F showed a higher within-person association between evisceration line speed and increased odds of a PFI-TLV score >1.0. However, the interval narrowly included 1.0 (OR=1.28; 95%CI: 0.96 to 1.71).

Table 5.4.3.A. Conditional odds ratio of having PFI-TLV score >1.0 per +100 HPH increase in evisceration line speed from mixed-effects logistic regression models

	Observations N	Individuals N	Odds Ratio[1] (95% CI)	p-value
By Establishment				
Establishment A	188	97	2.21 (0.41 to 11.82)	0.35
Establishment B	185	76	3.60 (1.89 to 6.87)	<0.01
Establishment C	174	89	0.54 (0.32 to 0.90)	0.02
Establishment D	199	96	0.84 (0.60 to 1.17)	0.30
Establishment E	181	87	0.94 (0.68 to 1.29)	0.69
Establishment F	191	102	1.28 (0.96 to 1.71)	0.09

1 Models adjusted for age, sex with a random intercept for person
2 Interaction term p<0.0001

Table 5.4.3.B. Conditional odds of PFI-TLV score >1.0 per +100 HPH increase in evisceration line speed from conditional logistic regression models using data matched by person

	Jobs N	Individuals N	Observations N	Odds Ratio (95% CI)	p-value
By Establishment					
Establishment A	17	19	38	4.69 (0.68 to 32.49)	0.12
Establishment B	13	20	40	3.98 (1.59 to 9.98)	0.03
Establishment C	17	26	52	0.55 (0.33 to 0.92)	0.02
Establishment D	18	26	52	0.81 (0.56 to 1.16)	0.24
Establishment E	15	17	34	0.79 (0.53 to 1.16)	0.23
Establishment F	17	20	40	1.33 (0.96 to 1.84)	0.08

1 Includes individuals with complete PFI-TLV score pairs recorded at non-TLT and TLT line speeds

At Establishment B, TLT Line Speed was associated with a statistically significant *increase* in the odds of PFI-TLV score >1.0. Conversely, at Establishment C, TLT Line Speed was associated with a statistically significant *decrease* in the odds of a PFI-TLV score >1.0. Non-statistically significant increases and decreases in the odds of a PFI-TLV score >1.0 were observed at the remaining four establishments.

Change in PFI-TLV Category. The sample size informing the conditional logistic regression analysis, which was limited to persons who had paired data, is shown in Table 5.4.3.C. The proportion of workers who changed category of PFI-TLV score from <1.0 to ≥1.0, or vice versa, between their observations while their establishment operated at the non-TLT Line Speed and the TLT Line Speed varied widely across establishments.

At Establishment B, only two persons (3%) changed from a PFI-TLV score >1.0 when their establishment operated at the non-TLT Line Speed to a PFI-TLV score of ≤1.0 when their establishment operated at the TLT Line Speed. However, 18 persons (26.9%) changed from a PFI-TLV score ≤1.0 to a PFI-TLV score >1.0. In contrast, at Establishment C, 19 persons (23.5%) changed from a PFI-TLV score >1.0 when their establishment operated at the non-TLT Line Speed to a PFI-TLV ≤1.0 score when their establishment operated at the TLT Line Speed, and while only seven persons (8.6%) changed from a PFI-TLV score ≤ 1.0 to a PFI-TLV score >1.0.

Notably, nearly half of the persons observed under non-TLT and TLT Line Speeds at Establishment A had a PFI-TLV score > 1.0 and one-third of workers had a PFI-TLV score >1.0 at both line speeds at Establishments B, D, and F. In contrast, more than half of workers at Establishments C (53.1%) and E (57.7%) had a PFI-TLV score ≤1.0 at both the non-TLT and TLT Line Speeds.

Table 5.4.3.C. Individual change in ACGIH TLV for Hand Activity category (PFI-TLV score ≤1.0 versus PFI-TLV score >1.0) by establishment using data matched by person

		Categories of PFI-TLV score change from non-TLT week to TLT week[1]			
	N	<1.0 to ≤1.0 N (%)	>1.0 to ≤1.0 N (%)	≤1.0 to >1.0 N (%)	>1.0 to >1.0 N (%)
By Establishment					
Establishment A	79	20 (25.3%)	7 (8.9%)	13 (16.5%)	39 (49.4%)
Establishment B	67	23 (34.3%)	2 (3.0%)	18 (26.9%)	24 (35.8%)
Establishment C	81	43 (53.1%)	19 (23.5%)	7 (8.6%)	12 (14.8%)
Establishment D	90	31 (34.4%)	16 (17.8%)	10 (11.1%)	33 (36.7%)
Establishment E	71	41 (57.7%)	11 (15.5%)	6 (8.5%)	13 (18.3%)
Establishment F	83	34 (41.0%)	7 (8.4%)	14 (16.9%)	28 (33.7%)

1 Includes individuals with complete PFI-TLV score pairs recorded at non-TLT and TLT line speeds

When comparing line speed conditions (non-TLT Line Speed versus TLT Line Speed), the number of workers who changed from low MSD risk (PFI-TLV score ≤1.0) to high MSD risk (PFI-TLV score >1.0), and vice versa, varied by establishment.

5.5. Associations between PFI-TLV score and Evisceration Line Speed by Processing Area

5.5.1. Summary of estimated PFI-TLV scores by evisceration line speed and processing area

The median PFI-TLV score and the proportion of workers who exceeded a PFI-TLV score of 1.0 varied by processing area (Table 5.5.1). The highest median PFI-TLV score was measured in the Cut Floor area and the lowest PFI-TLV score was measured in the Main Chain area during both the non-TLT Line Speed and the TLT Line Speed conditions. The Cut Floor also had the highest proportion of workers who exceeded the PFI-TLV score of 1.0 during the non-TLT Line Speed (54.7%) and the TLT Line Speed (62.7%).

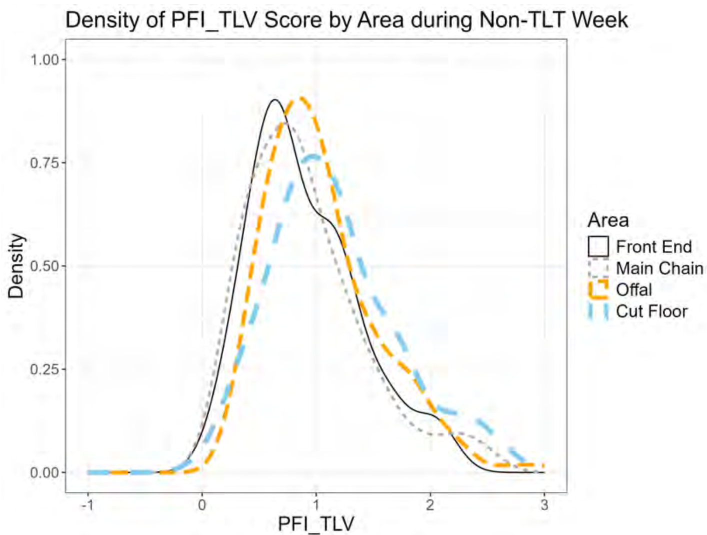
The distribution of PFI-TLV scores by processing area for each establishment at both the non-TLT and the TLT Line Speeds are shown in Figure 5.5.1.A. Although the Cut Floor has a median PFI-TLV score close to 1.0, many workers have PFI-TLV scores that exceed 1.0.

Scatter plots of PFI-TLV scores when establishments operated at non-TLT and TLT Line Speeds, stratified by processing area is shown in Figure 5.5.1.B. These plots show the contributions of exposures (NPF and HAL) that result in the PFI-TLV scores. Points above the red line have a PFI-TLV score of greater than 1.0, indicating an increased MSD risk.

Table 5.5.1. Comparison of median PFI-TLV score and the prevalence of workers exceeding the TLV (PFI-TLV score >1.0) by processing area, by non-TLT and TLT Line Speeds

	Non-TLT Line Speed			TLT Line Speed		
	N	PFI-TLV Median (IQR)	PFI-TLV score>1.0 N (%)	N	PFI-TLV Median (IQR)	PFI-TLV score>1.0 N (%)
By processing area						
Front End	55	0.86 (0.59 to 1.16)	24 (43.6%)	56	0.93 (0.63 to 1.37)	25 (44.6%)
Main Chain	154	0.80 (0.54 to 1.19)	53 (34.4%)	166	0.78 (0.56 to 1.17)	61 (36.8%)
Offal	160	0.96 (0.72 to 1.36)	77 (48.1%)	161	0.94 (0.70 to 1.33)	71 (44.1%)
Cut Floor	117	1.08 (0.78 to 1.48)	64 (54.7%)	126	1.14 (0.79 to 1.53)	79 (62.7%)

Figure 5.5.1.A. Distribution of PFI-TLV scores by processing area when establishments operated at both the non-TLT and TLT Line Speeds, by establishment



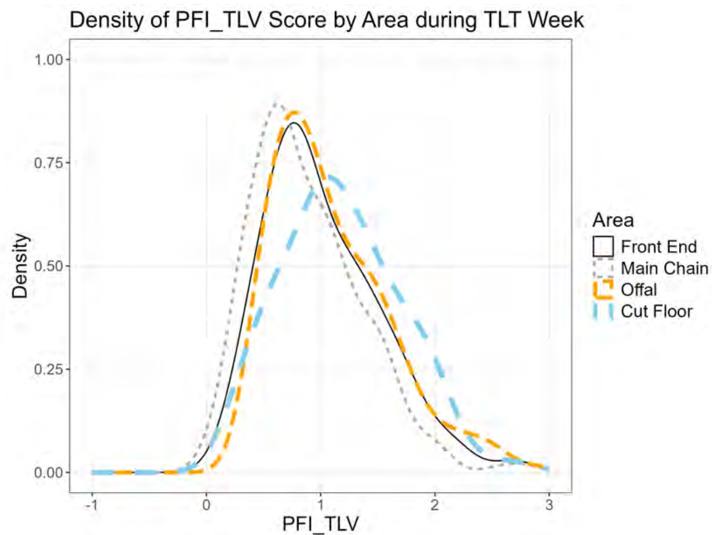
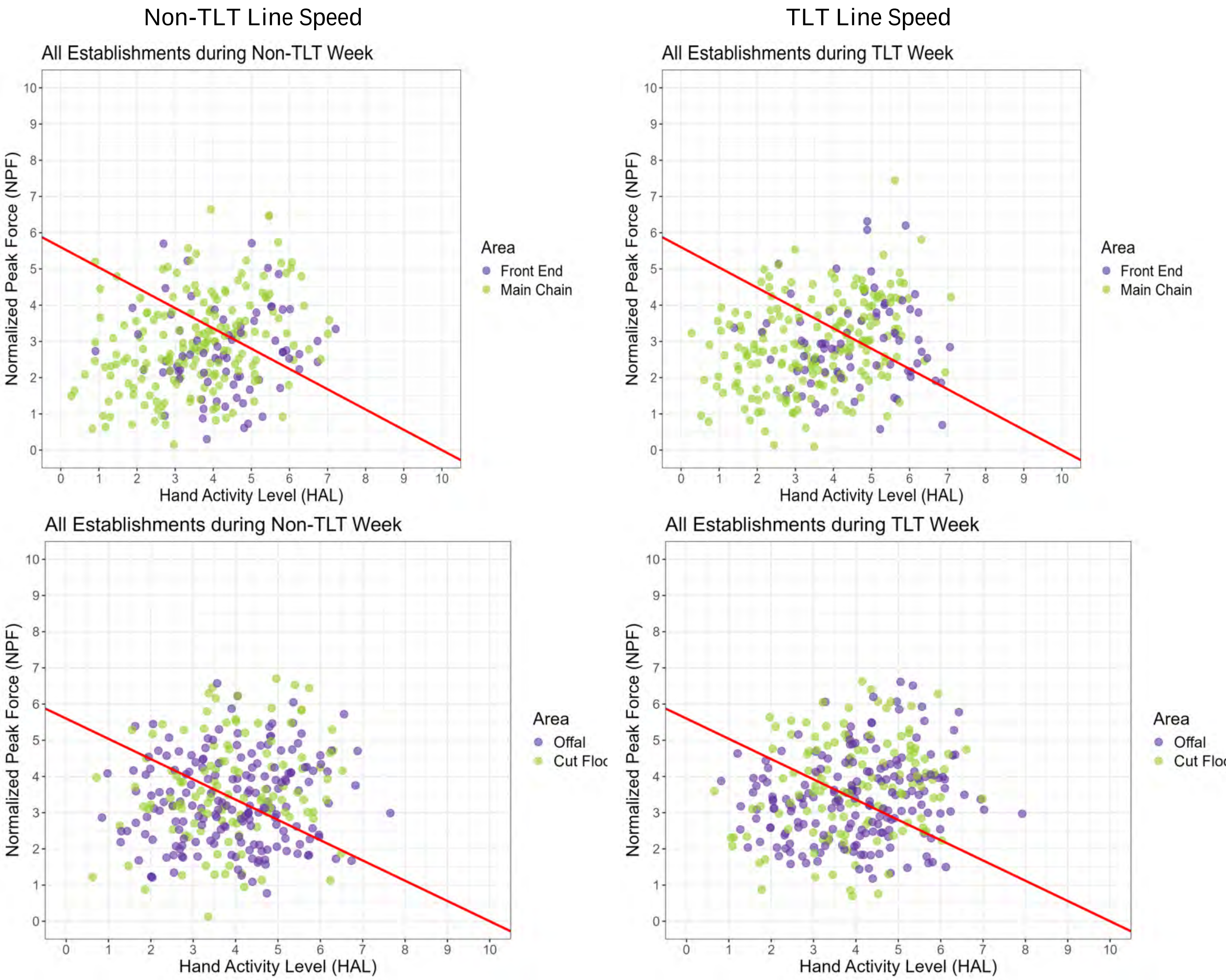


Figure 5.5.1.B. Scatter plots of PFI-TLV scores when establishments operated at non-TLT and TLT Line Speeds, stratified by processing area. Points above the red line have a PFI-TLV score>1.0 indicating increased MSD risk[1]



1 The NPF value is calculated from the 90th percentile of the amplitude probability distribution function of a worker's EMG data, and the HAL value is calculated from the repetition rate and duty cycle calculated from the video analysis of each worker's video. See section 4.6.2. for additional detail.

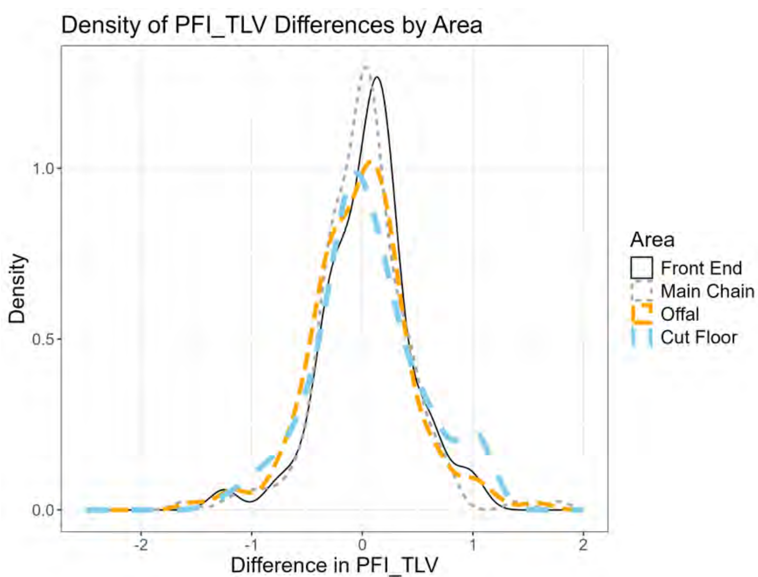
5.5.2. Unstratified and stratified linear regression models of the change in median PFI-TLV score per +100 HPH stratified by processing area

The distribution of change in PFI-TLV scores when establishments operated at the TLT Line Speed and the Non-TLT Line Speed by processing area is shown in Figure 5.5.2. These person-level changes in PFI-TLV scores are not all normally distributed variables, nor are they all strictly unimodal distributions.

Median Ratio Models. The results of mixed-effect parametric quantile regression models are provided in Table 5.5.2.A. The ratios of the median PFI-TLV ratio with line speed per +100 HPH, adjusted for fixed effects for age, sex, language, and tenure, and conditional on the person-level random intercepts, was not statistically different from 1.0 for all processing areas, meaning that no association was observed in any of the stratified models.

Median PFI-TLV score Difference Models. The results of the non-parametric quantile regression models are provided in Table 5.5.2.B. The differences in the median PFI-TLV score per +100 HPH line speed adjusted for age, sex, primary language, and job tenure were not statistically different from 0.00, meaning that no statistically significant associations were observed in any of the stratified models.

Figure 5.5.2. Distribution of change in PFI-TLV scores when establishments operated at the TLT Line Speed and the Non-TLT Line Speed by processing area



1 Change in PFI-TLV score = PFI-TLV score when the establishment is operating at the TLT Line Speed minus PFI-TLV score when the establishment is operating at the non-TLT Line Speed

Table 5.5.2.A. Adjusted ratio of median PFI-TLV score per +100 HPH increase in evisceration line speed from mixed-effects parametric quantile regression models assuming Weibull distributions

	Observations N	Individuals N	Median Ratio[1] (95% CI)	p-value
By Processing Area				
Front End	139	59	1.04 (0.98 to 1.11)	0.17
Main Chain	371	189	1.00 (0.96 to 1.03)	0.90
Offal	369	174	1.03 (0.99 to 1.06)	0.10
Cut Floor	239	129	1.00 (0.96 to 1.05)	0.87

1 Models adjusted for age, sex, primary language, and job tenure with a random intercept for person

Table 5.5.2.B. Adjusted difference in median PFI-TLV scores per +100 HPH from non-parametric quantile regressions

	Observations N	Change in median PFI-TLV scores per +100 HPH[1] (robust 95% CI)	p-value
By Processing Area			
Front End	139	0.03 (-0.07 to 0.13)	0.58
Main Chain	371	-0.03 (-0.08 to 0.03)	0.32
Offal	369	0.004 (-0.05 to 0.06)	0.89
Cut Floor	239	-0.02 (-0.09 to 0.04)	0.48

1 Models adjusted for age, sex, primary language, and job tenure with robust standard errors to account for repeated data

Within-Person-Matched Change Score Linear Regression Model. The results of the linear regression change score analysis using data matched by person are presented in Table 5.5.2.C. Although this was a linear regression, the typical homoskedastic normal residuals assumption would be violated, so we report a bias-corrected and accelerated 95% confidence interval as the basis for inference. In the stratified models, there was no change in mean PFI-TLV score per +100 HPH increase in line speed.

Table 5.5.2.C. The change in PFI-TLV score per +100 HPH in evisceration line speed from a linear regression change score analysis using data matched by person

	Jobs N	Individuals N	Change in PFI-TLV score per +100 HPH[1] (95% CI[2])
By processing area			
Front End	4	49	-0.05 (-0.21 to 0.11)
Main Chain	32	155	-0.04 (-0.13 to 0.04)
Offal	23	148	0.04 (-0.04 to 0.12)
Cut Floor	14	108	0.04 (-0.07 to 0.16)

1 Includes individuals with complete PFI-TLV score pairs recorded at non-TLT and TLT line speeds
2 bias-corrected and accelerated confidence intervals from 1000 bootstrap replicates

In analyses stratified by processing area, no statistically significant associations were observed between evisceration line speed and MSD risk.

5.5.3. Unstratified and stratified conditional logistic regression models of PFI-TLV score>1.0 per +100 HPH by processing area

Mixed-Effect Conditional Logistic Regression Models. The results of the mixed-effects logistic regression models stratified by processing area are presented in Table 5.5.3.A. In both, the unstratified models and the models stratified by processing area, associations between evisceration line speed and a PFI-TLV score >1.0, conditional on the person-level random effect and adjusted for age, sex, language, and job tenure across all establishments, were not statistically significant.

Within-Person Matched Conditional Logistic Regression Models. The results of the linear regression change score analysis using data matched by person are presented in Table 5.5.3.B. In the models stratified by processing area, associations between evisceration line speed and a PFI-TLV score >1.0 were not statistically significant, though suggestive in the Cut Floor area (conditional OR=1.31; 95% CI: 0.92 to 1.88).

Change in PFI-TLV Category. The lack of statistical significance from the conditional logistic regression models may be partly due to the limited sample size for the number of persons who converted from the PFI-TLV score ≤1.0 category to the PFI-TLV score >1.0 category or vice versa (Table 5.5.3.C). The Cut Floor area had more than twice as many people change from a PFI-TLV score ≤1.0 during the non-TLT Line Speed condition to a PFI-TLV score >1.0 during the TLT Line Speed condition than the reverse. The Cut Floor also had the highest proportion of people with a PFI-TLV score >1.0 during both line speed conditions.

Table 5.5.3.A. Conditional odds ratio of having PFI-TLV score > 1.0 per +100 HPH from mixed-effects logistic regression models

	Individuals N	Observations N	Odds Ratio[1] (95% CI)	p-value
By processing area				
Front End	57	136	1.15 (0.77 to 1.73)	0.49
Main Chain	189	371	0.99 (0.77 to 1.28)	0.96
Offal	174	369	1.02 (0.79 to 1.33)	0.86
Cut Floor	129	239	1.11 (0.79 to 1.55)	0.54

1 Models adjusted for age, sex, primary language, and job tenure with a random intercept for person

Table 5.5.3.B. The conditional odds of PFI-TLV score >1.0 per +100 HPH in evisceration line speed from conditional logistic regression models using data matched by person

	Jobs N	Individuals N	Observations N	Odds Ratio[1] (95% CI)	p-value
By processing area					
Front End	4	13	26	0.83 (0.48 to 1.44)	0.51
Main Chain	18	45	90	1.11 (0.83 to 1.49)	0.48
Offal	13	40	80	0.82 (0.60 to 1.12)	0.22
Cut Floor	10	30	60	1.31 (0.92 to 1.88)	0.14

1 Includes individuals with complete PFI-TLV score pairs recorded at non-TLT and TLT line speeds

Table 5.5.3.C. Individual change in ACGIH TLV for Hand Activity category (PFI-TLV score ≤1.0 versus PFI-TLV score >1.0) by processing area using data matched by person

		Categories of PFI-TLV score change from non-TLT week to TLT week[1]			
	N	≤1.0 to ≤1.0 N (%)	>1.0 to ≤1.0 N (%)	≤1.0 to >1.0 N (%)	>1.0 to >1.0 N (%)
By processing area					
Front End	51	22 (43.1%)	8 (15.7%)	5 (9.8%)	16 (31.4%)
Main Chain	148	73 (49.3%)	18 (12.2%)	24 (16.2%)	33 (22.3%)
Offal	161	66 (41.0%)	26 (16.3%)	18 (11.3%)	51(31.3%)
Cut Floor	111	31 (27.9%)	10 (9.0%)	21 (18.9%)	49 (44.1%)

1 Includes individuals with complete PFI-TLV pairs recorded at non-TLT and TLT line speeds

In the analyses stratified by processing area, there were no statistically significant associations between TLT Line Speed and the conditional odds of a PFI-TLV score>1.0.

5.6. Associations between PFI-TLV score and Piece Rate across all Establishments and by TLT Line Speed group

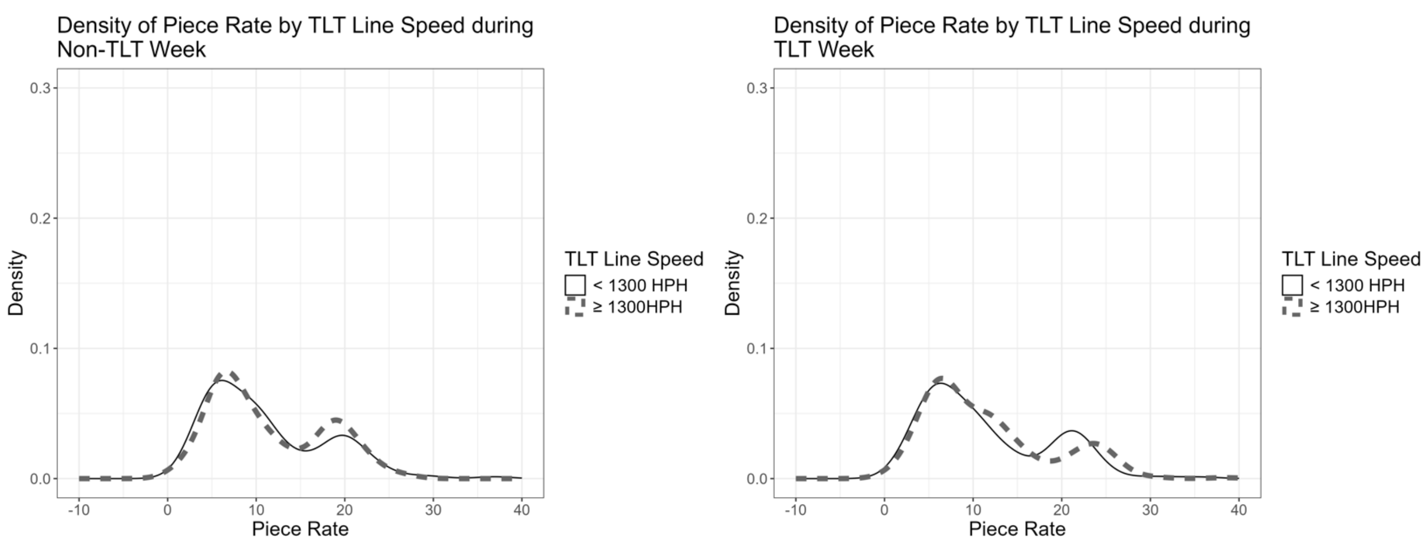
5.6.1. Summary of piece rate across all establishments and by TLT Line Speed group

Since piece rate is a measure that is specific to each job, only models that included job as a random intercept or included within-person matched data are presented. Further, since processing areas had similar job-specific line speeds, the piece rate (units/minute) data is summarized by processing area. The mean and standard deviation of piece rate by processing area and TLT Line Speed group are provided in Table5.6.1.

Table 5.6.1.A. Piece rate by processing area and establishment during non-TLT Line Speed

	Processing Area Piece Rate							
	Front End		Main Chain		Offal		Cut Floor	
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
Non-TLT Line Speed Group								
All Establishments	59	15.7 (5.3)	178	12.2 (6.7)	164	9.1 (5.1)	125	9.7 (8.5)
By TLT Line Speed Groups								
<1,300 HPH	25	15.5 (4.3)	76	12.8 (7.1)	82	8.8 (4.7)	69	10.4 (10.5)
≥1,300 HPH	34	15.8 (6.0)	102	11.7 (6.3)	82	9.4 (5.4)	56	8.7 (5.1)
TLT Line Speed Group								
All Establishments	62	16.1 (6.2)	183	12.4 (7.2)	166	9.4 (5.6)	127	10.0 (8.9)
By TLT Line Speed Groups								
<1,300 HPH	29	15.7 (5.5)	80	13.2 (7.8)	83	8.7 (4.6)	72	11.1 (10.4)
≥1,300 HPH	33	16.4 (6.8)	103	11.8 (6.6)	83	10.1 (6.5)	55	8.6 (6.2)

Figure 5.6.1. Distribution of piece rate when establishments operated at both the non-TLT and TLT Line Speeds by TLT Line Speed group



5.6.2. Unstratified and stratified linear regression models of the change in median PFI-TLV score per one unit/minute increase in piece rate by TLT Line Speed group

The distributions of within-person change in median PFI-TLV scores between the non-TLT and TLT Line Speeds are shown in Figure 5.6.2.

Median Ratio Models. The results of mixed-effect parametric quantile regression models are shown in Table 5.6.2.A. The association between median PFI-TLV score and piece rate (unit/min), adjusted for fixed effects for age, sex, language, and tenure, and conditional on the person-level and job random intercepts, was statistically significant. In the unstratified analysis, the median PFI-TLV score was one percent greater (median ratio = 1.01; 95% CI: 1.00 to 1.02) for each one unit/minute increase in piece rate (controlling for age, sex, primary language and job tenure with a random intercept for person and job). Similar associations (that were nearly statically significant) were observed in analyses stratified by TLT Line Speed group. This positive association between PFI-TLV score and piece rate is depicted in Figure 5.6.2.

Median PFI-TLV score Difference Models. Of note, there are no non-parametric quantile regression model evaluating the difference in median PFI-TLV scores per increase in piece rate (unit/min) because there are no random intercepts, thus job cannot be included in the model.

Figure 5.6.2. Distribution of change in piece rate stratified by TLT Line Speed group

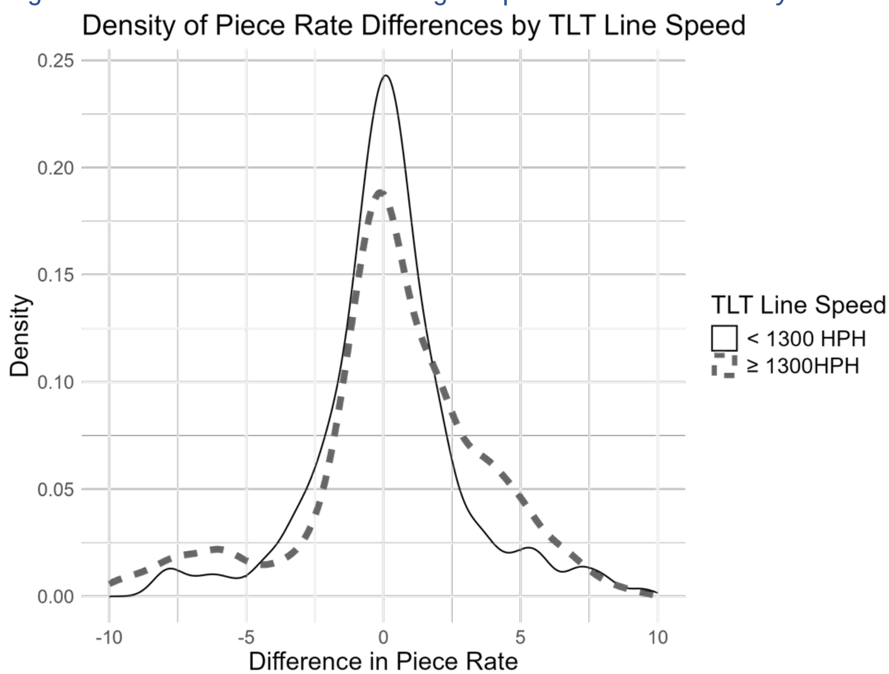
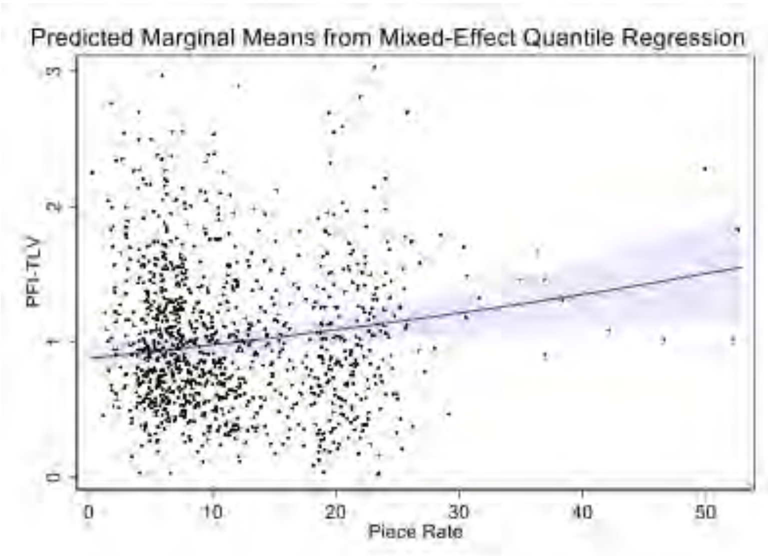


Table 5.6.2.A. Adjusted PFI-TLV median ratio per one unit/minute increase in piece rate from mixed-effects parametric quantile regression models assuming Weibull distributions

	Jobs	Individuals N	Observations N	Median Ratio[1] (95% CI)	p-value
All Establishments	74	611	1,107	1.01 (1.01 to 1.02)	<0.01
TLT Line Speed group					
<1,300 HPH	56	294	543	1.01 (1.00 to 1.01)	0.07
≥1,300 HPH	56	317	564	1.01 (1.00 to 1.02)	0.06

1 Models adjusted for age, sex, primary language, and job tenure with a random intercept for person and job

Figure 5.6.2. The predicted marginal means of PFI-TLV scores by piece rate from mixed-effect quantile regression that included a random intercept for person and job



Within-Person-Matched Change Score Linear Regression Models. The change in mean PFI-TLV score per increase in piece rate (unit/min) using matched data is presented in Table 5.6.2.B. In the unstratified model, when a worker's piece rate increased by one unit/minute, the mean PFI-TLV score increased by a mean of 0.02 (95% CI: 0.01 to 0.03). The strength of association was similar in models stratified by TLT Line Speed group.

Table 5.6.2.B. The change in mean PFI-TLV score per unit/minute increase in piece rate from a linear regression change score analysis using matched data

	Jobs N	Individuals N	Change in mean PFI-TLV score per 1 unit/min piece rate increase (95% CI[1])
All Establishments	69	444	0.02 (0.01 to 0.03)
TLT Line Speed group			
<1,300 HPH	49	215	0.03 (0.002 to 0.04)
≥1,300 HPH	49	229	0.02 (-0.01 to 0.03)

1 bias-corrected and accelerated confidence intervals from 1000 bootstrap replicates

Associations between piece rate and MSD risk were statistically significant.

5.6.3. Unstratified and stratified conditional logistic regression models of PFI-TLV score>1.0 per unit increase in piece rate by TLT Line Speed group

Mixed-Effect Conditional Logistic Regression Models. The results of the mixed-effect logistic regression models are presented in Table 5.6.3.A. There was a statistically significant association between piece rate and having a PFI-TLV score >1.0, conditional on the person-level and job random effects and adjusted for age, sex, language, and job tenure across when including observations from all establishments. Specifically, for a person in a particular job, as the piece rate increased by 1, the odds of PFI-TLV score>1.0 increased by 7%, controlling for age, sex, primary language, and job tenure. For example, an increase in 5 units handled per minute would increase the odds of exceeding a PFI-TLV score of 1.0 by 40%. This result was statistically significant.

The effect estimates were similar in the establishments operating at a TLT Line Speed of <1,300HPH compared to those operating at a TLT Line Speed ≥ 1,300HPH. When logistic regression models were stratified by TLT Line Speed, no statistically significant interaction was observed (p=0.31).

Within-Person Matched Conditional Logistic Regression Models. The odds of a person switching from PFI-TLV score ≤1.0 to a PFI-TLV score>1.0 were 28% higher per unit increase in piece rate (unit/min). The association was statistically significant within each TLT Line Speed group. The differences in the magnitudes of the associations between TLT Line Speed groups was negligible.

Table 5.6.3.A. Conditional odds ratio of having PFI-TLV score >1.0 per unit/minute increase in piece rate from mixed-effects logistic regression models

	Jobs N	Individuals N	Observations N	Odds Ratio[1] (95% CI)	p-value
All Establishments	74	611	1,107	1.07 (1.03 to 1.12)	0.002
TLT Line Speed group					
<1,300 HPH	56	294	543	1.06 (1.01 to 1.11)	0.03
≥1,300 HPH	56	317	564	1.06 (0.99 to 1.14)	0.09

1 Models adjusted for age, sex, primary language, and job tenure with random intercepts for job and person and job

Table 5.6.3.B. Conditional odds of PFI-TLV score >1.0 per unit/minute increase in piece rate, from conditional logistic regression models using data matched by person

	Jobs N	Individuals N	Observations N	Odds Ratio[1] (95% CI)	p-value
All Establishments	45	128	256	1.28 (1.12 to 1.47)	<0.01
TLT Line Speed group					
<1,300 HPH	33	65	130	1.27 (1.03 to 1.57)	0.03
≥1,300 HPH	35	63	126	1.29 (1.07 to 1.55)	0.01

1 Models adjusted for age, sex, primary language, and job tenure

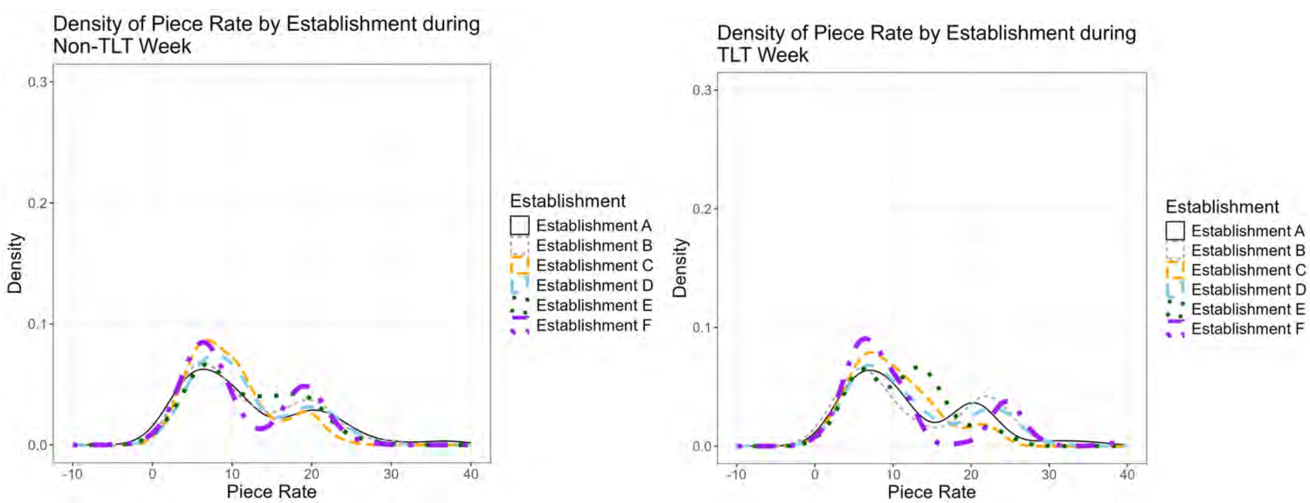
In the unstratified model, the odds of a PFI-TLV score >1.0 increased by 28% per each one additional unit/minute of piece rate. In the stratified models, the odds of a PFI-TLV score >1.0 increased by 27% and 29% per each one additional unit/minute of piece rate in the <1,300HPH and ≥1300HPH TLT Line Speed groups, respectively.

5.7. Associations between PFI-TLV score and Piece Rate by Establishment

5.7.1. Summary of piece rate by processing area and establishment

Since piece rate is a measure specific to each job, only models that include job as a random intercept or include matched data are presented. Further, since processing areas tend to have similar job-specific line speeds (Front End line speed may differ from Main Chain line speed, etc.), the piece rate data is summarized by processing area. Summary statistics of piece rates by area and establishment are provided in Table 5.7.1.A. To maintain the privacy of the establishments, the averages and standard deviations of piece rates in unit/minute by processing area and establishment were reviewed by the study team, but are not provided in this report. Generally, when averaged across all establishments by processing area, there were small increases in piece rate when establishments operated at the TLT Line Speed when compared to the piece rate while operating at the non-TLT Line Speed. Although the differences varied by establishment and processing area, most establishments had a mixture of changes in piece rates across processing areas. Overall, Establishment C was among the lowest piece rates across all processing areas and Establishment B piece rates were among the highest of all piece rates across all processing areas.

Figure 5.7.1. Distribution of piece rates when establishments operated at both the non-TLT and TLT Line Speeds by establishment



5.7.2. Unstratified and stratified linear regression models of the change in median PFI-TLV score per one unit/minute increase in piece rate by establishment

The distributions of within-person change in median PFI-TLV scores between the non-TLT and TLT Line Speeds are shown in Figure 5.7.2. These person-level changes in PFI-TLV scores are not all normally distributed variables, nor are they all strictly unimodal distributions.

Median Ratio Models. The results of mixed-effect parametric quantile regression models are shown in Table 5.7.2.A. The association between median PFI-TLV score and piece rate (unit/min), adjusted for fixed effects for age, sex, language, and tenure, and conditional on the person-level and job random intercepts, was consistent across establishments. Given a person in a particular job, as the piece rate increased one unit/minute, the median PFI-TLV score increased by up to 1%, controlling for age, sex, primary language, and job tenure.

Median PFI-TLV score Difference Models. Models comparing the difference between median PFI-TLV score per unit of piece rate using mixed effects quantile regression could not be adjusted by job; thus, results are not provided.

Within-Person-Matched Change Score Linear Regression Models. The change score analysis, stratified by establishment is presented in Table 5.7.2.B. When there was an increase in a worker's piece rate by 1, the PFI-TLV score increased between 0.01 and 0.03, on average, however associations were close to null and not statistically significant (the confidence intervals included zero).

Figure 5.7.2. Distribution of *change* in piece rate scores stratified by establishment

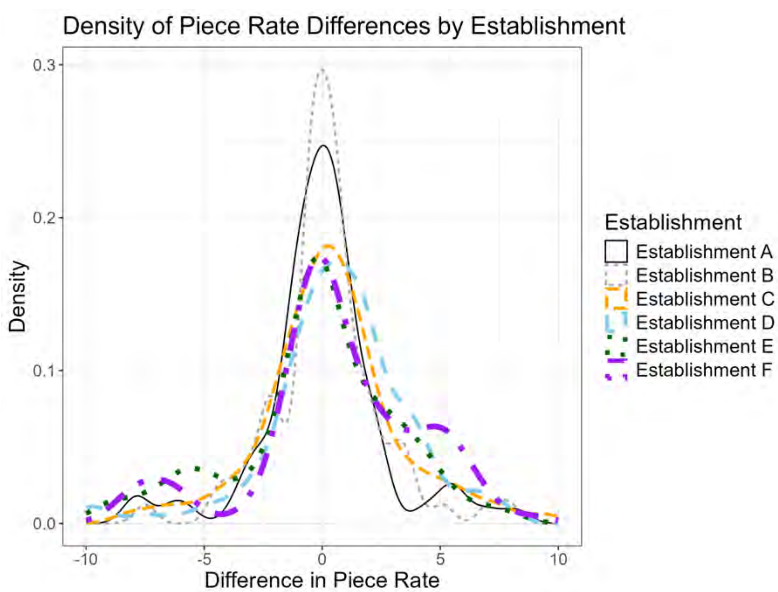


Table 5.7.2.A. Adjusted PFI-TLV median ratio per one unit/minute increase in piece rate from mixed-effects parametric quantile regression models assuming Weibull distributions

	Jobs N	Individuals N	Observations N	Median Ratio[1] (95% CI)	p-value
By Establishment					
Establishment A	40	104	187	1.01 (1.00 to 1.02)	0.06
Establishment B	27	99	184	1.00 (0.99 to 1.01)	0.96
Establishment C	33	91	172	1.00 (0.98 to 1.01)	0.59
Establishment D	38	104	197	1.01 (1.00 to 1.03)	0.08
Establishment E	28	105	178	1.01 (0.98 to 1.03)	0.55
Establishment F	34	108	189	1.00 (0.99 to 1.01)	0.99

1 Models adjusted for age, sex, primary language, and job tenure with a random intercept for person and job

Table 5.7.4.B. The change in mean PFI-TLV per unit change in piece rate from a linear regression change score analysis using data matched by person

	Jobs N	Individuals N	Change in mean PFI-TLV score per unit increase in piece rate (95% CI[1])
By Establishment			
Establishment A	34	76	0.02 (-0.01 to 0.05)
Establishment B	23	63	0.03 (-0.08 to 0.14)
Establishment C	31	76	0.03 (-0.004 to 0.06)
Establishment D	36	87	0.02 (-0.01 to 0.05)
Establishment E	25	66	0.03 (-0.01 to 0.07)
Establishment F	32	76	0.01 (-0.02 to 0.04)

1 Includes individuals with complete PFI-TLV pairs recorded at non-TLT and TLT line speeds
2 bias-corrected and accelerated confidence intervals from 1000 bootstrap replicates

5.7.3. Unstratified and stratified conditional logistic regression models of PFI-TLV score>1.0 per unit increase in piece rate by establishment

Mixed-Effect Conditional Logistic Regression Models. The results of the mixed-effects logistic regression models stratified by establishment are presented in Table 5.7.3.A. Although the effect estimates were elevated at two establishments there were no statistically significant differences in any of the stratified models.

Within-Person Matched Conditional Logistic Regression Models. The results of the conditional logistic regression matching on person and stratified by establishment are presented in Table 5.7.3.B. The odds of a person switching from PFI-TLV score ≤1.0 to a PFI-TLV score>1.0 were 80% higher per unit increase in piece rate (unit/min) (Establishment D). The association was statistically significant for Establishment D. All other establishments also had increased effect estimates but confidence intervals included 1.0.

Table 5.7.3.A. Conditional odds ratio of having PFI-TLV score > 1.0 per unit/minute increase in piece rate from mixed-effects logistic regression models

	Jobs N	Individuals N	Observations N	Odds Ratio[1] (95% CI)	p-value
By Establishment[2]					
Establishment A	40	104	187	1.07 (0.98 to 1.16)	0.12
Establishment B	27	99	184	1.01 (0.94 to 1.09)	0.75
Establishment C	33	91	172	0.99 (0.89 to 1.10)	0.83
Establishment D	38	104	197	1.08 (0.97 to 1.21)	0.17
Establishment E	28	105	178	0.96 (0.85 to 1.09)	0.57
Establishment F	34	108	189	1.02 (0.92 to 1.14)	0.68

1 Models adjusted for age, sex with a random intercept for person and job
2 Interaction term p=0.73

Table 5.7.3.B. Conditional odds of PFI-TLV score >1.0 per unit/minute increase in piece rate, from conditional logistic regression models using data matched by person

	Jobs N	Individuals N	Observations N	Odds Ratio (95% CI)	p-value
By Establishment					
Establishment A	17	19	38	1.27 (0.89 to 1.83)	0.19
Establishment B	13	20	40	1.17 (0.69 to 1.97)	0.57
Establishment C	17	26	52	1.30 (0.96 to 1.78)	0.09
Establishment D	18	26	52	1.80 (1.08 to 3.00)	0.02
Establishment E	15	17	34	1.12 (0.85 to 1.48)	0.40
Establishment F	17	20	40	1.21 (0.92 to 1.59)	0.18

1 Includes individuals with complete PFI-TLV score pairs recorded at non-TLT and TLT line speeds

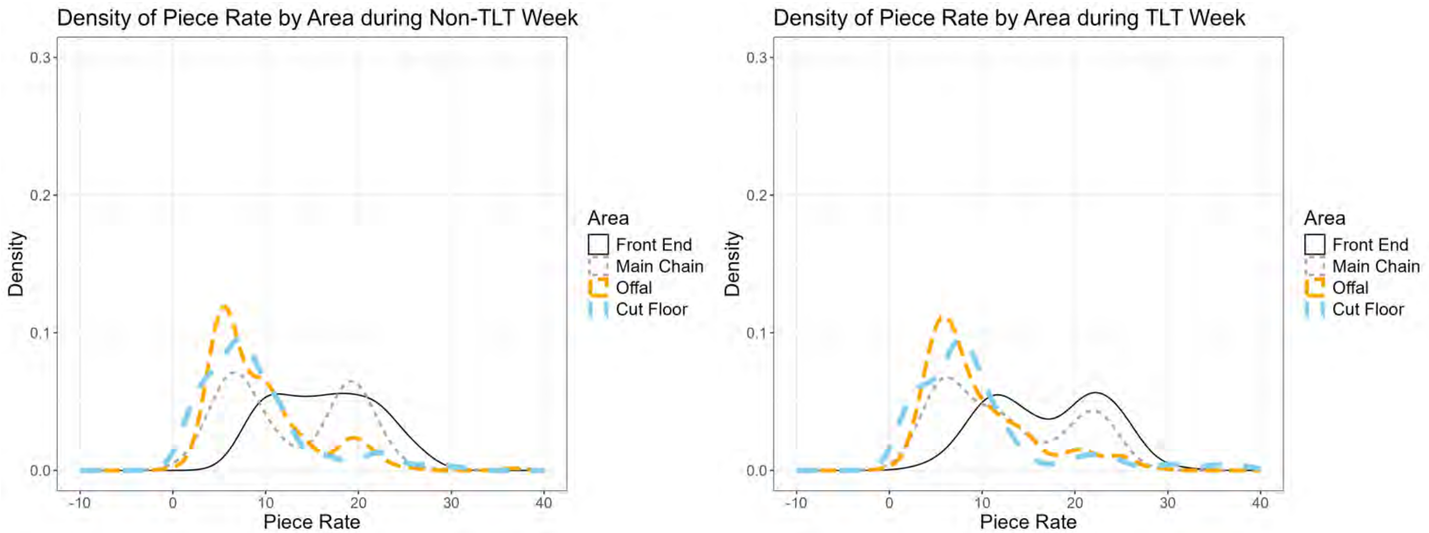
The association between piece rate and MSD risk varied by establishment. Although effect estimates were high for some establishments, confidence intervals were wide and the results were not statistically significant.

5.8. Associations between PFI-TLV scores and Piece Rate by Processing Area

5.8.1. Summary of piece rate by processing area

Since piece rate is a unit of measure that is specific to each job, only models that include job as a random intercept or include matched data are presented. Since processing areas tend to have similar job specific line speeds (front end speed may differ from main chain, etc.), the piece rate data is summarized by processing area.

Figure 5.8.1. Distribution of piece rates when establishments operated at both the non-TLT and TLT Line Speeds by processing area



5.8.2. Unstratified and stratified linear regression models of the change in median PFI-TLV score per one unit/minute increase in piece rate by processing area

The distributions of within-person change in median PFI-TLV scores between the non-TLT and TLT Line Speeds are shown in Figure 5.8.2. These person-level changes in PFI-TLV scores are not all normally distributed variables, nor are they all strictly unimodal distributions.

Median Ratio Models. The results of mixed-effect parametric quantile regression models are shown in Table 5.8.2.A. The association of median PFI-TLV score with piece rate (unit/min), adjusted for fixed effects for age, sex, language, and tenure, and conditional on the person-level and job random intercepts, was statistically significant for the Front End, Main Chain and Cut Floor processing areas. Given a person in a particular job, as the piece rate increases by 1 unit/min, the median PFI-TLV score increases by up to 2%, controlling for age, sex, primary language, and job tenure. There was no interaction by Establishment (p=0.79).

Median PFI-TLV score Difference Models. Of note, there is no non-parametric quantile regression model evaluating the difference in median PFI-TLV scores per increase in piece rate (unit/min) because there are no random intercepts; thus, job cannot be included in the model.

Figure 5.8.2. Distribution of change in piece rate scores when establishments operated at the TLT Line Speed and the Non-TLT Line Speed, stratified by processing area

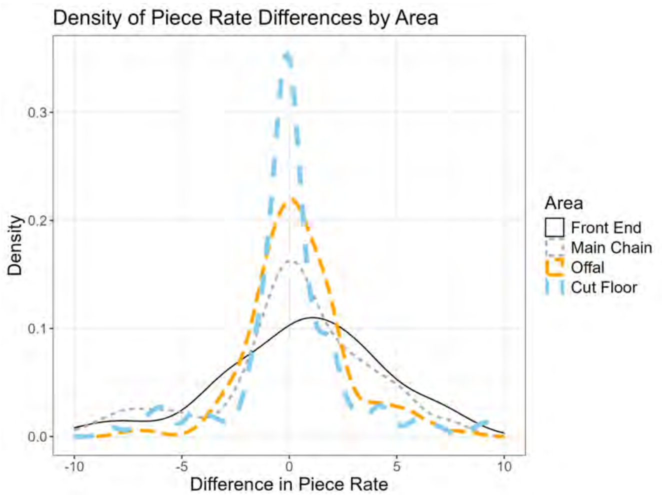


Table 5.8.2.A. The ratio of median PFI-TLV score per one unit/min increase in piece rate from mixed-effects parametric quantile regression models assuming Weibull distributions

	Job N	Individuals N	Observations N	Median Ratio[1] (95% CI)	p-value
By processing area					
Front End	4	77	139	1.02 (1.00 to 1.04)	0.02
Main Chain	33	203	367	1.01 (1.00 to 1.02)	0.02
Offal	23	202	367	1.00 (0.99 to 1.01)	0.47
Cut Floor	14	129	234	1.01 (1.00 to 1.02)	0.01

1 Models adjusted for age, sex, primary language, and job tenure with a random intercept for person and job

Within-Person-Matched Change Score Linear Regression Models. The change in mean PFI-TLV score per increase in piece rate (unit/minute) using matched data is presented in Table 5.8.2.B. None of the results were statistically significant and effect estimates varied in direction, likely due to differences across establishments.

Table 5.8.2.B. The change in PFI-TLV score per one unit/minute increase in piece rate from a linear regression change score analysis using data matched by person

	Jobs N	Individuals N	Change in mean PFI-TLV score per +unit/min piece rate[1] (95% CI[2])
By processing area			
Front End	4	49	-0.005 (-0.04 to 0.04)
Main Chain	30	153	0.01 (-0.01 to 0.03)
Offal	22	143	0.04 (-0.04 to 0.09)
Cut Floor	13	99	0.03 (0.01 to 0.05)

1 Includes only individuals with PFI-TLV scores at both non-TLT and TLT line speeds
2 bias-corrected and accelerated confidence intervals from 1000 bootstrap replicates

For 3 of the 4 processing areas, across all workers studied, there were statistically significant associations between piece rate and MSD risk (ratio of median PFI-TLV scores).

For just the subset of workers who had PFI-TLV data at both the non-TLT and TLT Line Speeds, the significant association was only observed for the Cut-Floor processing area

5.8.3. Unstratified and stratified conditional logistic regression models of PFI-TLV score>1.0 per unit increase in piece rate by processing area

Mixed-Effect Conditional Logistic Regression Models. The odds of a worker exceeding a PFI-TLV score >1.0 per unit/minute increase in piece rate could not be calculated by area since job and area are colinear.

Within-Person Matched Conditional Logistic Regression Models. Using matched data in conditional logistical regression models (Table 5.8.3.A), the odds of a person switching from PFI-TLV score ≤1.0 to a PFI-TLV score >1.0 were up to 57% higher per unit/min increase in piece rate in the offal area, a result that was statistically significant. The effect estimates were also elevated for the other processing areas and ranged between a 14% to 108% increase in odds of a person switching from low to high MSD risk per unit/minute increase in piece rate, although the confidence intervals were wide and included 1.0.

Table 5.8.3.A. Conditional odds of PFI-TLV score >1.0 per one unit/minute increase in piece rate, from conditional logistic regression models using data matched by person

	Jobs N	Individuals N	Observations N	Odds Ratio[1] (95% CI)	p-value
By processing area					
Front End	4	13	26	2.08 (0.93 to 4.68)	0.08
Main Chain	18	42	84	1.14 (0.97 to 1.35)	0.12
Offal	13	40	80	1.57 (1.05 to 2.35)	0.03
Cut Floor	10	30	60	1.31 (0.97 to 1.76)	0.07

1 Includes individuals with complete PFI-TLV score pairs recorded at non-TLT and TLT line speeds

Overall, an increase in piece rate by 1 unit/minute increased the odds of having a PFI-TLV score >1.0 by 57% for Offal workers. Effect estimates were elevated for the other processing areas but lacked statistical significance (p-values ranged between 0.07 and 0.12).

5.9. Case Study: Evisceration Line Speed and Low Back MSD Risk

Associations of TLT Line Speed and low back MSD risk. The Palletizing job involves manually lifting boxes of products on a conveyor and stacking them on pallets for transport. This job was analyzed using the RNLE at one of the six establishments. Details of the RNLE methodology are included in Section 4.6.2 of this report. A summary of the number of workers analyzed, the average lift frequency, the Composite Lift Index (CLI), and the FILI by evisceration line speed are summarized in Table 5.9.1.2.A. The average CLI across Palletizers exceeded 1.5, indicating a high risk for low back pain and injury (see Table 1.3.2). When the establishment operated at the non-TLT Line Speed, the CLI for individual workers ranged from 2.1 to 7.2. When they operated at the TLT Line Speed, the CLIs increased to a range of 4.0 to 7.8 when the establishment operated at the TLT Line Speed. The average CLI increased by 19%. These results indicate high hazard at *both* evisceration line speeds.

One of the primary elements of manual material handling contributing to the low back injury hazard among Palletizers was the weight of boxes lifted, a risk factor that is not influenced by line speed. Observed box weights of three different box sizes were read from package labels and ranged from 38 lbs. to 100 lbs. The weights used in the RNLE analysis were 40 lbs. (observed loads ranged from 38-42 lbs.), 65 lbs. (observed loads ranged from 63.9 - 70.5 lbs.), and 85 lbs. (a conservative weight given that the observed loads ranged from 84.5-100 lbs.). Other elements that contributed to the hazard were (i) the torso bending, shoulder flexion, and shoulder elevation required to stack boxes on pallets, (ii) the hours of exposure per day (8 hours), and (iii) the lifting frequency. Based on the physical lifting conditions (i.e., the biomechanical criterion which incorporates the loads lifted and the horizontal and vertical reach of the lifts), the highest Frequency Independent Lifting Index (FILI) exceeded 1.5 for all but two of the 10 workers analyzed; the two workers primarily lifted 40-lb boxes.

The CLI score was higher when workers palletized during the TLT Line Speed, but not due to frequency of the lifts. Despite this, the MSD risk was high when the establishment operated at both the non-TLT and the TLT Line Speed.

Table 5.9.1. The association between the line speed rate and the NIOSH Composite Lifting Index (CLI) for the Palletizing job

Job	N	Lift Frequency[1] Mean (SD)	CLI Mean (SD)	CLI Range	Highest FILI[2] Range
Palletizing	10				
Non-TLT Line Speed	5	4.3 (4.3)	4.3 (2.3)	2.1 - 7.2	1.1 - 2.4
TLT Line Speed	5	4.0 (1.2)	5.1 (1.5)	4.0 - 7.8	2.0 - 2.8

1 Lift frequency in lifts per minute
2 FILI is the frequency-independent lift index or the composite lift index if the frequency of lifting was ignored

> Low back MSD risk for the palletizing job at the establishment where this was evaluated was very high. As recommended in the OSHA Meatpacking Guidelines, engineering controls, such as pallet lifts and vacuum lifts, should be implemented at all establishments to reduce risk of low back MSDs.

5.10. Peracetic Acid Airborne Concentrations and Respiratory Symptoms

5.10.1. Summary of PAA data collection

In total, 35 sampling locations were selected across five different establishments. One establishment was excluded from the study as they did not use PAA as an antimicrobial intervention. At these 35 locations, 685 samples were collected, amounting to 3,425 minutes of sampling. At establishment C, the 10 repeat samples were not collected at each sampling location due to sensor issues, which resulted in 35 samples without a matched pair. However, at that location, the 35 samples missing a matched pair were all non-detectable samples of PAA set at 0.00 ppm. Thus, this did not impact the overall analysis. A summary of the airborne PAA concentration data collected and used in the analysis is summarized in Table 5.10.1.

Table 5.10.1 Airborne Peracetic Acid (PAA) concentration data collected by evisceration line speed group[1]

	<1,300 HPH Establishments (N)	≥1,300 HPH Establishments (N)*	All Establishments (N)
Sampling Locations	22	13	35
Total Minutes Sampled	2125	1,300	3425
Total Samples by Plant Grouping	425	260	685
Non-TLT Short-Term (5-minute) Samples Collected	195	130	325
TLT Short-Term (5-minute) Samples Collected	230	130	360

1 Following onsite confirmation, Establishment D was excluded from analysis due to no use of PAA

5.10.2. Comparison of antimicrobial exposure measures by line speed

Overall, PAA was well controlled across the five establishments that used it as an antimicrobial intervention. Only four samples were taken at two different sampling locations at two different establishments where the PAA exceeded the ACGIH STEL of 0.4 ppm. The one sampling location, the inlet of an antimicrobial intervention cabinet for the whole hog, was not where employees would typically stand and was used as a reference for the "worst" case of exposure at that establishment. The second sampling location, which had readings of 0.89 ppm and 0.72 ppm, was at a pack-off location where employees were working; however, the other samples collected at that sampling location ranged from 0.01 ppm to 0.05. This may indicate that throughout the workday, temporary factors may inhibit effective air movement in that location (such as stacking up boxes of products) and may prevent the building's overall ventilation system from providing fresh makeup air in certain areas.

When comparing all paired samples, there was a statistically significant difference between the measured levels of PAA at the non-TLT line speed and the TLT line speed. When grouped by establishments that ran <1,300 HPH at the TLT speed, the statistically significant difference between TLT and non-TLT line speeds remained, with higher levels of PAA at the TLT line speed. However, when grouped by the establishment that ran ≥1,300 HPH, that difference was no longer statistically significant.

Table 5.10.2. Summary of PAA exposure monitoring results by establishment groups

	Locations Sampled	PAA Concentration Range (PPM)	PAA Mean (SD)	# of Samples > ACGIH STEL of 0.4 PPM (%)	Wilcox-Signed Rank Test: TLT vs. Non-TLT
All Locations					
All Samples	685	0.00-0.89	0.06 (0.08)	4 (0.6%)	Z = -4.533 P-value =<.001 N=325 matched pairs
TLT	360	0.00-0.89	0.06 (0.10)	3 (0.8%)	
Non-TLT	325	0.00-0.41	0.05 (0.07)	1 (0.3%)	
<1,300 HPH Establishments					
All Samples	425	0.00-0.89	0.068 (0.089)	2 (0.5%)	Z = -6.031 P-value =<0.001 N=195 matched pairs
TLT	230	0.00-0.89	0.078 (0.109)	2 (0.9%)	
Non-TLT	195	0.00-0.23	0.056 (0.056)	0 (0.0%)	
≥1,300 HPH Establishments					
All Samples	260	0.00-0.43	0.0.39 (0.074)	2 (0.8%)	Z = -1.678 P-value =0.093 N=130 matched pairs
TLT	130	0.00-0.43	0.036 (0.067)	1 (0.8%)	
Non-TLT	130	0.00-0.41	0.042 (0.079)	1 (0.8%)	

5.10.3. Comparison of PAA by establishment, plant area, and PAA application type

Tables 5.10.3. A summarizes the airborne PAA concentrations at each establishment surveyed, excluding establishment D due to not using PAA. When comparing paired samples by establishment, only Establishment B had a statistically significant difference between TLT and non-TLT line speeds, with higher levels of PAA at the TLT line speed. This indication that the difference in airborne PAA concentrations only remained statistically significant for one establishment may be due to various reasons, including the type of PAA application and the area of the plant where the PAA was applied. To better understand this, the relationship between airborne PAA concentrations and line speeds was examined by the type of PAA application and the area of the plant in which the PAA was applied.

Two main PAA application methods were used in the establishments visited for this study: the antimicrobial intervention cabinets or enclosures for treating the whole hog and the antimicrobial interventions along the conveyor belts of the cut floor, where conveyor belts carrying cuts of meat cuts were sprayed with PAA. For the whole hog application, establishments used three different methods for antimicrobial intervention: three establishments had a “CHAD” cabinet, one had an “IST” Cabinet, and one used a hallway leading out of the chiller as an application point. Of these whole hog application sites, two (one CHAD cabinet and one IST cabinet) were positioned before the hogs entered the chiller, and three (two CHAD cabinets and the hallway application) occurred as the hogs were leaving the chiller. For the further processing antimicrobial interventions that were along the cut floor, the application of PAA was either a spray application of PAA directly onto a saw blade, a spray application (consisting of spray nozzles with no enclosure) over the cut floor processing line conveyor belts, or a spray application (consisting of spray nozzles with partial enclosure over the spray bars) on the cut floor processing line conveyor belts.

Table 5.10.3.A. Summary of airborne PAA concentrations by establishment

	Samples	PAA Concentration Range (PPM)	PAA Mean (SD)	# of Samples > ACGIH STEL of 0.4 PPM	Wilcox-Signed Rank Test: Fast vs. Slow
Establishment A					
All Samples	130	0.00-0.29	0.07 (0.08)	0	Slow-fast Z = -0.497 P-value =0.62
TLT	70	0.00-0.29	0.07 (0.08)	0	
Non-TLT	60	0.00-0.23	0.08 (0.07)	0	
Establishment B					
All Samples	200	0.00-0.89	0.10 (0.10)	2	Slow-fast Z =-7.200 P-value =<.001
TLT	100	0.00-0.89	0.13 (0.13)	2	
Non-TLT	100	0.00-0.21	0.06 (0.04)	0	
Establishment C					
All Samples	95	0.00-0.01	0.0001 (0.001)	0	Slow-fast Z =-1.000 P-value =0.317
TLT	60	0.00-0.00	0.00 (0.00)	0	
Non-TLT	35	0.00-0.01	0.0003 (0.002)	0	
Establishment E					
All Samples	120	0.00-0.13	0.01 (0.02)	0	Z =-0.017 P-value =0.986 N=60 matched pairs
TLT	60	0.00-0.05	0.01 (0.01)	0	
Non-TLT	60	0.00-0.13	0.01 (0.02)	0	
Establishment F				p	
All Samples	140	0.00-0.43	0.07(0.09)	2	Z = -1.565 P-value =0.118 N-70 matched pairs
TLT	70	0.00-0.43	0.06(0.08)	1	
Non-TLT	70	0.00-0.41	0.07(0.10)	1	

When examining the impact line speed has on the airborne PAA concentrations by the type of application, there was a statistically significant difference between the TLT and Non-TLT line speeds only in areas where PAA was applied to specific parts along the cut floor further processing versus the whole hog applications, which is shown in Table 5.10.3 B. One potential reason for there not being a statistical difference in airborne PAA concentrations for the whole hog application may be attributed to the chain speed of the hogs as they pass through the whole hog PAA application. For three of the whole hog applications of PAA cabinets/hallway, regardless of line speed, the chain speed for the hogs going through the cabinets/hallway remained the same, keeping the airborne PAA concentrations consistent for both the TLT and non-TLT line speed study weeks.

There was a statistically significant difference between the airborne PAA concentrations for the TLT and non-TLT line speeds for those areas applying PAA along the conveyor belts of the cut floor line as shown in Table 5.10.3.C. These application points tended to be less contained compared to the whole hog application cabinets and also tended to have greater potential for standing water containing PAA to accumulate. These PAA application points also tended to have greater exposure to workers, as these forms of PAA application were adjacent to where workers stood or were attached to the tools being used by the workers, whereas the whole hog applications, in general, tended to not have workers standing adjacent to the cabinets/hallway.

Table 5.10.3.B. Summary of airborne PAA concentrations by type of application: on the whole hog vs. parts wash application

	Locations Sampled	PAA Concentration Range (PPM)	PAA Median	# of Samples > ACGIH STEL of 0.4 PPM	Wilcox-Signed Rank Test: TLT vs. Non-TLT
Whole Hog Application					Z = -1.023 P-value =0.306 N=205 matched pairs
TLT	230	0.00-0.43	0.01	1	
Non-TLT	205	0.00-0.41	0.01	1	
Parts Wash Application					Z =-5.169 P-value =<.001 N=120 matched pairs
TLT	130	0.00-0.89	0.07	2	
Non-TLT	120	0.00-0.22	0.06	0	

Finally, the impact of line speed on airborne PAA concentration was examined by the location within the establishment, the results of this analysis are summarized in Table 5.10.3.C. There were only three locations where PAA was applied: the cut floor, the main chain, and the offal/head areas. Looking at the difference in airborne PAA concentrations for each location, comparing matched pairs of the TLT and non-TLT line speeds, only the cut floor, which is also where all of the parts wash applications were located, was found to have a statistically significant difference between the TLT and the non-TLT line speeds, with airborne PAA concentrations being higher on the TLT line speed weeks. This difference is consistent with the previous analysis, which found airborne PAA concentrations to be higher during the TLT line speed weeks for the parts wash application.

Table 5.10.3.C. Summary of airborne PAA concentrations by location in the establishment

Locations Sampled		PAA Concentration Range (PPM)	PAA Median	# of Samples > ACGIH STEL of 0.4 PPM	Wilcox-Signed Rank Test: Fast vs. Slow
Cut Floor					Slow-fast Z = -4.533 P-value =<0.001 N=325 matched pairs
TLT	360	0.00-0.89	0.02	1	
Non-TLT	325	0.00-0.41	0.03	1	
Main Chain					Slow-fast Z =-1.915 P-value =0.055 N=30 matched pairs
TLT	30	0.03-0.29	0.15	0	
Non-TLT	30	0.00-0.23	0.12	0	
Offal/ Head					Slow-fast Z =-1.565 P-value =0.118
TLT	70	0.00-0.43	0.03	1	
Non-TLT	70	0.00-0.41	0.03	1	

These results indicate that while increasing line speed does appear to lead to higher airborne concentrations of PAA, this impact is limited to parts wash applications of PAA on the cut floor. To mitigate this increase in airborne PAA concentrations, we recommend investigating enclosures for the spray bar applications of PAA, increasing ventilation in the areas of the establishment where PAA is applied, especially in areas where PAA application is integrated with the tools, and finally, making sure that there is effective drainage of water containing PAA.

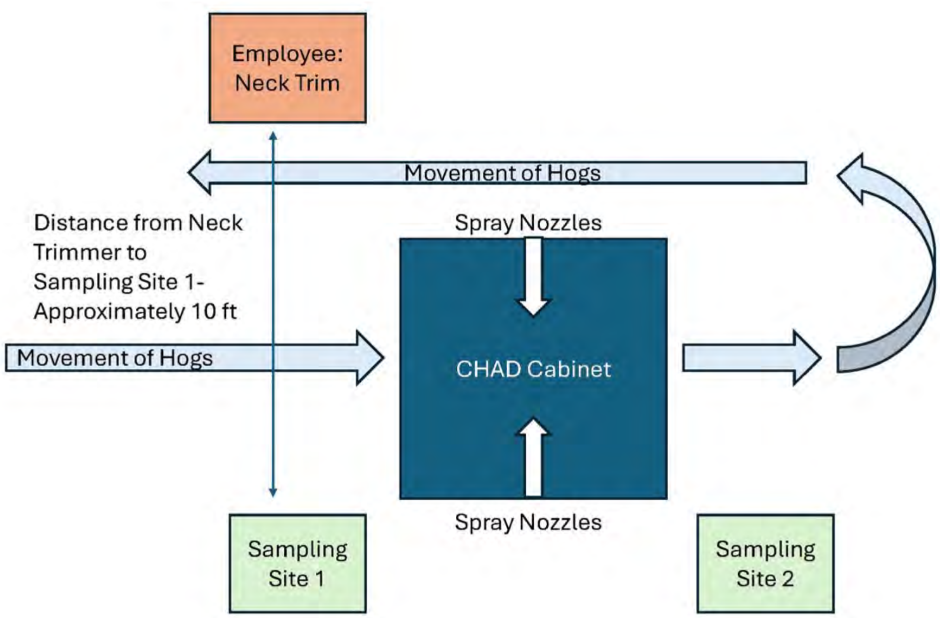
5.10.4. Case Study: Controlling exposure through ventilation controls and enclosures

Following discussions with the industrial hygienist, who performed the first week of sampling for PAA at one of the establishments and commented about the droplets of water spraying outside the antimicrobial intervention cabinet, the fan speed of the ventilation system was adjusted, and plastic strips were added to the inlet and outlet of the cabinet. For the integrity of the USDA study, the industrial hygienist onsite for week two requested that conditions be reverted to the original settings for the formal study but offered to conduct a secondary study comparing the two conditions for the company's benefit. This establishment sprays Terrastat 22 PAA product onto the carcasses using spray nozzles on both sides of the cabinet. The cabinet has an exhaust ventilation system pulling air from inside the cabinet up and out of the building, a capture basin at the bottom, and drainage in the capture basin to remove pooling water.

The ChemDAQ SafeSide™ was used for instantaneous real-time measurements and 5-minute time-integrated TWA samples at two different locations at the CHAD cabinet. A monitor was positioned on the industrial hygienist and was clipped onto the chest harness worn. The ChemDAQ SafeSide™ User’s Manual states that the sensor cannot get wet because condensation or water on the sensor's membrane will absorb PAA vapor. Additionally, a beard net was wrapped around the sensor to protect the membrane from exposure to water droplets. This case study was designed to compare the exposures before and after adjustments to the antimicrobial intervention cabinet ventilation and the addition of plastic slats to the inlet and outlet of the cabinet.

Two sampling locations were selected: one at the CHAD cabinet's inlet and another at its outlet. Sampling site 1 was approximately 10 feet from where the Next Trimmer stood, which was the closest employee working in proximity to the CHAD cabinet. These sampling locations are shown in Figure 5.84.

Figure 5.10.4 Layout of CHAD cabinet and sampling locations for case study



In total, 34 five-minute-long samples were collected. For location one, seventeen samples were collected:10 samples without controls (original ventilation settings and no plastic strips) and seven samples with the engineering control (adjusted fan speed and introduction of plastic strips). For location two, seventeen samples were collected:10 samples without engineering control adjustments (original ventilation settings and no plastic strips) and seven samples with engineering control adjustments (adjusted fan speed and introduction of plastic strips).

In summary, increasing the fan speed for the cabinet ventilation and encapsulating the cabinet to prevent the escape of water droplets has effectively reduced employee exposure to peracetic acid. The mean exposure for each of the locations and a combined average both before and after the implementation of controls are summarized in Table 1 below. Overall, the adjustments led to a 77% reduction in exposure to peracetic acid, which was statistically significant.

Table 5.10.4. Summary of results comparing pre- and post-adjustments to the ventilation and additional enclosure using plastic slats

Location	Mean PAA Exposure without Controls	Mean PAA Exposure with Controls	Percentage Decrease in PAA	Wilcoxon Sign-Rank Test p-value
Location 1 CHAD Inlet	0.035 ppm	0.007 ppm	80%	0.011
Location 2 CHAD Outlet	0.009 ppm	0.003 ppm	67%	0.025
Both Locations Combined	0.022 ppm	0.005 ppm	77%	0.001

Overall, airborne PAA concentration was well controlled across the five establishments that used it as an antimicrobial intervention. Only four of the 34 samples, taken at two different sampling locations, exceeded the ACGIH STEL of 0.4 ppm.

5.11. Health Effects

5.11.1. Associations between TLT Line Speed and moderate to severe upper extremity pain during the past 12 months

As described previously, work-related upper extremity pain was defined as any pain or discomfort during the past 12 months that was worse at work and lasted more than one day. Moderate to severe work-related upper extremity pain was defined as work-related upper extremity pain rated at a severity level of four or greater on a zero-ten Likert scale. Overall, 42.8% of 498 workers reported moderate to severe pain in the last 12 months, with similar proportions across establishments in the <1,300 and ≥1,300 HPH TLT Line Speed groups (Table 5.11.1.A).

In the unstratified analysis, the odds of reporting moderate to severe upper extremity pain were 31% greater per +100 HPH (OR=1.31; 95% CI: 1.04 to 1.66) (Table 5.11.1.A). In the stratified analysis, workers at establishments operating at lower TLT Line Speeds (<1,300 HPH) had a statistically significant 80% greater odds of experiencing moderate to severe upper extremity pain during the past 12 months per +100 HPH in line speed and workers at establishments operating at higher TLT Line Speeds had a non-statistically significant 58% greater odds of experiencing moderate to severe upper extremity pain during the past 12 months per +100 HPH in line speed. The association between evisceration line speed and moderate to severe upper extremity pain could not be stratified by establishment because the evisceration line speed did not vary by worker within each establishment.

Table 5.11.1.A. Association between TLT Line Speed and work-related moderate to severe upper extremity pain over the past 12 months from logistic regression models by , TLT Line Speed group

	All, N	Moderate to Severe Pain during the last 12 months N (%)	Odds of reporting Moderate to Severe Pain per +100 HPH OR (95% CI)	p-value
All Establishments	498	213 (42.8%)	1.31 (1.04 to 1.66)	0.02
TLT Line Speed Groups				
<1,300 HPH	243	101 (41.6%)	1.80 (1.06 to 3.07)	0.03
≥1,300 HPH	255	112 (43.9%)	1.58 (0.70 3.57)	0.27

1 Models adjusted for age, sex, primary language, and job tenure

There were no statistically significant associations between line speed and moderate to severe upper extremity pain by processing area (Table 5.11.1.B). When logistic regression models were stratified by area, no statistically significant interaction was observed (p=0.50).

Table 5.11.1.B. Association between line speed and moderate to severe upper extremity pain over the past 12 months by processing area from logistic regression models by processing area

	All, N	Moderate to Severe Pain during the last 12 months N (%)	Odds of having Moderate to Severe Pain per +100 HPH OR (95% CI)	p-value
By processing area				
Front End	46	27 (54.0%)	1.45 (0.55 to 3.84)	0.46
Main Chain	169	63 (36.6%)	0.96 (0.62 to 1.45)	0.84
Offal	156	70 (44.5%)	1.46 (0.93 to 2.30)	0.10
Cut Floor	120	53 (44.2%)	1.58 (1.0 to 2.52)	0.05

1 Models adjusted for age, sex, primary language, and job tenure

5.11.2. New hire "break-in" MSD pain

For the purpose of this report, *break-in pain* was defined as new-onset pain or discomfort of any severity that participants reported experiencing at the time that they first started working at the establishment. Approximately 66% of surveyed workers reported experiencing break-in pain regardless of the TLT Line Speed group. Sixty-six percent of workers in both TLT Line Speed groups reported resolution of their break-in pain by the second month after being hired. Additionally, 18% of workers who reported break-in pain at establishments operating at ≥1,300 HPH had continued pain at the time of the site visit compared to 13% of workers at establishments operating at <1,300 HPH.

Table 5.11.2. Summary of new hire or "break-in" pain by evisceration line speed

	<1,300HPH N (%)	≥1,300HPH N (%)	All Establishments N (%)
Pain or discomfort when first started working[1]			582
Yes	185 (65.6%)	197 (65.7%)	382 (65.6%)
No	95 (33.7%)	103 (34.3%)	198 (34.0%)
I don't recall	2 (0.7%)	0 (0.0%)	2 (0.3%)
Reported duration of break-in pain after time of hire[2]			382
Resolved in <2 weeks	46 (24.9%)	27 (13.7%)	73 (19.1%)
2- 4 Weeks	53 (28.6%)	67 (34.0%)	120 (31.4%)
1-2 Months	23 (12.4%)	36 (18.3%)	59 (15.4%)
2-3 Months	31 (16.8%)	29 (14.7%)	60 (15.7%)
Continued pain or discomfort	24 (13.0%)	36 (18.3%)	60 (15.7%)
I do not recall	8 (4.3%)	2 (1.0%)	10 (2.6%)

1 includes all those surveyed
2 includes only those who responded yes to having any work-related pain when they first started working (i.e., "break-in" pain), even those with a tenure of <90 days (<2.8%, see Table 5.2.2)

> Break-in pain experienced at the time of hire was reported by 65% of all interviewed workers. Break-in pain had not resolved as of the establishment visit for 16% of interviewed workers.

5.11.3. Work-related pain reporting behavior

Pain-reporting behavior and some characteristics of care provided to workers who reported any work-related pain lasting one or more days are provided by TLT Line Speed group in Table 5.11.3. Of the 322 workers who reported any work-related pain lasting one or more days during the 12 months prior to the site visit, about two thirds reported the pain to their supervisor and the onsite nurse. Among the 86 workers who did not report their work-related pain, one third reported that their pain was very mild and almost one fifth reported that they were able to care for the pain themselves. Seventeen percent of those who did not report their pain to their supervisor or the company nurse reported that they did not know how to report it to them and five percent were afraid of retribution in response to reporting of pain. Small differences were observed in pain reporting behavior by TLT Line Speed group. Eighty-three percent of those reporting pain received first aid from the onsite health are practitioner; 35% received such first aid for two weeks or longer. Sixteen percent of workers who reported pain reported that they were evaluated by any doctor.

As noted above, many workers reported experiencing pain when they first started their job and a substantial proportion reported ongoing pain. If the participants in our study represent those workers who "survive" (i.e., remain employed at the establishment after) the break-in period, it is possible that the proportion of participants employed at the time of the establishment site visit who reported pain (regardless of severity) was an underestimate of the proportion of all persons who had been employed as swine establishment workers (regardless of current employment status) during the year prior to the site visit who had experienced pain.

Table 5.11.3. Work-related pain reporting behavior by TLT Line Speed group

	TLT Line Speed		All Establishments
	<1,300HPH N (%)	≥1,300HPH N (%)	
Let supervisor know about your pain[1]			321
No, N (%)	39 (25.3%)	64 (38.3%)	103 (32.1%)
Reported to supervisor, N (%)	115 (74.7%)	103 (61.7%)	218 (67.9%)
Let onsite nurse know about your pain[1]			322
No, N (%)	50 (41.0%)	72 (59.0%)	122 (37.9%)
Reported to onsite nurse, N (%)	104 (52.0%)	96 (48.0%)	200 (62.1%)
Reason pain was not reported[2]			86
It was very mild, N (%)	12 (36.4%)	16 (30.2%)	28 (32.6%)
I can take care of myself, N (%)	5 (15.2%)	11 (20.7%)	16 (18.6%)
I didn't know how to report the problem, N (%)	1 (3.0%)	0 (0.0%)	1 (1.2%)
I didn't think the company would help me, N (%)	7 (21.2%)	8 (15.1%)	15 (17.4%)
I was afraid of being punished or losing job, N (%)	1 (3.0%)	3 (5.7%)	4 (4.6%)
Other, decline to answer, N (%)	7 (21.2%)	15 (28.3%)	22 (25.6%)
Received first aid from onsite health care practitioner[3]			218
No, N (%)	17 (14.8%)	20 (19.4%)	37 (17.0%)
Yes, N (%)	98 (85.2%)	83 (80.6%)	181 (83.0%)
Weeks of first aid by onsite health care practitioner[4]			180
<2 weeks, N (%)	62 (63.9%)	55 (66.3%)	117 (65.0%)
> 2 week but < 6 weeks, N (%)	18 (18.6%)	15 (18.1%)	33 (18.3%)
> 6 weeks and < 10 weeks, N (%)	7 (7.2%)	9 (10.8%)	16 (8.9%)
> 10 weeks, N (%)	10 (10.3%)	4 (4.8%)	14 (7.8%)
Evaluated (onsite or offsite) by any doctor[1]			321
No, N (%)	121 (78.6%)	134 (80.2%)	255 (79.4%)
Yes, N (%)	22 (14.3%)	28 (16.8%)	50 (15.6%)
Other, decline to answer, N (%)	11 (7.1%)	5 (3.0%)	16 (5.0%)

1 includes only those who responded yes to having any work-related pain over the past 12 months
2 includes only those who responded no to reporting their pain to their company nurse or supervisor
3 includes those who reported their pain to their company nurse or supervisor
4 includes only those who responded yes to having received first aid from the company

Approximately 1 in 3 workers who reported experiencing any pain during the 12 months prior to the study site visit *did not* report their pain to their supervisor or to the company nurse.

5.11.4. Impact of work-related pain

As reported above, 322 study participants reported experiencing any work-related pain lasting one or more days during the 12 months prior to the site visit. Among the participants who reported experiencing any pain lasting one or more days during the 12 months prior to the site visit, the number who (i) reported difficulty in maintaining the pace or quality of work, (ii) considered quitting or changing lines, (iii) had pain that prevented them from doing important activities outside of work or (iv) took time off work, as a consequence of their pain, is presented by Evisceration Line speed category in Table 5.11.4. Across all establishments, 19% of the 322 respondents reported moderate to severe difficulty maintaining their expected work pace or quality and 24% of workers reported that they considered quitting or changing lines because of pain, with a higher proportion in the higher TLT Line Speed group establishments (28.2% vs. 18.8%). Thirty-six percent of 322 respondents reported that their pain prevented them from engaging in important activities outside of work with a higher proportion in establishments in the TLT Line Speed <1,300HPH group (45.5% vs 27.5%). Seventeen percent of the 322 respondents took time off work because of pain.

Table 5.11.4. Impact of any pain in the last 12 months on work, consideration of quitting, and outside activities

	TLT Line Speed Group		
	<1,300 HPH N (%)	≥1,300 HPH N (%)	All Establishments N (%)
Difficulty maintaining expected work pace or quality of work[1]			321
No difficulty, N, %	87 (56.5%)	88 (52.7%)	175 (54.5%)
Mild difficulty, N, %	34 (22.1%)	51 (30.5%)	85 (26.5%)
Moderate difficulty, N, %	20 (13.0%)	25 (15.0%)	45 (14.0%)
Severe difficulty, N, %	13 (8.4%)	3 (1.8%)	16 (5.0%)
Considered quitting or changing lines because of pain[1]			321
No, N, %	125 (81.2%)	120 (71.8%)	245 (76.3%)
Considered changing lines, N, %	27 (17.5%)	39 (23.4%)	66 (20.6%)
Considered quitting, N, %	2 (1.3%)	8 (4.8%)	10 (3.1%)
Pain or discomfort prevents important activities outside of work[1]			321
No, N, %	84 (54.5%)	121 (72.5%)	205 (63.9%)
Yes, N, %	70 (45.5%)	46 (27.5%)	116 (36.1%)
Time off work[2] because of pain or discomfort[1]			321
No, N, %	115 (74.7%)	117 (70.0%)	232 (72.3%)
No, but I wanted to, N, %	11 (7.1%)	25 (15.0%)	36 (11.2%)
Yes, N, %	28 (18.2%)	25 (15.0%)	53 (16.5%)

1 includes only those who responded yes to having any work-related pain over the past 12 months
2 Time off work could include medical leave, paid time off, or unpaid time off

Among those who reported experiencing any work-related pain lasting one or more days during the past 12 months, almost 1 in 5 reported having moderate to severe difficulty maintaining their expected work pace and almost 1 in 4 reported that they considered quitting or changing lines because of their pain.

5.11.5. Medical interviews

A total of 36 medical interviews were completed onsite by study physicians across the six establishments. Two UCSF faculty physicians (RH and SG) reviewed all interview notes and thematic information about musculoskeletal symptoms, injuries, and medical management was abstracted.

Pain was common among interviewed workers and was accepted by workers as part of the job. Workers reported frequently experiencing pain on the job. Workers performing a range of jobs described experiencing ongoing pain with one long-term employee stating that he "still hurts every day." Others reported that "not one job is easy here", "this is a job that tests you", and "I've been here a long time, and I still hurt every day". Workers were unable to identify one job in the establishment that they believed was not physically demanding.

Reporting pain and injuries. Several workers expressed concerns about reporting their pain to their supervisor due to the risk of retaliation or out of frustration that their problems would not be helped. For example, one interviewed worker stated, "Everyone works in pain and is afraid to speak out". Workers also hesitated to seek treatment, citing concerns about loss of overtime eligibility and diminished job security. For example, one worker said that if he went to the clinic, he would lose eligibility for overtime pay. One Cut Floor worker described experiencing bilateral numbness and tingling of her hands. Although the company clinic offered treatment, she was not referred to a doctor. After seeking medical care outside of her company, she was diagnosed with carpal tunnel syndrome and was treated with physical therapy. Despite her ongoing symptoms, she did not report her numbness and tingling to her supervisors, fearing job loss.

Recognition and treatment of pain and injuries. Many workers reported that the establishment clinic staff primarily provided only very basic interventions such as ibuprofen, ice, and stretching exercises in response to their pain and other symptoms. Some workers reported that establishment clinic staff would not acknowledge that their pain or injury was caused or exacerbated by the work environment. Workers who received care from onsite medical providers generally expressed satisfaction with their care, although several noted initial treatment by athletic trainers who did not adequately treat their pain. As a result of some distrust of the onsite healthcare provider, some workers reported independently seeking treatment for their potentially work-related condition from their personal healthcare providers.

Accommodations for work injury. According to worker accounts, accommodations for work-related pain and injury were variable. One worker with hand pain suggested that "light duty" was rarely implemented. Another worker who was treated with joint injections and was instructed by an outside physician to restrict their lifting reported that the lifting restrictions were not implemented at work.

*Breaks and rest periods. W*orkers described limitations on taking bathroom and water breaks due to staffing constraints for line coverage. Female workers reported experiencing difficulties when requesting bathroom breaks and would, at times, be asked to disclose personal health information before being granted a break.

Ergonomic interventions after work injuries. Workers reported that their job was not modified nor were engineering controls implemented based on their pain or injuries. From the workers' perspective, jobs and work tasks (including the speed of the work and the number of staff who do the same job) appeared "fixed" or permanent. Most workers believed that their ability to meet productivity and quality requirements meant that they had to adapt to their job.

5.11.6. Associations between TLT Line Speed and respiratory symptoms during the past 12 months

Study participants were asked about their experience of work-related respiratory symptoms during the past year. Overall, 5.9% (n=30) of participants reported experiencing respiratory symptoms during the past year (Table 5.11.6.A). The proportion of workers experiencing respiratory symptoms ranged between 4% (Establishment E) to 9% (Establishment A) across the six establishments. There were no associations between respiratory symptoms and evisceration line speed overall (p=0.54) nor between respiratory symptoms and evisceration line speed when stratified by TLT Line Speed Group (interaction p=0.95). The association between line speed and respiratory symptoms could not be stratified by establishment because the evisceration line speed did not vary by worker within each establishment.

Table 5.11.6.A. Association between TLT Line Speed and respiratory symptoms over the past 12 months from logistic regression models by TLT Line Speed group,

	All, N	Respiratory symptoms during past year N (%)	Odds of having Respiratory Symptoms per +100 HPH OR (95% CI)	p-value
All Establishments	505	30 (5.9%)	0.87 (0.55 to 1.36)	0.54
TLT Line Speed Group				
<1,300 HPH	248	16 (6.5%)	0.60 (0.23 to 1.55)	0.29
≥1,300 HPH	257	14 (5.5%)	0.72 (0.14 to 3.73)	0.70

1 adjusted for age and sex

When logistic regression models were stratified by processing area, no statistically significant interaction was observed (p=0.49). Workers in the Front End area reported the highest proportion of respiratory symptoms (12%) whereas those in the Main Chain area reported the lowest (3.5%). Among the four areas, the OR for workers in the Offal area suggested a potential protective effect although it was not statistically significant.

Table 5.11.6.B. Association between TLT Line Speed and respiratory symptoms over the past 12 months from logistic regression models by processing area

	All, N	Respiratory symptoms during past year N (%)	Odds of having Respiratory Symptoms per +100 HPH OR (95% CI)	p-value
By processing area				
Front End	50	6 (12%)	1.31 (0.35 to 4.88)	0.69
Main Chain	174	6 (3.5%)	0.91 (0.32 to 2.59)	0.86
Offal	158	11 (7.0%)	0.50 (0.23 to 1.06)	0.07
Cut Floor	121	7 (5.8%)	1.07 (0.45 to 2.56)	0.87

1 adjusted for age and sex

6. Conclusions

6.1. The Effect of Evisceration Line Speed increase on MSD risk (PFI-TLV score>1.0) varied across the six establishments.

A key finding of this study was that the association between line speed and MSD risk varied by establishment. For example, at Establishment B, higher evisceration line speed was associated with *greater* MSD risk (a higher PFI-TLV score) whereas, conversely, at Establishment C, higher evisceration line speed was associated with *lower* MSD risk. At the four remaining establishments, higher evisceration line speed was not statistically significantly associated with MSD risk.

This finding was also observed with the association between evisceration line speed and the risk of exceeding the PFI-TLV score of 1.0. Workers at Establishment B had a statistically significant four-fold *increase* in the odds of workers exceeding a PFI-TLV score of 1.0 per +100 HPH increase in line speed. Workers at Establishment C had a statistically significant *decrease* in the odds of workers exceeding a PFI-TLV score of 1.0 per +100 HPH *increase* in line speed. Workers at Establishments A and F had non-statistically significant *increases* in the odds of workers exceeding a PFI-TLV score of 1.0. In comparison, Establishments D and E had non-statistically significant *decreases* in the odds of workers exceeding a PFI-TLV score of 1.0.

Another potentially important finding was the greater increase in the change in PFI-TLV score per +100 HPH among establishments operating at ≥1,300 HPH compared to establishments operating at <1,300 HPH. Although this could mean that excess risk occurs with increased line speed ≥1,300HPH, it could also be an artifact resulting from Establishment C being in the <1,300HPH group. However, the establishment at which MSD risk increased with increasing line speed was also in the <1,300HPH Line Speed group. These results are consistent with our opinion that evisceration line speed is a poor metric of MSD risk.

Overall, these findings indicate that simultaneously increasing line speed and reducing MSD risk *is* possible, but this was observed at only one of six establishments. This could be due to a variety of factors. First, this establishment had the lowest median PFI-TLV scores at both the non-TLT and the TLT Line Speeds and the lowest proportion of workers who exceeded a PFI-TLV score of 1.0. This establishment also had some of the lowest average piece rates at both the non-TLT and TLT Line Speeds which contributed to the lower PFI-TLV scores. It is also possible that other mitigation factors that we did not measure, such as a knife sharpening program, that reduces hand exertion force, could have contributed to their lower PFI-TLV scores. This is supported by the observation that many of the job-specific average NPF values were lower at Establishment C when compared to the same jobs at the other establishments. Establishment C had developed a comprehensive ergonomic program and had carried out many high-quality ergonomic evaluations and interventions completed or overseen by trained ergonomists. It is likely that their ergonomic program contributed to the lower PFI-TLV scores at both non-TLT and TLT Line Speeds. With that said, one in five of their jobs still exceeded a PFI-TLV score of 1.0 so continued efforts to mitigate MSD risk are warranted.

6.2. High biomechanical exposures and risk for MSDs existed for 46.1% (n=237) of the workers evaluated across all establishments operating at the TLT line speed. However, the percentage varied by establishment.

The percentage of workers that exceeded the PFI-TLV score of 1.0 when establishments operated at the TLT Line Speed ranged between 21.8% to 64.4% across establishments. These workers are at high risk of MSDs regardless of whether the establishment operates at the non-TLT or TLT Line Speed. Immediate efforts to mitigate the high risk for these workers is needed.

The percentage of workers who *changed* their level of risk (by being above or below the PFI-TLV score of 1.0) with changing line speed varied by establishment. Establishment C had a low percentage of workers (3%) whose MSD risk *decreased* with higher line speeds (i.e., non-TLT Line Speed PFI-TLV scores>1.0 changed to a TLT Line Speed PFI-TLV score<1.0) and a high percentage of workers (26.9%) whose MSD risk *increased* with higher Line Speed (i.e., non-TLT Line Speed PFI-TLV score<1.0 changed to TLT Line Speed PFI-TLV scores > 1.0). In contrast, Establishment B (with a nearly identical TLT Line Speed as Establishment B) had a higher percentage of workers (23.5%) whose MSD risk *decreased* when operating at the TLT Line Speed, and a lower percentage of workers (8.6%) whose risk *increased*. Establishments C and B show that increasing line speed can have opposing impacts on the number of workers at risk of MSDs.

The proportion of workers who exceeded the PFI-TLV score of 1.0 at the TLT Line Speed varied by processing area between 36.8% (workers on the Main Chain) to 62.7% (workers on the Cut Floor). The Cut Floor workers had an approximately 8% increase in the prevalence of workers that exceeded the PFI-TLV score of 1.0 when establishments operated at the TLT Line Speed (62.7%) compared to the non-TLT Line Speed (54.7%). Understanding the MSD risk by job and processing area may assist industrial engineers, ergonomists, management, and union representatives in determining operational changes in line speed and staffing that could mitigate MSD risk.

In summary, increased MSD risk levels were substantial although varied across establishments. Based on the PFI-TLV scores measured, 46% of workers performed a job with a PFI-TLV score>1.0 and 5% (n=25) of those workers had a PFI-TLV score greater than 2.0. Based on prior prospective studies, these workers have a two-fold to three-fold increased risk of CTS (Yung et al., 2019; Harris Adamson, paper under review). Put another way, among workers performing a job with a PFI-TLV score greater than 1.0, it is more likely than not that any CTS case is the result of occupational exposure as opposed to all other causes combined (see section 1.3.1.). This can be further interpreted as, among workers performing a job with a PFI-TLV score of 2.0, 69% of all CTS cases would be attributable to occupational exposure alone.

6.3. Over 42% of workers across all establishments reported moderate to severe upper extremity pain over the 12 months prior to the study. First aid was the most common establishment action taken for reported pain; however, the timing and allocation of treatment varied.

The proportion of workers who reported moderate to severe upper extremity pain varied by establishment, ranging between 33.7% and 55.7% of workers. There was a statistically significant 31% increase in the odds of having moderate to severe upper extremity pain per +100 HPH increase in line speed. The associations between line speed and upper extremity MSD pain were stronger among establishments with higher mean MSD risk scores. For example, mean MSD risk scores were relatively low at Establishment C which also had a weaker association between line speed and upper extremity MSD pain. Additionally, mean MSD risk scores were relatively high at Establishment B which also had a stronger association between line speed and upper extremity MSD pain. In these instances, the relative magnitude of the establishment-specific mean PFI-TLV scores was consistent with the establishment-specific strength of associations between line speed and pain.

Other important findings support the need for improved symptom monitoring and medical management. The report of "break-in" pain, or pain when first starting their employment, was very high. 65% of workers reported moderate to severe discomfort when newly hired, and 45% still had pain after one month. Most concerning was that 16% continued to have pain since they were first hired. Second, the underreporting of pain was observed across all establishments. 32% of workers who experienced pain did not report their pain and, therefore, did not receive any first aid or medical treatment. Further, 16% of all workers with moderate to severe upper extremity pain took time off work (paid or unpaid) due to pain, and many reported that their pain prevented them from doing important activities outside of work. In this cohort, nearly one in five workers seen by a company healthcare provider received first aid for more than 6 weeks, which could result in future underreporting of symptoms and/or progression of the disorder.

6.4. Increased piece rate was associated with MSD risk.

Piece rate was associated with increased MSD risk across all establishments, and the association between piece rate and MSD risk across establishments with different TLT Line Speeds was nearly identical. Piece rate impacts the number of hand exertions per unit/minute, and thus more accurately represents individual workload than evisceration line speed. For workers with a PFI-TLV score >1.0, reducing piece rate by increasing job-specific staffing levels, decreasing job-specific line speed, or both can reduce MSD risk. Concurrent strategies to reduce the magnitude of hand force exertions (i.e, knife sharpening programs, knife training programs, etc.) may also help reduce MSD risk. Further research, using similar measurement methods used in this study, can help identify the impact of these mitigation efforts on MSD risk.

6.5. Overall, airborne PAA concentration was well controlled across the five establishments that used it as an antimicrobial intervention.

There were only four samples, taken at two different sampling sites, where the airborne PAA concentration exceeded the ACGIH STEL of 0.4 ppm. Respiratory symptoms were reported by only 7% of workers and were not higher when establishments operated at TLT Line Speeds.

7. Strengths and Limitations

There were numerous strengths to this study, including:

- A large sample size of workers was recruited from six study establishments.
- Two matched sets of data were measured for the majority of participating workers, one when establishments operated at the non-TLT line speed and one when establishments operated at the TLT line speed.
- The ergonomic exposure measurements used to quantify upper extremity MSD risk were comprehensive and involved validated and objective methods to quantify hand force, repetition rate, and duty cycle.
- Workers were recruited from most jobs representative of work performed by swine processing workers.
- The high participation rate (98.6%) reduced the impact of selection bias from non-participants being systematically different from participants.

The study limitations included:

- Due to a high employee annual turnover (2023 average of 49.0% (SD=10.2%)), the study sample was likely healthier than the sample of all exposed workers. Since data collection was completed over a two-week period and included only employees who could perform the demands of their jobs, those who left employment due to pain or the inability to keep up with the high pace of work were underrepresented. This healthy worker survivor effect likely led to an underestimate of reported pain.
- Interviews were conducted onsite and in multiple languages using telephone interpreters, and some survey questions may have been misunderstood.

8. Recommendations

8.1. Reduce the PFI-TLV score to less than 1.0 for all swine processing jobs

The PFI-TLV score is the most established and validated measure of risk for upper extremity MSDs available for use by occupational health and safety professionals. Our recommendation of a PFI-TLV score less than 1.0 is not overly protective. Specifically, a recent analysis of data collected from 4,321 workers in the US and European Union found that workers with a PFI-TLV score of 1.0 or greater had a two-fold or more increase in risk of upper extremity MSDs compared to workers with a PFI-TLV score of less than 1.0 (Harris-Adamson et al., in review). As previously stated, a two-fold increase in risk indicates that MSDs among workers with PFI-TLV score greater than 1.0 are more likely than not due to occupational hazards than all other causes combined. Therefore, reducing the hazard to a PFI-TLV score of less than 1.0 across all swine processing jobs should be the minimal threshold used by the industry for achieving acceptable upper extremity MSD risk.

8.1.1. Reduce piece rate in jobs with high levels of MSD risk (PFI-TLV score >1.0)

Workers with a PFI-TLV score >1.0 are exposed to a combination of excessive work pace (HAL) and/or hand force (NPF) that, when combined to calculate the PFI-TLV score, result in an unacceptable level of MSD risk. Implementing changes that reduce work pace, hand force, or both, will reduce upper extremity MSD risk.

Work Pace. The six establishments in this study had different approaches to staffing various jobs in the four areas we observed. In three areas, establishments increased staff when the evisceration line speed increased; however, the jobs and areas that increased staff varied across establishments, even between the two establishments that increased to approximately the same TLT line speed. Of particular interest is that these two establishments with identical non-TLT line speeds and nearly identical TLT line speeds also were the two establishments that showed opposite relationships between line speed and upper extremity MSD risk. Since this was a within-subjects study design, all other factors except line speed and staffing were likely controlled. This indicates that staffing is important for mitigating MSD risk while optimizing operational efficiency and production. Further research may help to identify a staffing approach that optimizes productivity and quality while minimizing worker risk of MSDs.

8.1.2. Reduce hand force

In this study, physiological measures of muscle activity (EMG) were used as the metric of hand force. Although outside the scope of this report, peer-reviewed scientific literature has shown that workers using sharper knives exert lower hand forces than workers using less sharp knives (Tirloni et. al., 2021). Given the objective assigned to this study team by the USDA, to assess the impact of evisceration line speed on MSD risk among swine workers, our focus has necessarily been on the impact of work pace on MSD risk. However, it is important to acknowledge that efforts to reduce hand force for any particular job could change the recommended piece rate while keeping the PFI-TLV score to less than 1.0, particularly for jobs requiring cutting tools.

8.1.3. Increase fatigue allowances when identifying appropriate cycle times.

A common approach to job design (or redesign) is to perform time and motion studies of workers performing the job. One outcome of time and motion studies is the cycle time of the job. Cycle times are used to estimate the number of staff necessary at any particular line speed to meet production goals. When designing jobs, cycle times measured with time and motion studies are commonly modified by incorporating a “fatigue allowance” to provide recovery time to workers performing the job. Standard fatigue allowances used commonly in industry are not typically based on the mitigation of quantifiable MSD risk. However, fatigue allowances could be assigned with the goal of mitigating MSD risk. Specifically, we recommend that fatigue allowances that reduce the job-specific PFI-TLV score to less than 1.0 be added to the job’s cycle time. Simple mathematical modeling could estimate the impact of such additional fatigue allowances on the PFI-TV score, and then be assessed through follow-up job evaluations and symptom monitoring.

8.2. Implement long-established meat packing best practices.

Every decade since 1993, OSHA has published guidelines that established best practices for the meatpacking industry. In 1993, OSHA published Ergonomic Program Management Guidelines for Meat Packing Plants (US DOL, 1993). Another set of guidelines was published in 2013 (US DOL, 2013). Further, in 2021, NIOSH completed a health hazard evaluation (HHE 2021-0117-3397) and numerous recommendations, the first of which was to design job tasks to be below the ACGIH TLV for hand activity to minimize the risk of developing carpal tunnel syndrome. However, our study found that 46% of workers evaluated still exceeded the PFI-TLV score of 1.0. Despite decades of best practices, many have not been implemented uniformly or comprehensively across establishments regardless of line speed.

In this study of six swine processing establishments, there were examples of effective practices reflecting the implementation of the previously referred guidelines. There were examples of automation reducing exposure in the main chain area, which varied between establishments. There were engineering controls such as vacuum lifts that eliminated the risk of low back pain due to lifting. In contrast, there was one establishment where workers were at extremely high risk for low back pain with no engineering controls at all. In summary, there are numerous opportunities for establishments to improve their ergonomic programs to mitigate the risks previously described.

To facilitate the implementation of best practices, one option is to develop an industry and labor safety and health consortium. An example from the automobile manufacturing industry are the United States Council for Automotive Research (USCAR) and Automotive Industry Action Group (AIAG). These consortia include Ford Motor Company, General Motors, and Stellantis. They facilitate the legal collaboration of its participants to address safety and health challenges in their industry. Solutions come from collaborative efforts to develop and implement industry best practices. Optimizing the integration of the PFI-TLV score into additional fatigue allowances could be another collaborative initiative. Such initiatives could have an important impact on reducing the proportion of workers exposed to excessive biomechanical hazards that are associated with MSDs.

8.3. Reduce PAA exposure to below the ACGIH 0.4ppm STEL

For the four samples where airborne PAA concentrations were above the ACGIH 0.4 ppm STEL, two were collected at the inlet of the whole hog antimicrobial intervention cabinet and two were in parts wash areas and were collected where conveyor belts were sprayed with PAA.

Several engineering and administrative controls may reduce exposures in and around the whole hog antimicrobial intervention cabinets. First, if there is the ability to adjust the ventilation system of the cabinet, it is recommended that an establishment use a PAA sensor to collect repeated samples before and after adjusting the ventilation in the cabinet to see if there is a reduction in exposure. Next, drainage to the cabinet should be kept clear of any matter to ensure the effective removal of water from the cabinet. On several occasions, it was observed that the drainage system would become clogged, and water containing PAA would pool at the bottom of the cabinet and sometimes spill over onto the floor, potentially increasing the amount of PAA that would become airborne, creating an exposure risk for employees. Cabinets should be visually inspected to see if the direction of the PAA spray is resulting in water to spray outside the cabinet. One method to reduce this waste of antimicrobial intervention spray is to partially enclose the cabinet with plastic strips. These strips should be positioned in such a way to cover potions of the inlet and outlet that would not come in contact with the hogs as they pass through the cabinet.

For the parts wash applications of PAA, visually inspect the application points to observe if the spray nozzles are not clogged, if the spray nozzles are positioned in the intended direction, if there is po0ling water containing PAA in the vicinity of the application point, and if there is overspray of the PAA from the nozzles. The goal is to reduce the amount of airborne PAA concentrations being generated from PAA-containing water. This is achieved by partially enclosing the spray bars, increasing the drainage of the water after it is sprayed onto the conveyor belts or the parts, and finally increasing the movement of air in the areas surrounding the antimicrobial application points.

- Periodically review policies and procedures to assess employee exposure to PAA, including establishing a PAA monitoring program for daily production.
- Provide hazard communication training for employees about the health effects from exposure to PAA (as required by the OSHA hazard communication standard 29 CFR 1910.1200).
- Conduct regular walk-throughs of the production plant to assess the ventilation in the facility with respect to the location of where employees are working and the sources of PAA exposure.
- Adjust any drip pans positioned under conveyor lines to an angle that would prevent collection of standing water, which may be an additional source of airborne PAA in the workplace. This surface area may promote the conversion of PAA into the vapor phase from the water, and adjustment of the water drip pans to drain this water away from employee workstations may reduce concentrations of PAA in the air.
- Provide a mechanism for employees to report any adverse health effects resulting from exposure to PAA.
- When possible, increase employee distance from the source of PAA. Researchers found the further an employee stood from the PAA source, the lower the employee’s exposure to PAA.

8.4. Encourage early reporting of MSD symptoms and provide appropriate care beyond first aid.

OSHA recently updated its recommendations for medical management including best practices for first aid, medical management, aligning service providers with their scope of practice, and collaboration with workplace safety and health programs (US DOL 2024). Data from this study, such as, i) the proportion of workers not reporting their pain, ii) the extended duration of first aid care, and iii) the low number of workers who received medical care from a doctor, indicate opportunities to improve medical management practices at Swine Processing Establishments.

Swine processing employers should utilize first aid only to precede definitive assessment of the need for medical care and should not involve multiple first aid encounters with the same patient presenting the same concerns. Additionally, swine processing employers should ensure timely referral of workers with pain to medical treatment and minimize the time over which initial first aid is administered. First aid should be limited to the initial response to a worker's pain and not used as a way to provide ongoing palliative care. OSHA defines first aid as "medical attention that is usually administered immediately after [an] injury occurs and at the location where it occurred." Swine processing facilities should ensure that workers receive evaluation and treatment from healthcare providers whose scopes of practice are appropriate to the level of care being provided. This should include a board-certified occupational medicine physician who can provide on-site care or consultation, including restricted or modified duty assignments. The use of any health care practitioners, such as athletic trainers, occupational therapists, and physical therapists, should only be for immediate early symptom management and not for ongoing care unless directed by an Occupational Health Physician. OSHA also recommends that medical management programs collaborate with safety and health programs by providing them with information on first-aid visits, injuries, illnesses, incidents, and near misses.

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References

ACGIH “2024 TLVs and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices.” Cincinnati, OH.

Altunas, Y. D., & Cankaya, T. (2020). Effects of working years in cold environments on the musculoskeletal system and carpal tunnel symptoms. Agri, 32(3), 120–127.

Bao, S., Howard, N., Spielholz, P., Silverstein, B., & Polissar, N. (2014). Interrater reliability of posture observations. Human Factors, 51(3), 292–309.

Bernard, B. P. (1997). Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. National Institute for Occupational Safety and Health. Publication Number DHHS (NIOSH) 97-141.

Blackley, B. H., Nett, R. J., Cox-Ganser, J. M., Harvey, R. R., & Virji, M. A. (2023). Eye and airway symptoms in hospital staff exposed to a product containing hydrogen peroxide, peracetic acid, and acetic acid. *American journal of industrial medicine*, *66*(8), 655–669.

Bonfiglioli, R., Mattioli, S., Armstrong, T. J., Graziosi, F., Marinelli, F., Farioli, A., & Violante, F. S. (2013). Validation of the ACGIH TLV for hand activity level in the OCTOPUS cohort: A two-year longitudinal study of carpal tunnel syndrome. *Scandinavian Journal of Work, Environment & Health*, 39(2), 155–163.

Cal/OSHA [2017] Cal/OSHA Draft Substance Summary for the December 12, 2017 HEAC Meeting. (Dated December 12, 2017). https://www.dir.ca.gov/dosh/DoshReg/5155-Meetings/Peracetic-Acid-2017-12-12.pdf

Campbell, D. S. (1999). Health hazards in the meatpacking industry. Occupational Medicine, 14(2), 351–372.

Cartwright, M. S., Walker, F. O., Blocker, J. N., Schulz, M. R., Arcury, T. A., Grzywacz, J. G., ... & Quandt, S. A. (2012). The prevalence of carpal tunnel syndrome in Latino poultry-processing workers and other Latino manual workers. Journal of Occupational and Environmental Medicine, 54(2), 198–201.

Cristofari-Marquand, E., Kacel, M., Milhe, F., Magnan, A., & Lehucher-Michel, M. P. (2007). Asthma caused by peracetic acid-hydrogen peroxide mixture. Journal of occupational health, 49(2), 155-158.

Crowther, M. J. (2019). Multilevel mixed-effects parametric survival analysis: Estimation, simulation, and application. Stata Journal, 19, 931–949.

Dempsey, P. G., & Ayoub, M. M. (1996). The Revised NIOSH Lifting Equation: A review. Ergonomics, 39(6), 989–1004.

Dempsey, P. G., & McGorry, R. W. (2004). Investigation of a pork shoulder deboning operation. Journal of Occupational and Environmental Hygiene, 1(3), 167–172.

Descatha, A., Leclerc, A., Chastang, J. F., & Roquelaure, Y. (2016). Incidence of shoulder pain in repetitive work. Occupational Medicine, 66(3), 198–204.

Dias, N. F., Tirloni, A. S., Cunha dos Reis, D., & Moro, A. R. P. (2021). The effect of different work-rest schedules on ergonomic risk in poultry slaughterhouse workers. Work, 69, 215–223.

Frost, P., Andersen, J. H., & Nielsen, V. K. (1998). Occurrence of carpal tunnel syndrome among slaughterhouse workers. Scandinavian Journal of Work, Environment & Health, 24(4), 285–292.

Fox, R. R., & Jansen, J. J. (2019). Understanding outcome metrics of the revised NIOSH lifting equation. Applied Ergonomics, 81, 102897.

GAO [2005]. Workplace safety and health. Safety in the meat and poultry industry, while improving, could be further strengthened. Washington, DC: U.S. Government Accountability Office, GAO-05-96.

GAO [2016]. Workplace safety and health. Additional data needed to address continued hazards in the meat and poultry industry. Washington, DC: U.S. Government Accountability Office, GAO-16-337.

Garg, A., Moore, J. S., & Kapellusch, J. M. (2017). The Revised Strain Index: An improved upper extremity exposure assessment model. Ergonomics, 60(7), 912–922.

Gerr, F., Fethke, N. B., Merlino, L., Anton, D., Rosecrance, J., Jones, M. P., Marcus, M., & Meyers, A. R. (2014). A prospective study of musculoskeletal outcomes among manufacturing workers: I. Effects of physical risk factors. *Human Factors, 56*(1), 112–130.

Gorsche, R., Wiley, J. P., Renger, R., et al. (1998). Prevalence and incidence of stenosing flexor tenosynovitis (trigger finger) in a meat-packing plant. Journal of Occupational and Environmental Medicine, 40(6), 556–560.

Government Accountability Office (GAO). (2016). Workplace safety and health: Additional data needed to address continued hazards in the meat and poultry industry. GAO-16-337.

Hagberg, M., Violante, F. S., Bonfiglioli, R., Descatha, A., Gold, J., Evanoff, B., & Sluiter, J. K. (2012). Prevention of musculoskeletal disorders in workers: Classification and health surveillance—Statements of the Scientific Committee on Musculoskeletal Disorders of the International Commission on Occupational Health. BMC Musculoskeletal Disorders, 13, 109.

Harmes, J. L., Engelbrecht, J. C., & Bekker, J. L. (2016). The impact of physical and ergonomic hazards on poultry abattoir processing workers: A review. International Journal of Environmental Research and Public Health, 13, 197.

Harris, C., Eisen, E. A., Goldberg, R., Krause, N., & Rempel, D. (2011). Workplace and individual factors in wrist tendinosis among blue-collar workers—The San Francisco study. Scandinavian Journal of Work, Environment & Health, 37(2), 86–98.

Harris-Adamson, C., Eisen, E. A., & Dale, A. M. (2015). Personal and workplace psychosocial risk factors for carpal tunnel syndrome: A pooled study cohort. Occupational and Environmental Medicine, 72(1), 33–41.

Harris-Adamson, C., Eisen, E. A., & Dale, A. M. (2015). Biomechanical and psychosocial exposures are independent risk factors for carpal tunnel syndrome: Assessment of confounding using causal diagrams. Occupational and Environmental Medicine, 72(11), 806–814.

Harris-Adamson, C., & Rempel, D. (2021). Ergonomic interventions for the mitigation of work-related musculoskeletal disorders of the upper extremity: A systematic review. Ergonomics, 64(5), 586–608.

Hawley, B., Casey, M., Virji, M. A., Cummings, K. J., Johnson, A., & Cox-Ganser, J. (2018). Respiratory symptoms in hospital cleaning staff exposed to a product containing hydrogen peroxide, peracetic acid, and acetic acid. Annals of work exposures and health, 62(1), 28-40.

Kapellusch, J. M., Gerr, F. E., Malloy, E. J., Garg, A., Harris-Adamson, C., Bao, S. S., Burt, S. E., Dale, A. M., Eisen, E. A., Evanoff, B. A., Hegmann, K. T., Silverstein, B. A., & Rempel, D. M. (2014). Exposure–response relationships for the ACGIH threshold limit value for hand-activity level: Results from a pooled data study of carpal tunnel syndrome. *Scandinavian Journal of Work, Environment & Health*, 40(6), 610–620

Koukoulaki, T. (2014). The impact of lean production on musculoskeletal and psychosocial risks: An examination of sociotechnical trends over 20 years. Applied Ergonomics, 45(2), 198–212.

Kuijer, P. P., Gouttebarge, V., & Frings-Dresen, M. H. (2018). Low back pain: Prevalence and risk factors among construction workers. Occupational Medicine, 68(7), 512–516.

Kurppa, K., Viikari-Juntura, E., & Kuosma, E. (1991). Incidence of tenosynovitis or peritendinitis and epicondylitis in a meat-processing factory. Scandinavian Journal of Work, Environment & Health, 17(1), 32–37.

Kyeremateng-Amoah, E., Nowell, J., Lutty, A., Lees, P. S., & Silbergeld, E. K. (2014). Laceration injuries and infections among workers in the poultry processing and pork meatpacking industries. American Journal of Industrial Medicine, 57(6), 669–682.

Lander, L., Sorock, G. S., Stentz, T. L., Eisen, E. A., Mittleman, M., Hauser, R., & Perry, M. J. (2010). A case-crossover study of occupational laceration injuries in pork processing: Methods and preliminary findings. Occupational and Environmental Medicine, 67(10), 686–692.

Latko, W. A., Armstrong, T. J., Foulke, J. A., Herrin, G. D., & Franzblau, A. (1997). Development and evaluation of an observational method for assessing repetition in hand tasks. American Industrial Hygiene Association Journal, 58(4), 278–285.

Leibler, J. H., & Perry, M. J. (2017). Self-reported occupational injuries among industrial beef slaughterhouse workers in the Midwestern United States. Journal of Occupational and Environmental Hygiene, 14(1), 23–30.

Lipscomb, H. J., Epling, C. A., Pompeii, L. A., & Dement, J. M. (2007). Musculoskeletal symptoms among poultry processing workers and a community comparison group: Black women in low-wage jobs in the rural south. American Journal of Industrial Medicine, 50(4), 327–338.

Lipscomb, H. J., Kucera, K., Epling, C., & Dement, J. (2008). Upper extremity musculoskeletal symptoms and disorders among a cohort of women employed in poultry processing. American Journal of Industrial Medicine, 51(1), 24–36.

McGorry, R. W., Dowd, P. C., & Dempsey, P. G. (2003). Cutting moments and grip forces in meat cutting operations and the effect of knife sharpness. Applied Ergonomics, 34(4), 375–382.

Moore, J. S., & Garg, A. (1994). Upper extremity disorders in a pork processing plant: Relationships between job risk factors and morbidity. American Industrial Hygiene Association Journal, 55(8), 703–715.

Moore, J. S., & Garg, A. (1995). The strain index: A proposed method to analyze jobs for risk of distal upper extremity disorders. American Industrial Hygiene Association Journal, 56(5), 443–456.

Moore, J. S., & Garg, A. (1996). Use of participatory ergonomics teams to address musculoskeletal hazards in the red meat packing industry. American Journal of Industrial Medicine, 29(4), 402–408.

Moore, J. S., & Garg, A. (1997). Participatory ergonomics in a red meat packing plant Part II: Case studies. American Industrial Hygiene Association Journal, 58(7), 498–508.

Moore, J. S., & Garg, A. (1998). The effectiveness of participatory ergonomics in the red meat packing industry: Evaluation of a corporation. International Journal of Industrial Ergonomics, 21(1), 47–58.

Musolin, K., Ramsey, J. G., Wassell, J. T., Hard, D. L., & Mueller, C. (2014). Evaluation of musculoskeletal disorders and traumatic injuries among employees at a poultry processing establishment. National Institute for Occupational Safety and Health, Health Hazard Evaluation, Report No. 2012-0125-3204.

Musolin, K. M., & Ramsey, J. G. (2017). Carpal tunnel syndrome prevalence: An evaluation of workers at a raw poultry processing establishment. International Journal of Occupational and Environmental Health, 23(3), 282–290.

NAS [2010]. Chapter 7: peracetic acid-acute exposure guideline levels. In: acute exposure guideline levels for selected airborne chemicals: volume 8. [http://www.epa.gov/opptintr/aegl/pubs/peracetic_acid_final_volume8_2010.pdf].

National Research Council (NRC). (2001). *Musculoskeletal disorders and the workplace: Low back and upper extremities*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10032

National Institute for Occupational Safety and Health (NIOSH). [1994]. Applications manual for the revised NIOSH lifting equation. By Waters TR, Ph.D., Putz–Anderson V, Ph.D., Garg A, Ph.D. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 94-110 (Revised 9/2021)

National Institute for Occupational Safety and Health (NIOSH). (2014). Participatory ergonomic interventions in meatpacking plants. DHHS publication No. (NIOSH) 94-124. Retrieved from ttps://stacks.cdc.gov/view/cdc/6890..

National Institute for Occupational Safety and Health (NIOSH). [draft 2015]. Immediately dangerous to life or health (IDLH) value profile for peracetic acid. External review draft (Dated: March 2015). [https://www.cdc.gov/niosh/docket/review/docket156a/pdfs/g1-013-peracetic-acid-cas-79-21-0.pdf].

National Institute for Occupational Safety and Health (NIOSH). (2024). Evaluation of ergonomic risks, musculoskeletal disorders, and peracetic acid exposure among employees at a pork processing plant in Michigan. By Grant, M. P., Rinsky, J. L., & Dunn, K. H. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. Health Hazard Evaluation Report 2021-0117-3397.

National Research Council (NRC). (2001). Musculoskeletal disorders and the workplace: Low back and upper extremities. Washington, DC: The National Academies Press.

Petit Le Manac'h, A., Roquelaure, Y., Ha, C., Bodin, J., Meyer, G., Bigot, F., Veaudor, M., Descatha, A., Goldberg, M., & Imbernon, E. (2011). Risk factors for de Quervain's disease in a French working population. Scandinavian Journal of Work, Environment & Health, 37(5), 394–401.

Quandt, S. A., Grzywacz, J. G., Marin, A., Carrillo, L., Coates, M. L., Burke, B., & Arcury, T. A. (2006). Illnesses and injuries reported by Latino poultry workers in Western North Carolina. American Journal of Industrial Medicine, 49(5), 343–351.

Radwin, R. G., & Bao, S. (2004). A new method for estimating hand activity level. Human Factors, 46(4), 651–660.

Ramos, A. K., Carvajal-Suarez, M., Trinidad, N., Quintero, S., Molina, D., & Rowland, S. A. (2021a). "No somos máquinas" (We are not machines): Worker perspectives of safety culture in meatpacking plants in the Midwest. American Journal of Industrial Medicine, 64(2), 84–96.

Ramos, A. K., Carvajal-Suarez, M., Trinidad, N., & Rowland, S. A. (2021b). Health and well-being of Hispanic/Latino meatpacking workers in Nebraska: An application of the health belief model. Workplace Health & Safety, 69(12), 564–572.

Rosenbaum, D. A., Mora, D. C., Arcury, T. A., & Quandt, S. A. (2014). Employer differences in upper-body musculoskeletal disorders and pain among immigrant Latino poultry processing workers. Journal of Agromedicine, 19(4), 384–394.

Rowland, S., Ahmed, R., Roman, M. J. S., & Ramos, A. K. (2024). Workplace health culture and trust in the occupational health office: A descriptive study of meatpacking workers. American Journal of Industrial Medicine, 67(8), 723–731.

Rowland, S. A., Ramos, A. K., & Carvajal-Suarez, M. (2021). Musculoskeletal pain and cardiovascular risk in Hispanic/Latino meatpacking workers. Workplace Health & Safety, 69(12), 556–563.

Seidler, A., Bolm-Audorff, U., & Petereit-Haack, G. (2020). Work-related risk factors for specific shoulder disorders: A systematic review and meta-analysis. Occupational and Environmental Medicine, 77(6), 374–381.

Sundstrup, E., Jakobsen, M. D., Jay, K., Brandt, M., & Andersen, L. L. (2014). High-intensity physical exercise and pain in the neck and upper limb among slaughterhouse workers: Cross-sectional study. Biomed Research International, 2014, 218546.

Taibi, Y., Metzler, Y., & Bellingrath, S. (2021). Work-related psychosocial and organizational factors associated with musculoskeletal disorders in hospital nurses: A cross-sectional study. International Journal of Environmental Research and Public Health, 18(2), 578.

Tirloni, A. S., Cunha dos Reis, D., Tirloni, S. F., & Moro, A. R. P. (2020). Exertion perception when performing cutting tasks in poultry slaughterhouses: Risk assessment of developing musculoskeletal disorders. International Journal of Environmental Research and Public Health, 17(24), 9534.

U.S. Department of Labor Occupational Safety and Health Administration [3160-05R 2024] Best Practices for Non-Health Care Employers with On-site Health Care Services

U.S. Department of Labor. (1993). *Ergonomics program management guidelines for meatpacking plants*. Occupational Safety and Health Administration. Retrieved from https://www.osha.gov

U.S. Department of Labor. (2004). *Guidelines for poultry processing*. Occupational Safety and Health Administration. Retrieved from https://www.osha.gov

U.S. Department of Labor. (2013). *Guidelines for mitigating ergonomic risks in meat and poultry processing*. Occupational Safety and Health Administration. Retrieved from https://www.osha.gov

Vergara, L. G. L., & Pansera, T. R. (2012). Ergonomics analysis of the activity of boning shoulder in a pig slaughterhouse in the city of Ipiranga-SC. Work, 41, 703–709.

Viikari-Juntura, E. (1983). Neck and upper limb disorders among slaughterhouse workers—An epidemiologic and clinical study. Scandinavian Journal of Work, Environment & Health, 9, 283–290.

Walters, G. I., Burge, P. S., Moore, V. C., Thomas, M. O., & Robertson, A. S. (2019). Occupational asthma caused by peracetic acid-hydrogen peroxide mixture. Occupational Medicine, 69(4), 294-297.

Wagstaff, A. S., & Sigstad Lie, J. A. (2011). Shift and night work and long working hours—A systematic review of safety implications. Scandinavian Journal of Work, Environment & Health, 37(3), 173–185.

Waters, T. R., Putz-Anderson, V., Garg, A., & Fine, L. J. (1993). Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics, 36(7), 749–776.

Yung, M., Dale, A. M., Kapellusch, J., Bao, S., Harris-Adamson, C., Meyers, A. R., Hegmann, K. T., Rempel, D., & Evanoff, B. A. (2019). Modeling the effect of the 2018 revised ACGIH® hand activity threshold limit value® (TLV) at reducing risk for carpal tunnel syndrome. Journal of Occupational and Environmental Hygiene, 16(9), 628–633.

Appendix 1. Background – Phase 1

After reviewing data provided by the six TLT establishments, the study team concluded that the data was not sufficient to advise the USDA on whether the TLT should continue beyond the current time period. For this reason, the study team spent two days at each establishment to evaluate all aspects of facility operations (Phase 1). After an initial meeting with establishment managers and worker representatives to explain the purpose and scope of the site visit, a walkthrough was conducted to understand the process flow. In consultation with establishment managers and worker representatives, the study team selected specific areas and work processes for observation and videotaping. In addition, the study team interviewed the facility manager, safety/ergonomics manager(s), line leaders, supervisors, human resources representative, medical department staff, industrial hygienist, and union representative(s) where present. The study team also reviewed written documents about the core elements of establishment ergonomics, safety, and health, antimicrobial agents (PAA), and medical management programs.

Before these Phase 1 site visits, our null hypothesis was that the higher line speeds would not change the risk of MSDs and respiratory diseases throughout the facility. During the Phase 1 visits, we observed tasks that required hand intensive and materials handling that could be impacted by increased evisceration line speed. We observed that establishments vary considerably in their design and implementation of ergonomics programs, medical management and recordkeeping systems, and PAA usage and systems.

Our Phase 1 site visits and interviews with management and workers confirmed that work organization (staffing levels, mandatory overtime, work hours, turnover, training) may be critical factors in understanding the impact of line speed on worker safety and health. Further, a positive safety culture may increase workers' willingness to speak up if they are struggling to meet the required pace of work or quality of work or are in pain. This could lead to earlier staffing, placement, line speed, and first aid treatment interventions, decreasing the incidence and severity of MSDs. A detailed summary of Phase 1 findings is in the Appendix.

The overall goal in Phase 2 was to determine whether swine slaughter evisceration line speeds above 1,106 HPH have measurable effects on the safety and health of workers employed by swine processing establishments. We hypothesized that an increase in line speed might not directly correlate with *injury rates* and antimicrobial-related respiratory symptoms (such as first aid reports, medical treatment records, workers' compensation claims, lost time/days away from work, and OSHA Log reports) since the reporting of pain, the implementation of medical management and recordkeeping systems, including their definition and provision of first aid, varied widely across plants. Additional concerns about how worker reporting of symptoms to their employers may be influenced by fear of job or wage loss, discouragement from reporting symptoms, few or no options for light duty or modified work, and lack of access to trained and independent occupational health specialists led us to exclude first aid logs and OSHA Log reports as outcome variables in the Phase 2 analysis. We also considered medical examinations and testing as an outcome measure, but these were outside the scope and resources for a Phase 2 study. Therefore, we did not analyze first aid logs or OSHA-reportable injuries or illnesses as a measure to determine whether swine slaughter line speeds above 1,106 HPH have measurable effects on the safety and health of workers.

Appendix 2. Worker Survey

Baseline Survey

Start of Block: Intro

Q1.1 We are here at the request of the US Department of Agriculture. We have been asked to evaluate the impact of line speed on the work of employees like you. I am a university researcher, and I would like to ask you some questions about your work using this questionnaire. Your responses will be anonymous and confidential. Your participation is completely voluntary.

Q1.2 Indicate the facility Study Site number: Site 1 (1), Site 2 (2), Site 3 (3), Site 4 (4), Site 5 (5), Site 6 (6).

Q1.3 Participant ID (write "Decline" if the worker declines to participate) ____________

Q1.4 Will this participant be asked to have measurements made with the wearable devices?

No (0), Yes (1).

Q1.5 Which line speed is being evaluated today?

Slower Line Speed (1), Faster Line Speed (2).

Start of Block: Work Organization Block

Q2.1 How long have you worked at this facility?

<90 days (1), ≥90 days but <1 year (2), ≥1 year but <5 years (3), ≥5 years but <10 years (4), ≥10 years (5).

Q2.2 What are the job(s) that you perform most often? ____________

Q2.3 What is the job that you are performing TODAY while the research team videotapes you? ____________

Q2.4 Which shift do you usually work?

Day (1), Swing/Evening (2), Night (3), Other: ____________ (4).

Q2.5 How many hours per day do you typically work here?

Hours: 1 2 3 4 5 6 7 8 9 10 11 12 13 14.

Q2.6 How many days per week do you typically work here?

Days: 1 2 3 4 5 6 7.

Q2.7 What is the most number of hours you have ever worked in a week? ____________

Q2.8 Do you ever work overtime (more than 40 hours per week)?

No (0), Yes, voluntary (1), Yes, mandatory (2), Yes, both (3).

Q2.9 During your usual shift, how often do you move from one task to another?

Never/Rarely (0), Once per day (1), Two or more times per day (2).

Q2.10 When everyone is at work, how many workers are doing the same job as you?

Workers: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20.

Q2.11 During your usual shift, how often do you rotate between different jobs on the line?

Never/Rarely (0), Once per day (1), Two to three times per day (2), More than three times per day (3).

Q2.12 How often are there days when there are fewer workers on the line doing the same job as you?

Never or Rarely (1), Some of the time (2), Most of the time (3), All of the time (4).

Q2.13 Comments about staffing, job or position rotation, or line speed: ____________

Q2.14 How many hogs or parts of a hog do you usually handle per hour? ____________

Q2.15 Over the past month, do you think the SPEED OF THE LINE for your task is:

Much too slow (1), A little too slow (2), Just about right (3), A little too fast (4), Much too fast (5).

Q2.16 Over the past month, have you had any problems keeping up with the speed of your work?

Rarely/Never (0), Sometimes (1), Most of the time (2), Always (3).

Q2.17 Does the company require you to do a certain amount of work for every hour that you work?

No (0), Not sure (1), Yes (2).

Q2.18 Please describe the amounts the company requires: ____________

Q2.19 What would make your work easier? (Choose all that apply):

1. Sharper knives
2. Changing jobs during the shift
3. More training
4. More team members on the line
5. Better trained workers on the line
6. More flexible work hours
7. Shorter workday with equal pay
8. Slower line speed
9. Supervisors who listen to workers' ideas and concerns
10. Supervisors who care and respect my work
11. Machines running smoothly with fewer breakdowns
12. More space to do my work
13. Adjustable workstation to fit my size
14. Different tools to do my job
15. More consistent work pace/task speed
16. Other: ____________

Q2.20 Comments about suggested improvements: ____________

Q2.21 Do you receive any bonus or incentive pay for your work?

No (0) Yes(1)

Q.2.2: Do you get any extra pay for doing a better job (ex: quality, good attendance)? ____________

Start of Block: Task Evaluation Block

Q3.1 Are you right-handed or left-handed?

Right (1), Left (2), Both (3).

Q3.2 Please rate the HIGHEST HAND FORCE (squeezing, gripping, pinching) that you use for this job with your (right/left) hand. (scale: 0–10):

1. 0 Nothing at all
2. 0.5 Extremely Weak (just noticeable)
3. 1 Very Weak
4. 2 Weak (light)
5. 3 Moderate
6. 4
7. 5 Strong (heavy)
8. 6
9. 7 Very Strong
10. 8
11. 9
12. 10 Extremely Strong

Q3.3 Please rate the AVERAGE HAND FORCE (squeezing, gripping, and pinching) that you use for this job with your (right or left) hand. (scale: 0–10)

1. 0 Nothing at all
2. 0.5 Extremely Weak (just noticeable)
3. 1 Very Weak
4. 2 Weak (light)
5. 3 Moderate
6. 4
7. 5 Strong (heavy)
8. 6
9. 7 Very Strong
10. 8
11. 9
12. 10 Extremely Strong

Q3.4 How does the number of people on your job TODAY compare to a usual day?

A lot more people (1), A few more people (2), About the same number of people (3), A few less people (4), A lot less people (5).

Q3.5 I would like you to think about the speed of your line today. Is it moving faster, slower, or about the same as normal?

A lot faster (1), A little faster (2), About the same (3), A little slower (4), A lot slower (5).

Q3.6 TODAY, have you had any difficulty keeping up with your work?

No (0), Sometimes (1), Most of the time (2), Always (3).

Start of Block: Health Outcomes Block

Q4.1 TODAY (or within the past 24 hours), are you having any pain or discomfort in your hands, arms, neck, back, or legs while at work?

No (0), Yes (1).

Q4.2 How is your pain TODAY? Rate your pain for each part of your body on a scale of 0 to 10, where 0 is no pain and 10 is the worst possible pain:

- Neck
- Shoulder
- Arm/Elbows/Forearm
- Hands/Wrist
- Back
- Hips/Knees/Legs

Q4.3 Thinking back to when you first started working at this company, did you have any NEW pain or discomfort lasting more than a day in your hands, arms, neck, back, legs, or feet?

No (0), Yes (1), I don't recall (2).

Q4.4 How long did it take for you to work a full shift at a typical pace without pain or discomfort?

Less than 2 weeks (1), 2 weeks to less than 4 weeks (1 month) (2), 4 weeks to less than 8 weeks (2 months) (3), 8 weeks to less than 12 weeks (3 months) (4), I've continued to have some pain or discomfort (5), I do not recall (6).

Q4.5 In the past 12 MONTHS, did you have any pain in your hands, arms, neck, back, or legs while at work that lasted longer than 1 day?

No (0), Yes (1).

Q4.6 For each body part where you told me you had pain or discomfort, rate your pain on a scale of 0 to 10 (0 is no pain, 10 is the worst possible pain):

- Neck
- Shoulder
- Arm/Elbows/Forearm
- Hands/Wrist
- Back
- Hips/Knees/Legs

Q4.7 What job were you doing when you had that pain? Is that the same job that you are doing today? If not, what job were you performing?

No: ____________ (0), Yes (1).

Q4.8 Do you have any difficulty keeping up with your work because of your pain?

No difficulty with work (0), Mild difficulty (1), Moderate difficulty (2), Severe difficulty (3).

Q4.9 Do you take medication—prescription or non-prescription—for this pain? If yes, how often?

Daily (1), 2–3 times this week (2), At least once this week (3), Rarely/Never (4).

Q4.10 Have you ever asked to be moved to a different job because of your pain?

No (0), Yes, I've considered changing lines (1), Yes, I've considered quitting (3).

Q4.11 Did you tell your supervisor about your pain?

No (0), Yes (1).

Q4.12 What did your supervisor do after you told them about your pain?

Nothing (1), Job rotation (2), Moved me to a different job (3), Reduced my hours (4), Sent me to the plant nurse (5), Sent me for more training (6), Other: ____________ (7).

Q4.13 Did you tell the plant nurse about your pain?

No (0), Yes (1).

Q4.14 Why didn't you report your pain?

It was very mild (1), I can take care of the pain myself (2), I didn't think the company would help me (3), I didn't know how to report the problem (4), I was afraid of being punished or losing my job (5), Other: ____________ (6).

Q4.15 Did you receive any treatment or first aid from the on-site company nurse or another healthcare provider?

No (0), Yes (1).

Q4.16 What first aid or treatment did you receive? (Choose all that apply):

1. None
2. Ice
3. Ibuprofen/Acetaminophen (Advil, Motrin, Tylenol)
4. Aspirin
5. Instructions for stretches
6. Instructions for exercises
7. Training
8. Hot wax treatment
9. Creams (e.g., Biofreeze, IcyHot)
10. Soft splints or wraps
11. Other: ____________

Q4.17 How many weeks did you receive first aid or treatment from the onsite clinic?

<2 weeks (1), 2–6 weeks (2), 6–10 weeks (3), 10 weeks (4).

Q4.18 Did you go to any other doctor or nurse outside of the company clinic?

No, I did not want to see a doctor or nurse at a different clinic (1), No, but I wanted to see a doctor or nurse at a different clinic (2), Yes, I saw my own doctor or healthcare provider for treatment (3), Yes, I was referred by the company to a doctor or nurse at a different clinic for treatment (4), Other: ____________.

Q4.19 Was your job modified/changed because of pain or discomfort?

No (0), Job rotation (1), Moved me to a different job (2), Reduced my hours (3), Increased my breaks (4), Sent me for more training (5), Other: ____________ (6).

Q4.20 During the past YEAR, did you take any time off work because of the pain or discomfort?

No, I did not need to (0), No, but I wanted to (1), Yes (2).

Q4.21 How many days did you take off from work due to pain? ____________

Q4.22 Did your pain prevent you from doing important activities outside of work?

No (0), Yes (1).

Q4.23 What type of activities? ____________

Q4.25 Now, I would like to ask you about injuries at work like cuts from knives, getting hit by machines, tripping from hazards on the floor, or other ways you might have been injured at work. In the past YEAR, have you had any of these kinds of injuries?

No (0), Yes (1).

Q4.26 In the past YEAR, have you had any respiratory problems at work, such as burning in your eyes, nose, throat, or lungs?

No (0), Yes, Sometimes (1), Yes, Often (2).

Q4.27 How bad were your respiratory problems (eye or nose irritation, tightness in the chest, or a cough) during the past YEAR, where 1 represents mild symptoms and 4 represents very severe?

0 (No symptoms), 1 (Mild), 2 (Moderate), 3 (Severe), 4 (Very severe).

Q4.28 What were you doing at work when you had respiratory problems? ____________

Q4.29 If you started to have pain from your job, would you be likely to report it to someone like a supervisor, safety team member, or company nurse?

No (0), Yes (1).

Q4.30 What would be your reason for not reporting your pain?

I can take care of the pain myself (1), I don't think the company would help me (2), I don't know how to report the pain (3), I would be afraid of being punished or losing my job (4), Other: ___________.

Start of Block: Demographics Block

Q5.1 What is your age (years)? ___________

Q5.2 What is your gender?

Female (1), Male (2), Non-binary (3), Decline to answer (4), Other: ___________

Q5.3 What is your race or ethnicity?

White/Caucasian (1), White Latino/Hispanic (2), African (3), African American (4), Asian (5), Other: ___________

Q5.4 What is the primary language you spoke at home growing up?

English (1), Spanish (2), Other: ___________

Q5.5 How many levels of school have you completed?

Did not complete 5th grade (1), Elementary School (2), Middle School (3), High School (4), Associates Degree (5), Bachelor's Degree (6), Graduate Degree (7).

Q5.6 What country were you born in? ___________

Q5.7 If born in another country, approximately how many years have you been in the US?

Less than 5 years (1), 5–10 years (2), More than 10 years (3), Decline to answer (4).

Q5.8 Height (inches): ___________

Q5.9 Weight (lbs): ___________

Follow-Up Survey

Q1.1 We are here at the request of the US Department of Agriculture. We have been asked to evaluate the impact of line speed on the work of employees like you. I am a university researcher, and I would like to ask you some questions about your work using this questionnaire. Your responses will be anonymous and confidential. Your participation is completely voluntary.

Q1.2 Indicate the facility Study Site number: Site 1 (1), Site 2 (2), Site 3 (3), Site 4 (4), Site 5 (5), Site 6 (6).

Q1.3 Participant ID (write "Decline" if the worker declines to participate; do not include the site number or your initials; if practicing, write "test"): ___________

Q1.4 Will this participant be asked to have measurements made with the wearable devices?

No (0), Yes (1).

Q1.5 Which line speed is being evaluated today?

Slower Line Speed (1), Faster Line Speed (2).

Start of Block: Task Evaluation Block

Q2.1 What is the job that you are performing TODAY while the research team videotapes you? ___________

Q2.2 Is this the SAME job that you were doing last week when we videotaped you?

No (0), Yes (1).

Q2.3 STOP: TALK TO STUDY TEAM LEADER TO HAVE THIS PERSON MOVED BACK TO THE SAME JOB AS LAST WEEK BEFORE PROCEEDING. ___________

Q2.4 Are you right-handed or left-handed?

Right (1), Left (2), Both (3).

Q2.5 Please rate the HIGHEST HAND FORCE (squeezing, gripping, pinching) that you use for this job with your dominant hand (scale: 0–10):

1. 0 Nothing at all
2. 0.5 Extremely Weak (just noticeable)
3. 1 Very Weak
4. 2 Weak (light)
5. 3 Moderate
6. 4
7. 5 Strong (heavy)
8. 6
9. 7 Very Strong
10. 8
11. 9
12. 10 Extremely Strong

Q2.6 Please rate the AVERAGE HAND FORCE (squeezing, gripping, pinching) that you use for this job with your dominant hand (scale: 0–10):

1. 0 Nothing at all
2. 0.5 Extremely Weak (just noticeable)
3. 1 Very Weak
4. 2 Weak (light)
5. 3 Moderate
6. 4
7. 5 Strong (heavy)
8. 6
9. 7 Very Strong
10. 8
11. 9
12. 10 Extremely Strong

Q2.7 How are staffing levels on your line TODAY compared to a typical day?

A lot more people (1), A few more people (2), About the same number of people (3), A few less people (4), A lot less people (5).

Q2.8 How many people are performing YOUR job today?

Workers: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20.

Q2.9 I would like you to think about the speed of your line today. Is it moving faster, slower, or about the same as normal?

A lot faster (1), A little faster (2), About the same (3), A little slower (4), A lot slower (5).

Q2.10 TODAY, have you had any difficulty keeping up with your work?

No (0), Sometimes (1), Most of the time (2), Always (3).

Q2.11 Comments about workload: ___________

Q2.12 TODAY (or within the past 24 hours), are you having any pain or discomfort in your hands, arms, neck, back, or legs while at work?

No (0), Yes (1).

Q2.13 How is your pain TODAY? Rate your pain for each part of your body on a scale of 0 to 10, where 0 is no pain and 10 is the worst possible pain:

- Neck
- Shoulder
- Arm/Elbows/Forearm
- Hands/Wrist
- Back
- Hips/Knees/Legs

Q2.14 Comments about fatigue, pain, or discomfort: ___________

Q2.15 Do you have a change in respiratory problems at work THIS WEEK, such as burning in your eyes, nose, throat, or lungs?

Less problems (1), The same (2), More problems (3).

Q2.16 Do you have a change in respiratory problems at work THIS WEEK, such as burning in your eyes, nose, throat, or lungs?

Less problems (1), The same (2), More problems (3).

Appendix 3. Methods

A.3.1 Videotaping

All participants included in the ergonomic assessment were videotaped at 30 frames per second (FPS) for up to 10 minutes while performing their job. Five minutes of the video was taken from an overhead perspective to evaluate the movement of the hands and approximately five minutes of video was taken from the side to capture sagittal plane shoulder movements. Due to space constraints, or primary movement in the frontal plane, some sagittal views were replaced by frontal views (i.e., video taken while facing the worker). While being videotaped, participants were also donned with wearable devices that measured wrist kinematics and forearm muscle activity during their videotaped assessment.

Video was analyzed frame by frame using specialized software (Multivideo Task Analysis (MVTA), University of Wisconsin, Madison) that allows each frame to be allocated to a particular category, ultimately to evaluate the frequency and duration of each exertion and the overall repetition rate (exertions per minute) and duty cycle (% time spent in hand exertion) of the job. There were two levels of analysis that allocated each frame to different categories of interest: the tool used (Figure A.3.1.1) and the type of hand exertion (Figure A.3.1.2.), as defined below (Tables A.3.1.3).

Figure A.3.1.1. Example of video analyzed in MVTA by tool used

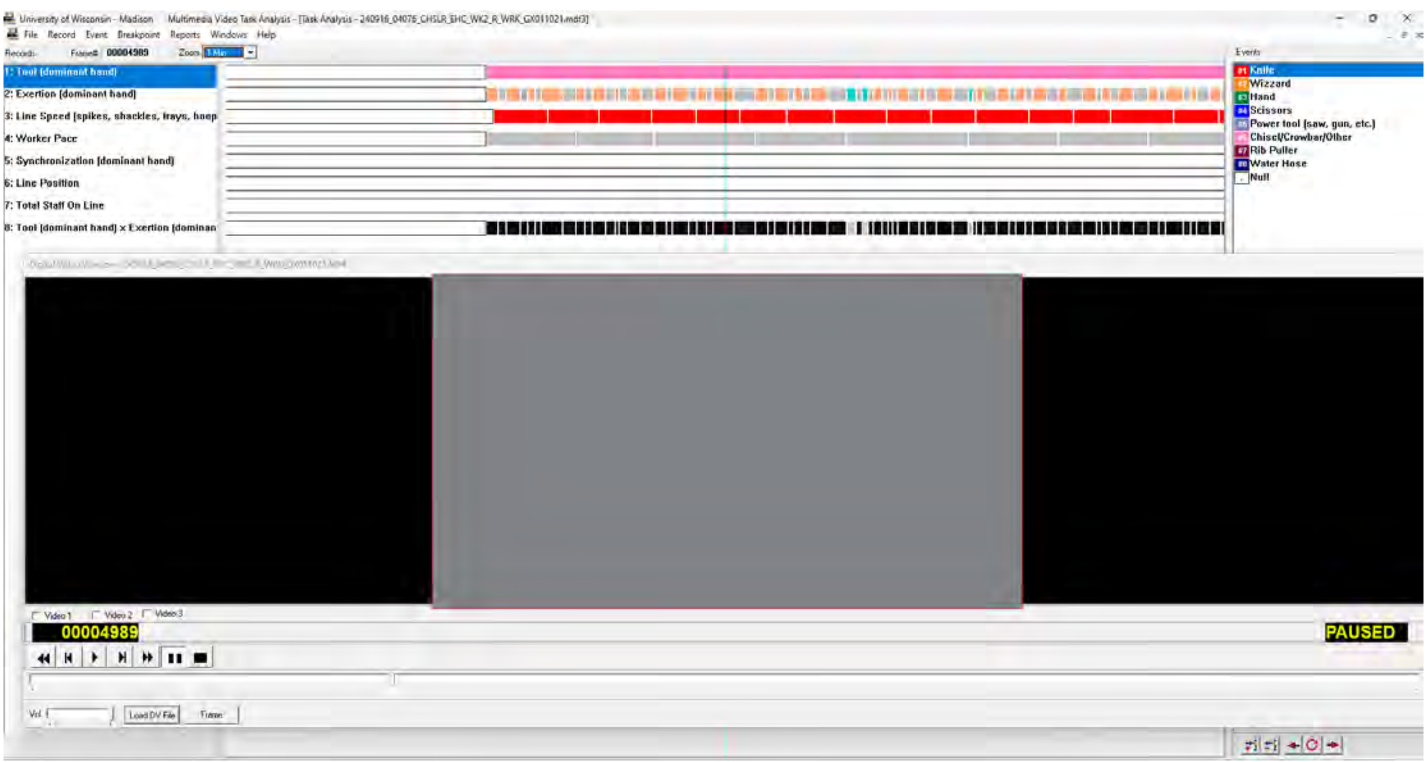


Figure A.3.1.2. Example of video analyzed in MVTA by type of hand exertion

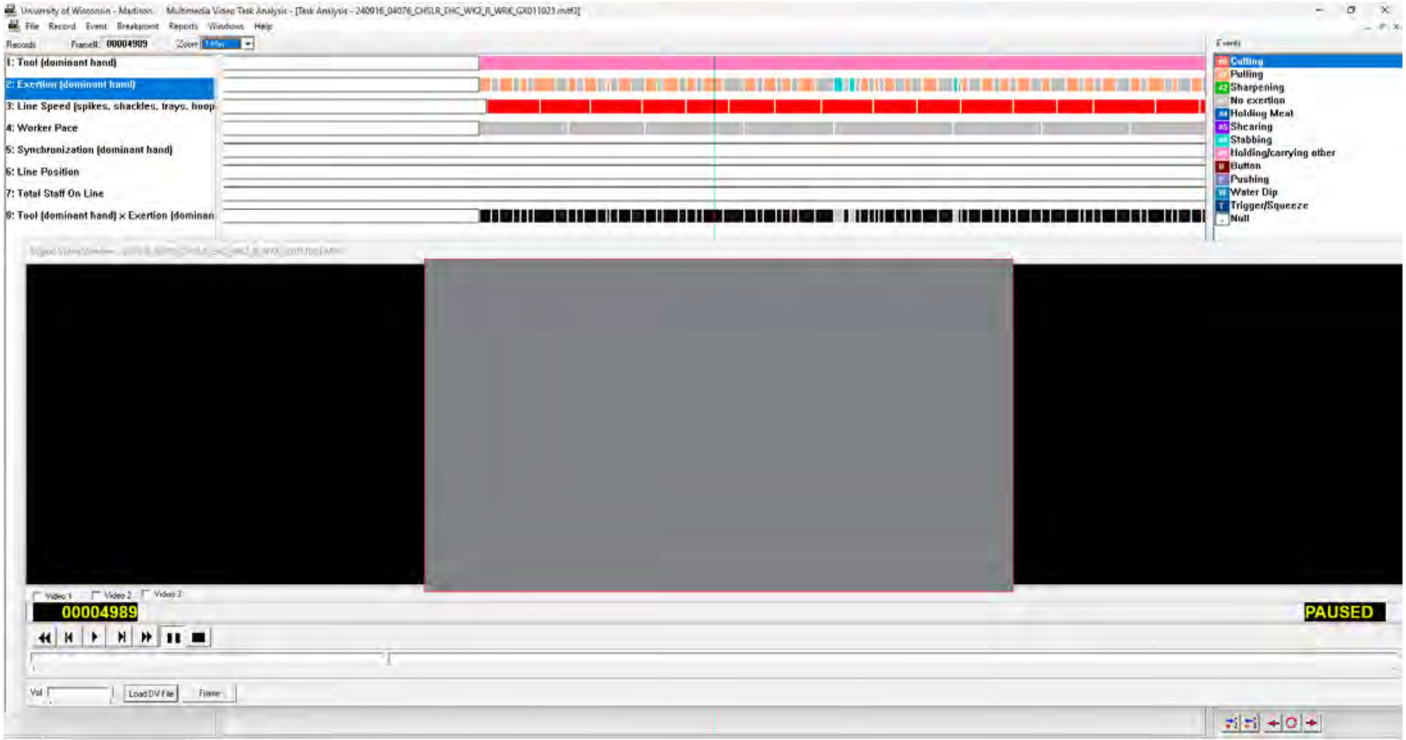
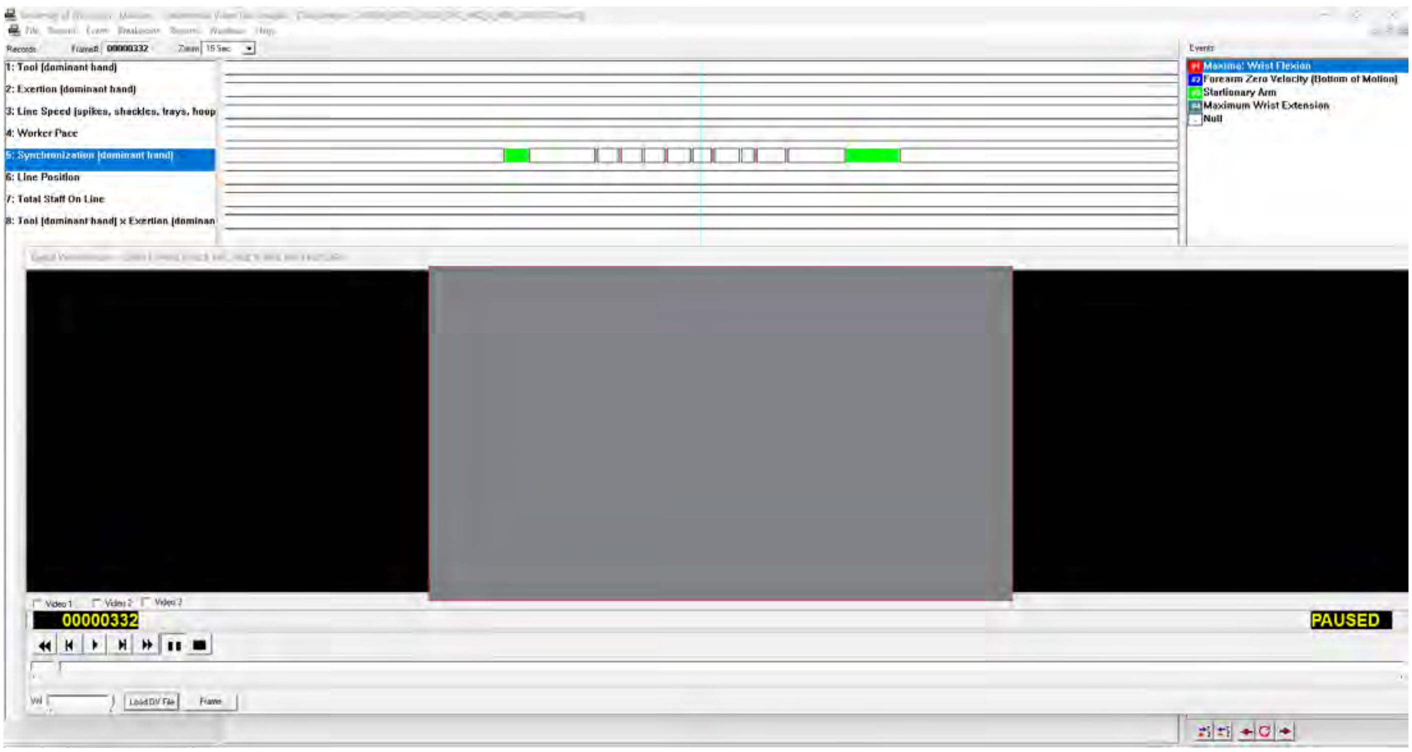


Table A.3.1.3. List of definitions used to classify hand exertions

Category	Event	Definition
Tool	Knife	Single blade, straight or curved
	Whizard	Electric circular blade, various sizes
	Hand	While wearing gloves
	Scissors	Standard scissors
	Power tools (saws, guns, etc)	Any mechanized tool that is not a Whizard
	Chisel/Crowbar/Other	Various non-powered tools that are not knife or scissors
	Water Hose	Any hose/spigot that workers use to their tools and PPE while working
Exertion	Cutting	Knife, scissor, or Whizard
	Pulling	Using hand or tool to pull meat
	Pushing	Using hand or tool to push meat
	Sharpening	Using blade sharpener with knife or scissors
	Holding Meat	Using hand to hold meat
	Shearing	Pushing with scissors or tool, without closing the blades
	Stabbing	Pressing end of tool into meat to move it
	Water Dip	Dippingtool into a water container
	Holding/Carrying other	Holding non-meat object (box, bag, etc.)
	Trigger/Squeeze	Utilizing a water hose to wash off tools or PPE
	Button	Pushing a button
	No Exertion	None of the above exertions
	Null	Hand not clearly in view

One minute of work from each video was analyzed by first categorizing the tool used, and then the type of hand exertion identified in every frame, for one hand only. The hand holding the cutting tool was analyzed, or when no cutting tool was used, the worker's dominant hand was used and identified by the presence of wearable devices. The first and last frames of the tool and exertion analyses were aligned to ensure a consistent length of working time for each record. An interaction term for tool and exertion categories was created in MVTA (Tool x Exertion) and reports for Time Study and Breakpoint were exported for use in data processing and analysis. Additionally, MVTA was used to synchronize data streams for subjects equipped with wearable measurement devices (Figure A.2.1.3). MVTA was also used to quantify: 1) the speed of the line; 2) the number of pieces of product handled by the worker (i.e., piece rate); 3) the number of staff performing the same job on the same line; and 4) the position within a consecutive group of workers performing the same job. Breakpoint and Frequency reports were exported and used to create a data set for analysis.

Figure A.3.1.3. Example of video analyzed in MVTA to synchronize data streams.



A.3.2. Electromyography

Instrumentation. Data was collected on the dominant hand using an EMG armband (MindRove, Kft., Győr, Hungary) which has eight surface electrodes and an inertial measurement unit (IMU). Channels 7, 8, and the IMU were positioned approximately 1-2" from the elbow crease and positioned over the muscle mass of the forearm extensors, then tightened to ensure a snug fit. Skin was prepped using alcohol wipes and blue coban tape was used to secure (and protect) the device.

Figure A.3.2. Example of the placement of the EMG cuff on the forearm

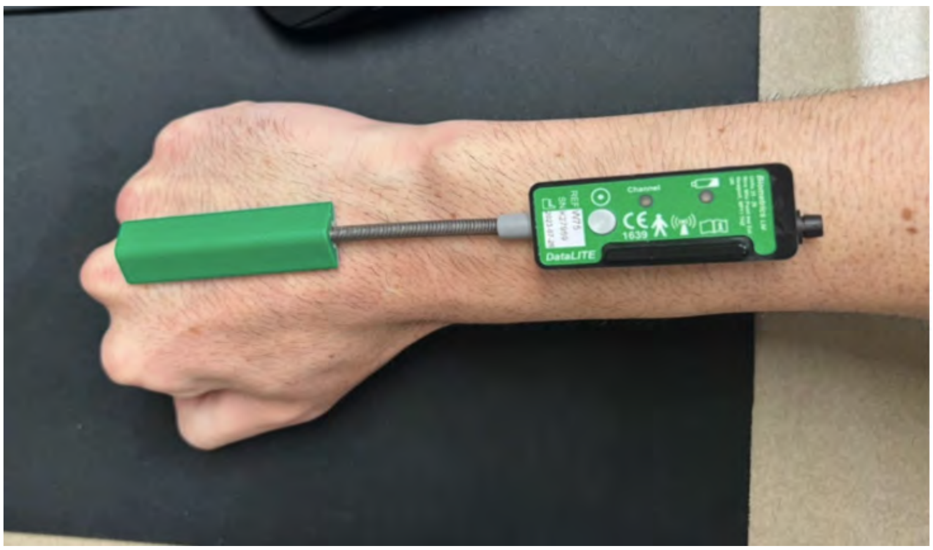
Maximum voluntary contractions were elicited using a hand grip dynamometer (Biometrics, Ltd., Cwmfelinfach, Wales) which collected data at 500 Hz. For instances in which the dynamometer collected data at 100 Hz (n=48), the data was resampled to 500 Hz using linear interpolation. Three maximum voluntary contractions were collected with sufficient rest (typically 30 to 60 seconds) between trials. Additionally, maximum voluntary contractions were elicited manually. The worker's forearm was positioned on a support while the researcher applied four forces sequentially to elicit maximum contractions of the wrist extensors, wrist flexors, wrist ulnar deviators, and wrist radial deviators. If the person had active pain, he/she was told to stop when the pain was elicited.

Data Collection. All electromyographic data was collected during normal work activities with a sampling frequency of 500 Hz and collected continuously throughout the ten-minute observation period. The raw data was streamed to a laptop held by the study team member, then transferred to a hard drive and different computer for data processing. EMG data was processed using a 5th-order Butterworth high-pass filter with a cutoff frequency of 20 Hz. The signal was then smoothed using a moving mean with a sliding window of 300 milliseconds (MATLAB function *movmean*). Maximum voluntary contractions (MVCs) were identified using a moving mean with a sliding window of 1 second. Similarly, reference voluntary contractions were identified within the trial data using the same method. Normalization of the EMG signal, by channel, was then performed using the greater of either MVC or reference voluntary contraction for each channel. Normalized trial data then underwent its final stage of processing in which an artifact removal script is used to remove any peaks that exceed 250% of the mean peak signal. Amplitude probability distribution functions (APDFs) were then calculated for each EMG channel. Channel exclusion was performed in instances where the APDF 90 for the given channel exceeded 100%MVC. Remaining EMG signals were then discretely averaged across all temporal steps in order to yield a single, characteristic signal (and APDF) of the forearm's muscle activity, which was subsequently used to inform risk assessment.

A.3.3. Goniometry

Instrumentation and Data Collection. A twin-axis electronic goniometer (Biometrics, Ltd., Cwmfelinfach, Wales) was placed so that one anchor was over the dorsal side of the distal forearm (bisected) and the second was over the dorsal side of the third digit. Devices were secured with athletic tape then blue coban tape was used to secure (and protect) the device. Data was collected continuously at 500 Hz throughout the ten-minute observation period. The raw data was streamed to a laptop held by the study team member, then transferred to a hard drive and different computer for data processing. Electronic goniometer data was numerically differentiated (MATLAB function *gradient*) to yield both sagittal- and coronal-plane angular speeds of the wrist. APDFs of these angular speeds were then calculated and reported. Median wrist posture (flexion-extension) was calculated for use in the Revised Strain Index risk assessment.

Figure 3.3 Example of goniometer placement on the dorsal aspect of the distal forearm and hand



A.3.4. Data Synchronization

MATLAB (MathWorks, Inc., Natick, MA) was used for all wearables data analyses. EMG data and electronic goniometer data were synchronized using computerized timestamps. Wearable data was then brought into the temporality of the video using Multimedia Video Task Analysis (MVTA; NexGen Ergonomics, Inc., Pointe-Claire, QC, Canada) (Figure 4.2.1.C.) and signal processing based upon discrete, high-acceleration peaks generated in the inertial measurement unit (IMU) onboard the EMG armband (collected at 50 Hz) during a protocol designed specifically to generate identifiable signatures in EMG, IMU, and electronic goniometer signals.

A.3.5. Biomechanical Exposure Measurements

Temporal Exposure Metrics

Exported time study analyses from MVTA provided the data to calculate the following time-based measures:

- Duration ($D_{observed}$) of each exertion was the sum of the duration (in seconds) of all hand force exertions over the entire video divided by the number of hand exertions over the entire video
  - $D_{observed}$ = Σ seconds while in forceful hand exertion / Σ number of forceful hand exertions
- Repetition Rate ($F_{min(observed)}$) was the sum of the number of exertions over the entire video divided by the total seconds of analysis
  - $F_{min(observed)}$ = (Σ number of forceful hand exertions/ duration (in seconds) of video) * 60
  - $F_{Hz(observed)}$ = (Σ number of forceful hand exertions/ duration (in seconds) of video)
- Duty Cycle (DC) was the sum of duration of each forceful hand exertion (in seconds) divided by the total number of seconds in the entire video
  - $DC_{observed}$ = ($F_{min(observed)}$* $D_{observed}$)/ * 100
- Hand Activity Level (HAL) was calculated using the estimated repetition rate and duty cycle
  - $HAL_{observed}$= 6.56 ln ($DC_{observed}$*100) $F_{Hz(observed)}$ 1.31 1 + 3.18 $F_{Hz(observed)}$ 1.31]

Muscle Activity Metrics

- Median Muscle Activity (MM50) was calculated as the 50th percentile on an amplitude probability distribution function (APDF) where each %MVC data point was ranked in ascending order and the 50th percentile value indicated that 50% of the time, the worker was at or below the corresponding %MVC.
- Peak Muscle Activity (MM90) was calculated as the 90th percentile on an amplitude probability distribution function (APDF) where each %MVC data point was ranked in ascending order and the 90th percentile value indicated that 90% of the time, the worker was at or below the corresponding %MVC.

Wrist Posture Metrics

- Median Sagittal Wrist Angle (P50) was calculated as the 50th percentile on an amplitude probability distribution function (APDF) where each data point describing wrist flexion-extension angle was ranked in ascending order (conventionally, flexion is positive and extension is negative) and the 50th percentile value indicated that 50% of the time, the worker was at or above the corresponding angle of extension (or flexion, conversely).
- Median wrist flexion angle (PF50) was calculated as the 50th percentile on an amplitude probability distribution function where each data representing posture when flexion was ranked in ascending order and the 50th percentile value represented the median wrist flexion angle.
- Median wrist flexion angle (PE50) was calculated as the 50th percentile on an amplitude probability distribution function where each data representing posture when flexion was ranked in ascending order and the 50th percentile value represented the median wrist flexion angle.
- The duration of time in wrist flexion (DC_{flex}) was calculated as the time in any wrist flexion divided by the total time of the video analyzed.
- The duration of time in wrist extension(DC_{ext}) was calculated as the time in any wrist extension divided by the total time of the video analyzed.

- Median sagittal wrist speed (S50) was calculated as the 50th percentile on an amplitude probability distribution function where each data representing speed in the sagittal plane was ranked in ascending order and the 50th percentile value represented the median speed.
- Peak sagittal wrist speed (S90) was calculated as the 90th percentile on an amplitude probability distribution function where each data representing speed in the sagittal plane was ranked in ascending order and the 90th percentile value represented the median speed.

Appendix 4. MSD Risk Assessment Scores

A.4.1. ACGIH Threshold Limit for Hand Activity

A Peak Force Index Threshold Limit Value (PFI-TLV score) greater than 1.0 has been shown to increase risk of upper extremity disorders and thus was used to define acceptable jobs (PFI-TLV≤1) and unacceptable jobs (PFI-TLV score >1). The PFI-TLV is calculated using modified peak muscle activity (MM90) and hand activity level (HAL) using the following equations:

- Normalized Peak Force (NPF) is reported as peak muscle activity in the range of 0 to 10
  - NPF = MM90/10
- PFI-TLV score = NPF/(5.6 - 0.56 · HAL)

A.4.2. The Revised Strain Index

The 1995 Strain Index is a commonly used tool in the United States to support the design of work tasks and evaluate for risk of upper extremity MSDs. Numerous studies have demonstrated its validity over the years, including studies that have include meat processing workers (Knox et al., 2001). The Revised Strain Index (RSI) was published in 2017 as a revision to the 1995 Strain Index, a tool that estimated risk of upper extremity MSDs using the intensity, duration and frequency of exertions, wrist posture and duration per day that the exertions are performed. The 1995 version used categorical inputs that posed challenges with its use. The RSI was proposed as a solution to the limitations of the 1995 Strain Index mostly, by providing equations that allows the calculation of multipliers on a continuous scale providing better differentiation of risk. Most recently, the RSI was evaluated in a cohort of 372 incident-eligible manufacturing, service and healthcare workers followed for up to six years and found a dose-response relationship between increased RSI scores and increased risk of carpal tunnel syndrome. Based on this and other studies on elbow epicondylitis and hand/wrist tendinosis, and its inclusion of multiple types of exposures (force, repetition, duty cycle, posture) the RSI is used to evaluate risk as well as for job intervention and design improvements that mitigate risk.

RSI	Hazard Ratio (95%CI)	Interpretation
>8.5	HR=1.0	Low Risk
>8.5 and <15	HR=1.4 (1.0-2.1)	Moderate risk
>15	HR = 1.8 (1.2-2.7)	High/Unacceptable risk

Scores above 15 were identified as having an increased risk for MSDs. The metrics above were applied to the following equations to estimate the Revised Strain Index, which is equal to the product of the following five multipliers:

RSI = IM · EM · DM · PM · HM

- Intensity of exertion multiplier (IM):
  - Intensity of exertion (I) is reported as the peak muscle activity in the range of 0 to 1.0:
    - I = MM90/100
  - $IM = 30.00 \cdot I^3 - 15.60 \cdot I^2 + 13.00 \cdot I + 0.40$: $0.0 < I \leq 0.4$
  - $IM = 36.00 \cdot I^3 - 33.30 \cdot I^2 + 24.77 \cdot I - 1.86$: $0.4 < I \leq 1.0$
- Exertions per minute multiplier (EM):
  - $EM = 0.10 + 0.25 \cdot F_{min(observed)}$: $F_{min(observed)} \leq 90$ per min.

  - $EM = 0.00334 \cdot F_{min(observed)}^{1.96}$: $F_{min(observed)} > 90$ per min.
- Duration per exertion multiplier (DM):
  - $DM = 0.45 + 0.31 \cdot D_{observed}$: $D_{observed} \leq 60$ s
  - $DM = 19.17 \cdot \ln(D_{observed}) - 59.44$: $D_{observed} > 60$ s
- Posture multiplier (PM):
  - $PM = 1.2 \cdot e^{(0.009 \cdot P50)} - 0.2$: P50 = degrees of wrist flexion
  - $PM = 1.0$: $P50 \leq 30$ degrees of wrist extension
  - $PM = 1.0 + 0.00028 \cdot (P50 - 30)^2$: $P50 > 30$ degrees of wrist extension
- Duration of task per day multiplier (HM): time spent, H, set to 8 hours
  - $HM = 0.20$: $H \leq 0.05$ h
  - $HM = 0.042 \cdot H + 0.090 \cdot \ln(H) + 0.477$: $H > 0.05$ h

A.4.3. The ACGIH Upper Limb Localized Fatigue Threshold Limit Value Limits (ULLF-TLV)

The risk of persistent fatigue and pain of the upper extremity (fingers-hand-wrist-elbow-shoulder) from repeated hand exertions was assessed using the 2022 ACGIH Upper Limb Localized Fatigue TLV (ULLF-TLV) (ACGIH 2022, p 204). The TLV is based on physiological, biomechanical, and epidemiological studies and the TLV levels are selected to protect workers from persistent fatigue and pain.

The ULLF TLV uses two exposure measures to categorize work tasks as acceptable or unacceptable, i.e., the hand exertion duty cycle and the average force applied by the hand over time. The ACGIH ULLF TLV instructions specify that the duty cycle is the duration of time that the hand is applying more than 5% of posture-specific strength divided by the total time sampled (work time + rest time). However, due to limited resources, for the analyses presented in this report we used 10% of the posture-specific strength for calculating the duty cycle, an approach that somewhat underestimated the risk. The reference population for this investigation was the 25th percentile female, so an acceptable task will protect 75% of female workers and almost all male workers from persistent upper extremity fatigue and pain.

The ULLF is calculated using duty cycle (DC) using the following equation:

- $ULLF\ \%MVC = -0.143 \cdot \ln(DC/100) + 0.066$
- $ULLF\ Ratio = MM50 / ULLF\ \%MVC$

Appendix 5. Summary of Participants by Establishment

Table A.5.1. Demographic characteristics of study participants

	Establishment A	Establishment B	Establishment C	Establishment D	Establishment E	Establishment F
Age, Mean (SD)	43.4 (12.1)	40.7 (11.1)	41.1 (11.1)	36.3 (10.2)	37.1 (11.0)	39.0 (11.3)
Gender						
Male, N (%)	56 (53.3%)	64 (81.0%)	88 (88.0%)	75 (72.8%)	86 (94.5%)	75 (69.4%)
Female, N (%)	49 (46.7%)	15 (19.0%)	12 (12.0%)	28 (27.2%)	5 (5.5%)	33 (30.6%)
Race/Ethnicity	105	79	100	103	91	108
Black N (%)	4 (3.8%)	26 (32.9%)	4 (4.0%)	9 (8.7%)	21 (23.1%)	3 (2.8%)
White/Caucasian, N (%)	0 (0.0%)	14 (17.7%)	4 (4. 0%)	5 (4.9%)	6 (6.6%)	3 (2.8%)
Hispanic, N (%)	88 (83.8%)	31 (39.2%)	63 (63.0%)	82 (79.6%)	44 (48.4%)	98 (90.7%)
Other, N (%)	13 (12.4%)	8 (10.1%)	28 (28.0%)	6 (5.8%)	19 (20.9%)	3 (2.8%)
Primary Language Spoken						
English, N (%)	1 (1.0%)	24 (30.4%)	4 (4.0%)	8 (7.8%)	7 (7.7%)	4 (3.7%)
Other, N (%)	104 (99.0%)	55 (69.6%)	96 (96.0%)	95 (92.2%)	84 (92.4%)	104 (96.3%)
Born outside the US						
Yes, N (%)	101 (97.1%)	48 (60.7%)	93 (93.0%)	63 (61.2%)	81 (89.0%)	81 (75.0%)
No, N (%)	4 (3.9%)	31 (39.3%)	5 (5.0%)	39 (37.9%)	10 (11.0%)	24 (22.2%)
Work Tenure						
< 90 days	3 (2.9%)	1 (1.3%)	4 (4.0%)	2 (1.9%)	0 (0.0%)	6 (5.5%)
≥ 90 days but < 1 year	11 (10.5%)	11 (13.9%)	20 (20.0%)	24 (23.3%)	39 (42.9%)	7 (6.5%)
≥ 1 year and < 5 years	40 (38.1%)	31 (39.2%)	35 (35.0%)	45 (43.7%)	48 (52.7%)	56 (51.8%)
≥ 5 years and < 10 years	25 (23.8%)	12 (15.2%)	16 (16.0%)	18 (17.5%)	4 (4.4%)	15 (13.9%)
≥ 10 years	26 (24.8%)	24 (30.4%)	24 (24.0%)	14 (13.6%)	0 (0.0%)	22 (20.3%)

Percent values that do not add to 100% are the result of missing data

Appendix 6. Summary of PFI-TLV scores across all establishments, by TLT Line Speed Group, and by establishment

Figure A.6.1. Distribution of PFI-TLV scores of workers measured across all establishments while operating at a) the non-TLT line speed and b) the TLT line speed.

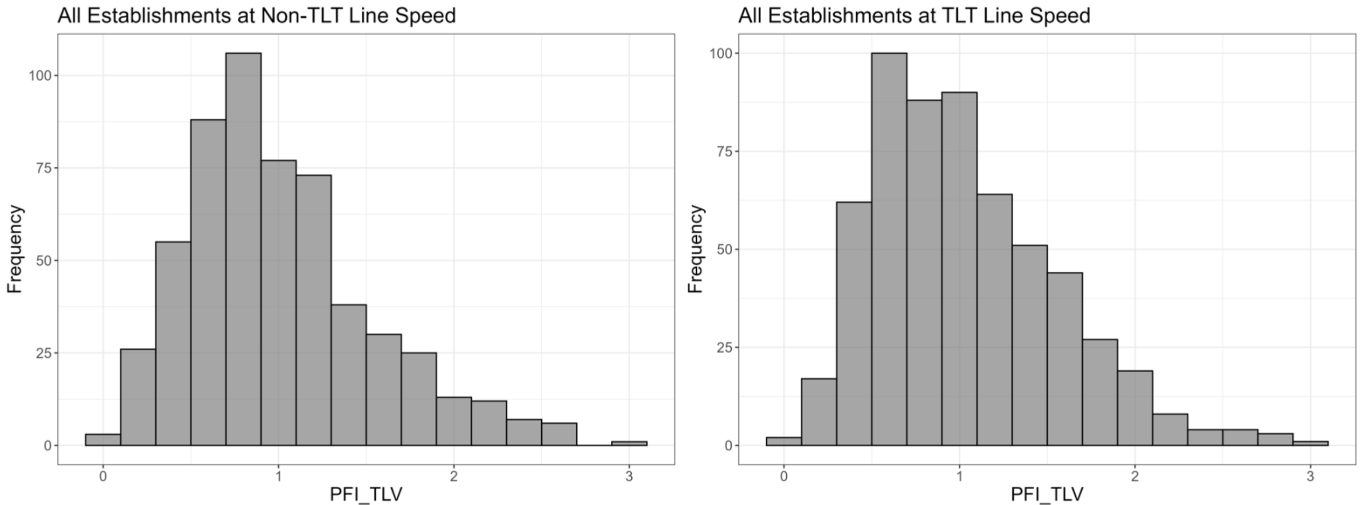


Table A.6.1. Summary of PFI-TLV scores and the proportion of workers with a PFI-TLV score>1.0 for the top 19 most common jobs across establishments

Mean (SD)	N	NPF Mean (SD)	HAL Mean (SD)	PFI-TLV Score Mean (SD)	PFI-TLV Score Range	PFI-TLV score >1.0 N	PFI-TLV Score >1.0 (%)	Range Across Establishments
Front End								
Shackler	25	2.89 (1.06)	4.17 (0.88)	0.91 (0.41)	0.754 - 1.1	5	20.0%	0.43 - 2.12
Roll Hog	21	2.59 (1.30)	4.83 (1.26)	0.99 (0.60)	0.429 - 1.9	10	47.6%	0.21 - 2.69
Insert Gam	25	3.17 (1.12)	4.65 (1.66)	1.12 (0.48)	0..51 - 1.85	12	48.0%	0.37 - 1.99
Main Chain								
Head Drop	28	3.80 (1.03)	4.81 (1.13)	1.36 (0.44)	0.92 - 1.68	22	78.5%	0.33 - 2.05
Opener	18	3.18 (0.89)	4.25 (0.75)	1.01 (0.28)	0.77 - 1.22	8	44.4%	0.48 - 1.56
Gut Snatcher	27	2.98 (1.06)	3.35 (1.50)	0.851 (0.39)	0.61 - 1.32	8	29.6%	0.03 - 1.61
Leaf Lard Gun	24	2.46 (0.89)	2.68 (0.89)	0.614 (0.25)	0.39 - 0.76	3	12.5%	0.17 - 1.12
Offal								
Tongue Pull	26	3.74 (1.41)	4.61 (0.54)	1.26 (0.52)	0.88 - 2.38	14	53.8%	0.55 - 2.38
Tongue Trim	20	3.65 (1.18)	4.34 (1.06)	1.19 (0.45)	0.89 - 2.25	9	45.0%	0.55 - 2.25
Head Round	20	3.64 (1.36)	4.19 (1.17)	1.18 (0.54)	0.60 - 1.94	11	55.0%	0.44 - 2.38
Ear Trim	20	3.32 (1.07)	4.47 (1.41)	1.18 (0.58)	0.87 - 1.45	12	60.0%	0.37 - 2.55
Chiseler	22	3.32 (1.16)	4.26 (0.97)	1.07 (0.46)	0.77 - 1.26	12	54.5%	0.42 - 2.55
Cheeks	30	2.99 (0.81)	2.43 (0.92)	0.709 (0.20)	0.51 - 0.86	2	6.66%	0.37 - 1.24
Head Meat	16	3.33 (1.16)	3.00 (0.89)	0.873 (0.36)	0.74 - 0.94	4	25.0%	0.39 - 1.61
Cut Floor								
Rib Puller	18	2.72 (1.30)	3.13 (1.29)	0.768 (0.46)	0.56 - 1.08	4	22.2%	0.19 - 1.70
Bone Butts	14	4.16 (1.17)	4.45 (1.70)	1.49 (0.65)	0.83 - 1.52	9	64.2%	0.67 - 2.49
Neckbone Lifter	24	4.47 (1.06)	3.54 (0.80)	1.25 (0.33)	1.15 - 1.41	17	71.0%	0.79 - 2.02
Picnic	20	4.14 (1.35)	4.07 (1.18)	1.29 (0.53)	1.00 - 1.61	15	75.0%	0.45 - 2.76
Cryovac	12	3.37 (0.92)	5.35 (0.67)	1.31 (0.37)	1.31 - 1.32	11	91.6%	0.44 - 1.76

Figure A.6.2. Distribution of PFI-TLV scores of workers when establishments operated at non-TLT and TLT Line Speeds, stratified by establishments operating at a TLT Line Speed of<1,300HPH versus ≥1,300HPH

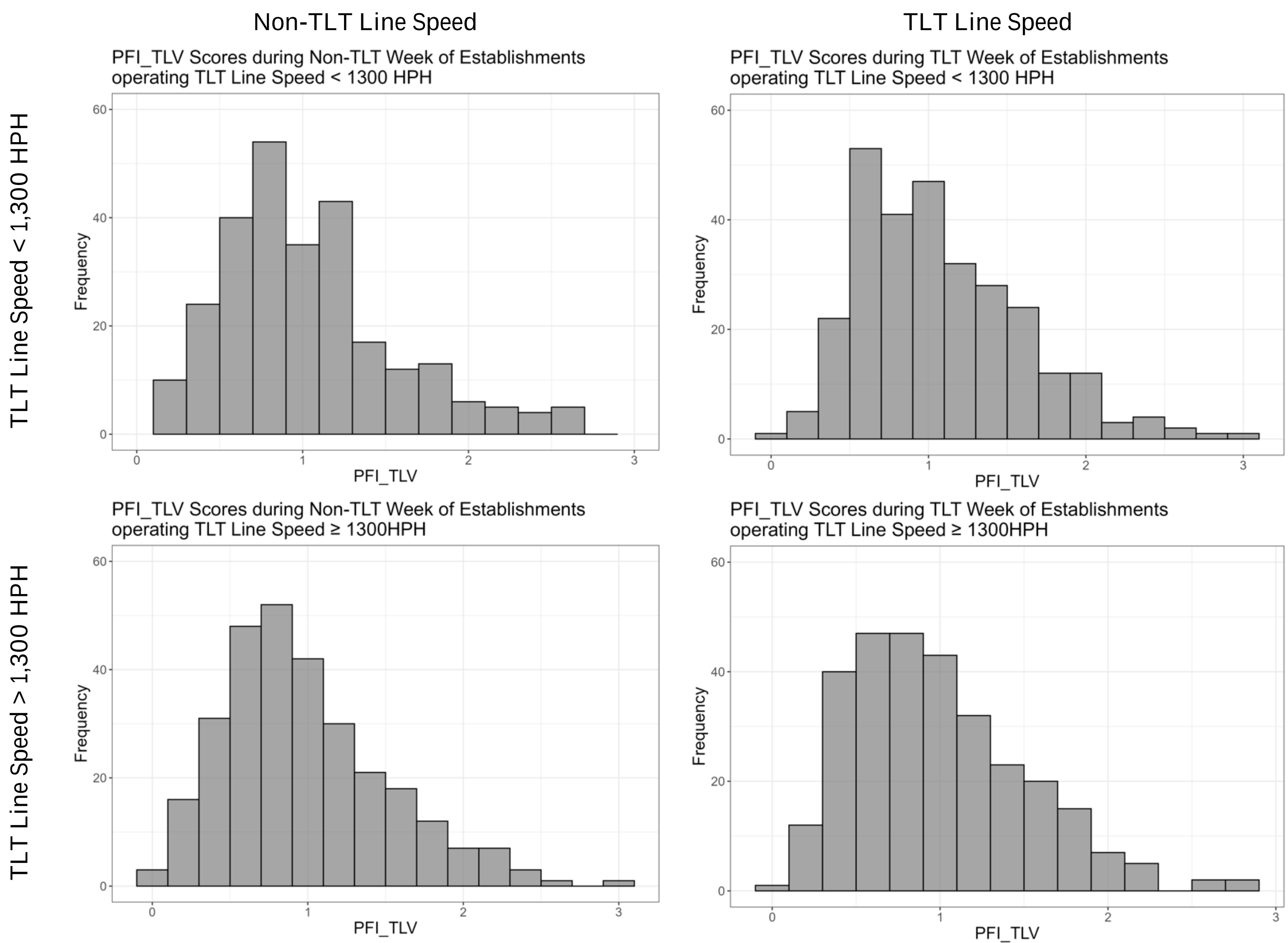


Figure A.6.3. Distribution of the change in PFI-TLV scores of workers measured a) across all establishments, and while operating at b) the non-TLT Line Speed (1,106HPH) and c) the TLT Line Speed (>1,106HPH)

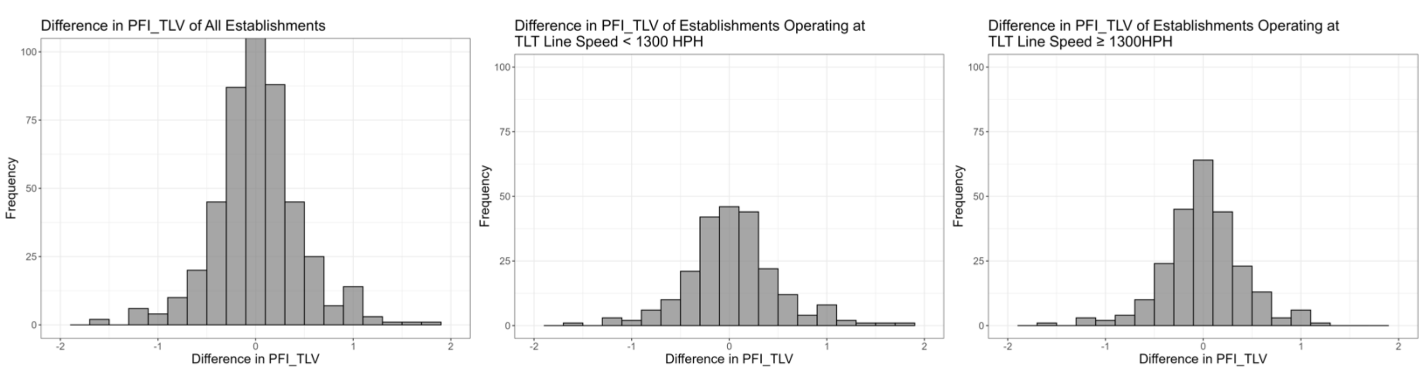
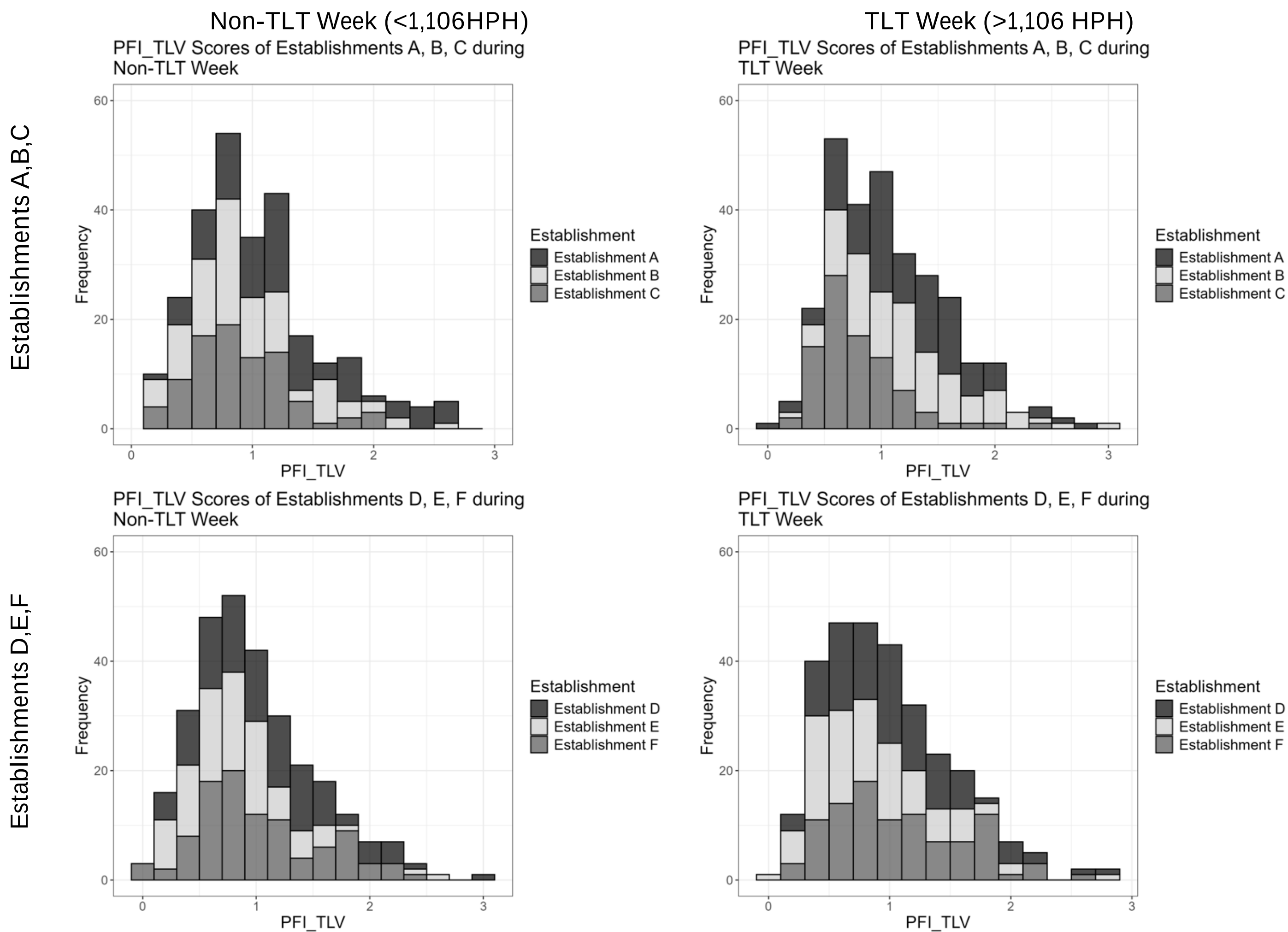


Figure A.6.4. Distribution of PFI-TLV scores of workers when establishments operated at non-TLT and TLT Line Speeds, stratified by establishment



Appendix 7. Summary of Biomechanical Exposures and Risk Scores

A.7.1. Biomechanical Exposure and Risk of MSDs by Job Category

Table A.7.1. Mean and Standard Deviation of Biomechanical Exposures by Area and Job Category

Mean (SD)		N	Exertion Duration(s).	Repetition Rate (reps/min)	Duty Cycle (%)	Hand Activity Level (HAL)	Median Muscle Activity (%MVC)	Peak[1] Muscle Activity (%MVC)	Median Sagittal Wrist Angle (°)	Median Sagittal Wrist Speed (°/s)	Peak[1] Sagittal Wrist Speed (°/s)
All Establishments	Front End	168	1.4 (1.0)	32.6 (16.0)	55.5 (17.8)	4.4 (1.3)	13.7 (6.8)	28.1 (12.0)	-15.1 (14.4)	42.6 (13.7)	161.8 (42.1)
	Main Chain	418	1.2 (1.1)	28.7 (17.2)	37.1 (17.7)	3.5 (1.5)	14.5 (7.9)	29.4 (12.6)	-7.5 (16.3)	29.5 (12.3)	108.0 (44.7)
	Offal	416	1.1 (0.8)	30.4 (15.0)	42.6 (16.1)	4.0 (1.4)	17.1 (7.2)	33.6 (11.8)	-8.3 (16.9)	29.7 (11.3)	108.8 (41.7)
	Cut Floor	272	1.1 (0.9)	28.5 (13.8)	44.0 (14.2)	3.9 (1.3)	18.3 (9.1)	37.0 (13.8)	-6.8 (13.3)	33.3 (11.7)	124.5 (43.0)
By TLT Line Speed Groups											
< 1,300 HPH	Front End	82	1.4 (1.1)	31.3 (15.5)	54.5 (18.1)	4.3 (1.3)	12.9 (6.6)	27.0 (11.8)	-17.4 (12.6)	40.4 (11.7)	154.3 (41.6)
	Main Chain	211	1.2 (1.2)	28.2 (16.9)	38.1 (17.9)	3.5 (1.5)	14.8 (8.2)	29.6 (13.0)	-8.8 (13.6)	29.2 (11.6)	106.7 (42.9)
	Offal	212	1.2 (1.0)	29.9 (14.6)	43.3 (16.1)	4.0 (1.4)	16.7 (7.4)	33.2 (12.1)	-7.3 (19.5)	28.3 (10.0)	104.8 (38.8)
	Cut Floor	137	1.3 (1.3)	28.3 (14.1)	44.4 (13.4)	3.9 (1.3)	18.2 (9.4)	36.6 (14.2)	-5.7 (12.9)	32.4 (10.9)	122.0 (42.0)
≥ 1,300 HPH	Front End	86	1.3 (0.9)	33.8 (16.5)	56.4 (17.6)	4.6 (1.3)	14.5 (6.9)	29.3 (12.1)	-13.0 (15.7)	44.7 (15.0)	168.6 (41.6)
	Main Chain	207	1.1 (1.1)	29.1 (17.4)	36.2 (17.5)	3.6 (1.5)	14.2 (7.6)	29.3 (12.2)	-6.3 (18.4)	29.9 (12.9)	109.1 (46.4)
	Offal	204	1.0 (0.7)	31.0 (15.4)	41.8 (16.1)	4.0 (1.4)	17.6 (6.9)	34.0 (11.5)	-9.3 (13.9)	31.1 (12.4)	112.8 (44.1)
	Cut Floor	135	1.0 (0.4)	28.8 (13.5)	43.5 (15.0)	4.0 (1.3)	18.4 (8.7)	37.3 (13.4)	-7.9 (13.6)	34.2 (12.4)	127.0 (44.0)

Table A.7.2. MSD Risk Summary by Area and Job Category

Mean (SD)		N	Revised Strain Index (RSI)	ACGIH PFI-TLV	ACGIH ULLF (%MVC)	ULLF Ratio
All Establishments	Front End	168	24.0 (13.9)	1.0 (0.5)	1.0 (0.7)	0.2 (0.1)
	Main Chain	418	21.5 (15.9)	0.9 (0.5)	0.8 (0.6)	0.2 (0.1)
	Offal	416	25.6 (19.6)	1.1 (0.5)	1.0 (0.6)	0.2 (0.1)
	Cut Floor	272	27.7 (16.7)	1.2 (0.5)	1.1 (0.6)	0.2 (0.1)
By TLT Line Speed Groups						
< 1,300 HPH	Front End	82	21.8 (12.4)	0.9 (0.5)	0.9 (0.7)	0.2 (0.1)
	Main Chain	211	21.6 (16.1)	0.9 (0.5)	0.8 (0.6)	0.2 (0.1)
	Offal	212	25.7 (23.0)	1.0 (0.5)	1.0 (0.6)	0.2 (0.1)
	Cut Floor	137	27.8 (17.2)	1.1 (0.6)	1.0 (0.6)	0.2 (0.0)
≥ 1,300 HPH	Front End	86	25.9 (15.0)	1.0 (0.5)	1.0 (0.6)	0.2 (0.0)
	Main Chain	207	21.4 (15.8)	0.9 (0.5)	0.7 (0.5)	0.2 (0.1)
	Offal	204	25.5 (15.5)	1.1 (0.5)	1.0 (0.5)	0.2 (0.1)
	Cut Floor	135	27.6 (16.2)	1.2 (0.5)	1.1 (0.7)	0.2 (0.1)

A.7.2. Differences in Hand Activity Level and Normalized Peak Force by Area, Job Category and TLT Line Speed

Figure A.7.2. Scatter plots of PFI-TLV scores when establishments operated at non-TLT and TLT Line Speeds, stratified by job. Points above the red line have a PFI-TLV score>1.0 indicating increased MSD risk

Figure. A.7.2.A. Scatter plots of PFI-TLV scores for the Shackler job

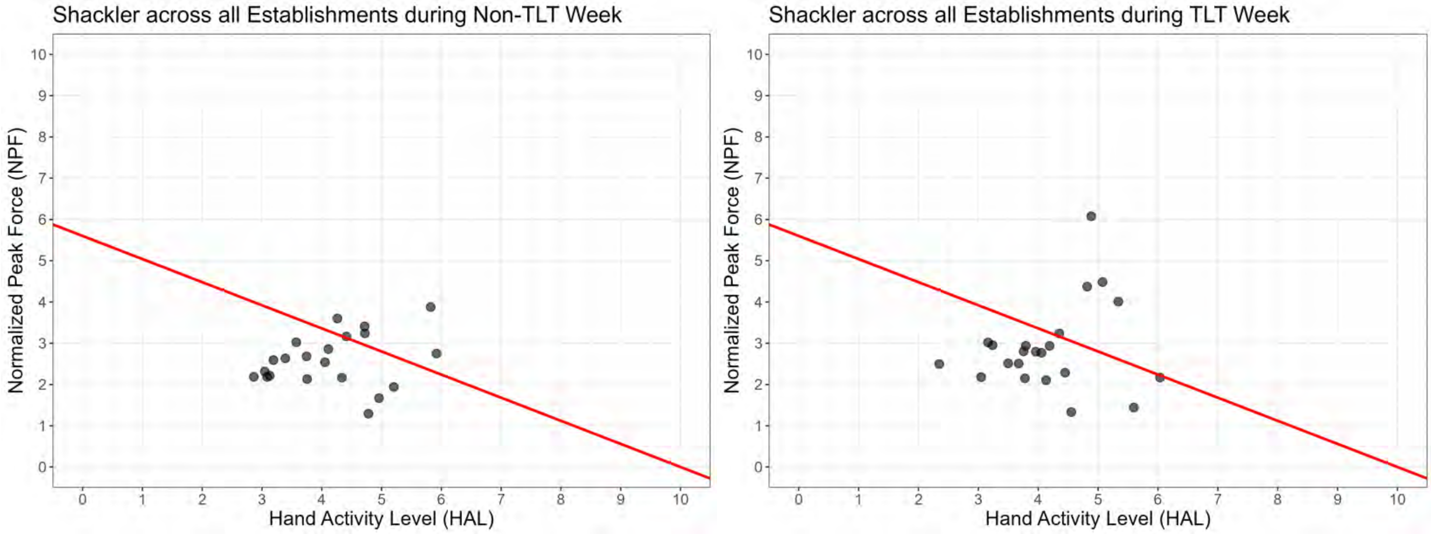


Figure. A.7.2.B. Scatter plots of PFI-TLV scores for the Roll Hog job

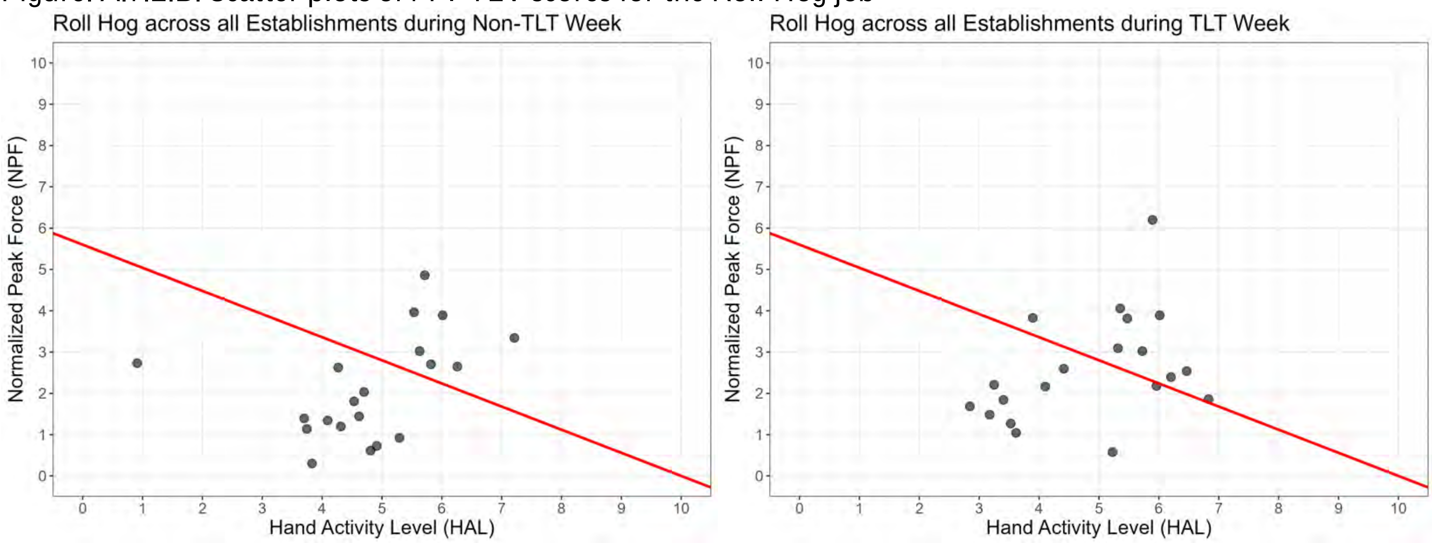


Figure. A.7.2.C. Scatter plots of PFI-TLV scores for the Insert Gam job

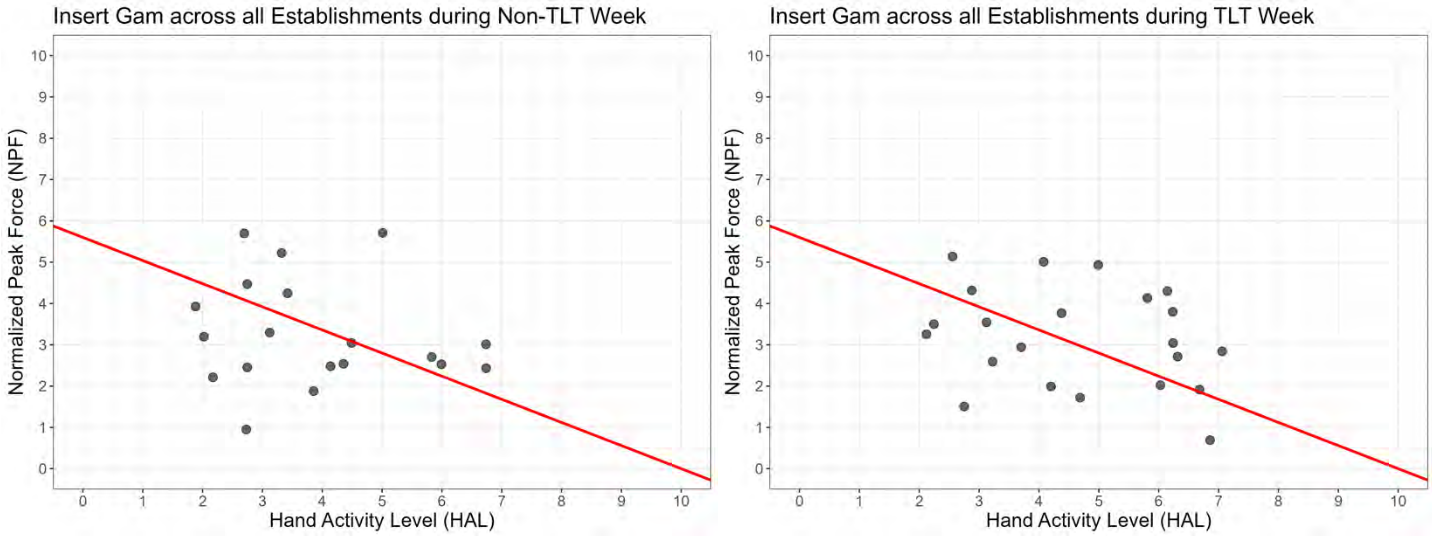


Figure. A.7.2.D. Scatter plots of PFI-TLV scores for the Head Drop job

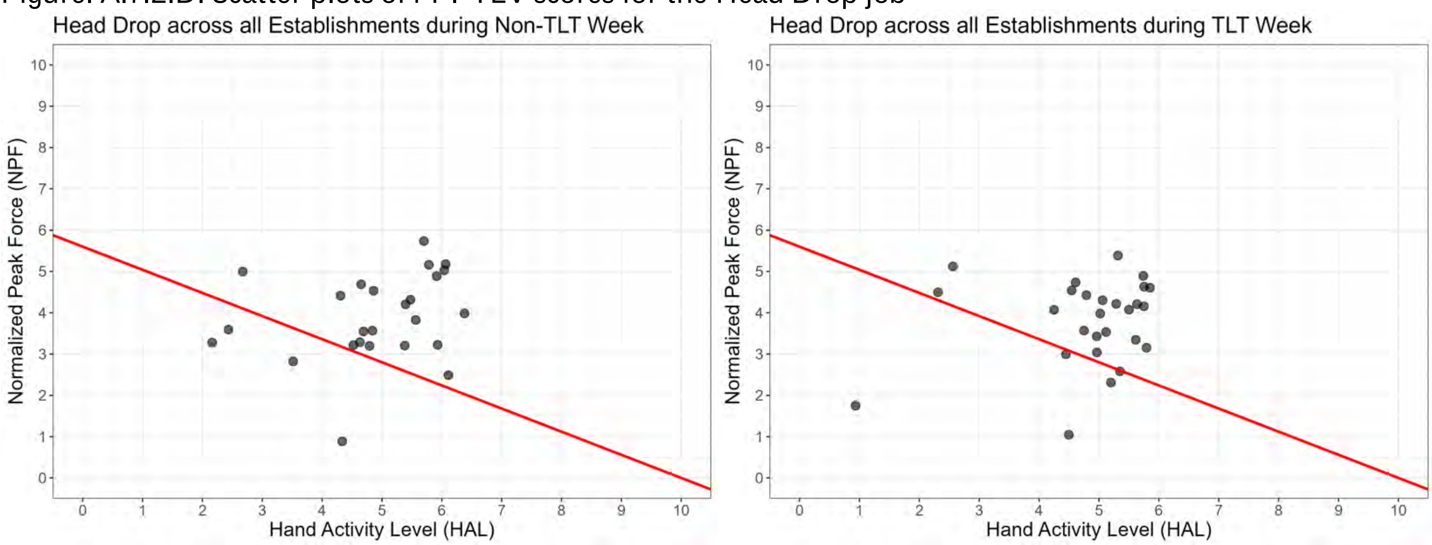


Figure. A.7.2.E. Scatter plots of PFI-TLV scores for the Opener job

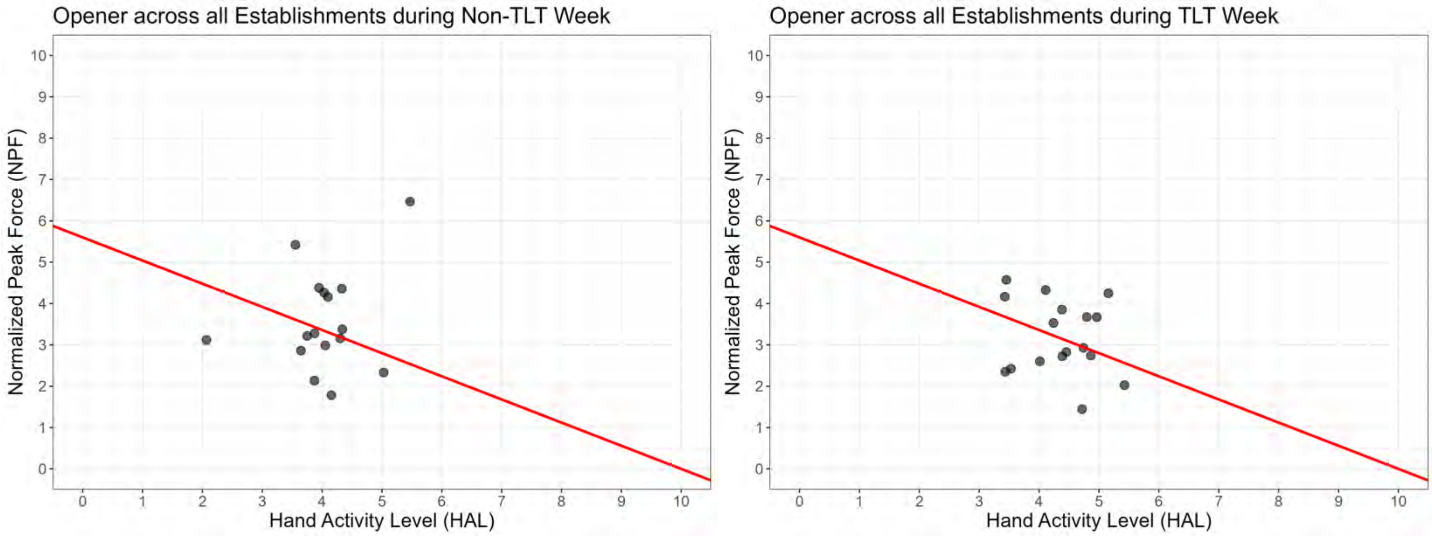


Figure. A.7.2.F. Scatter plots of PFI-TLV scores for the Gut Snatcher job

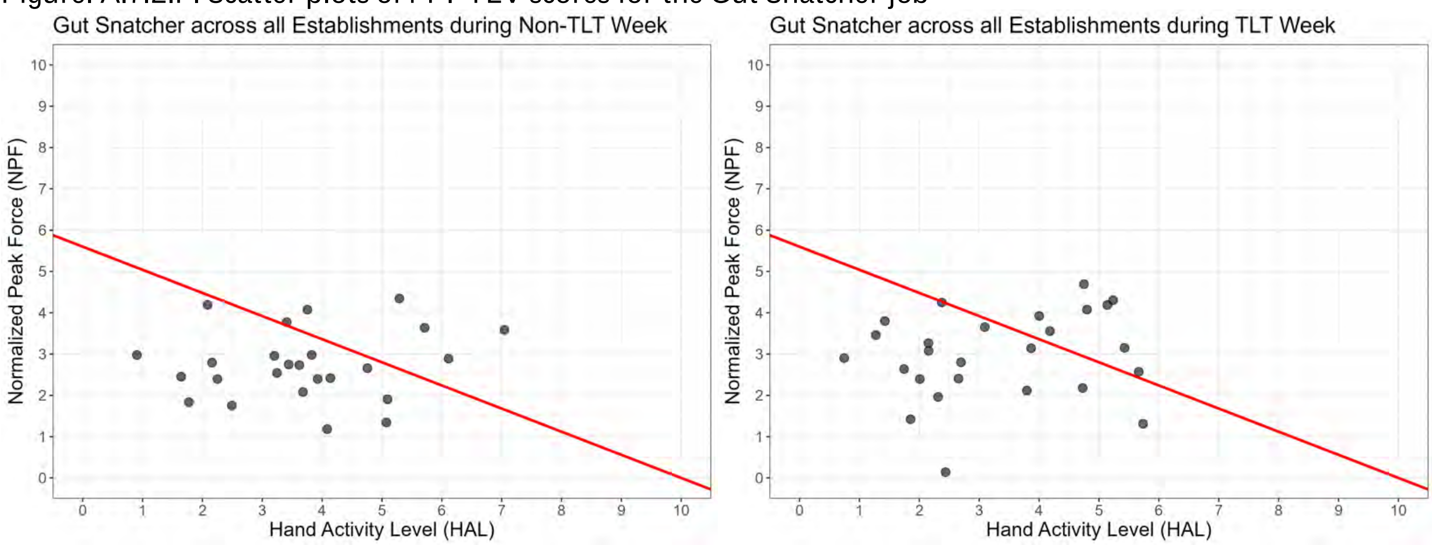


Figure. A.7.2.G. Scatter plots of PFI-TLV scores for the Leaf Lard Gun job

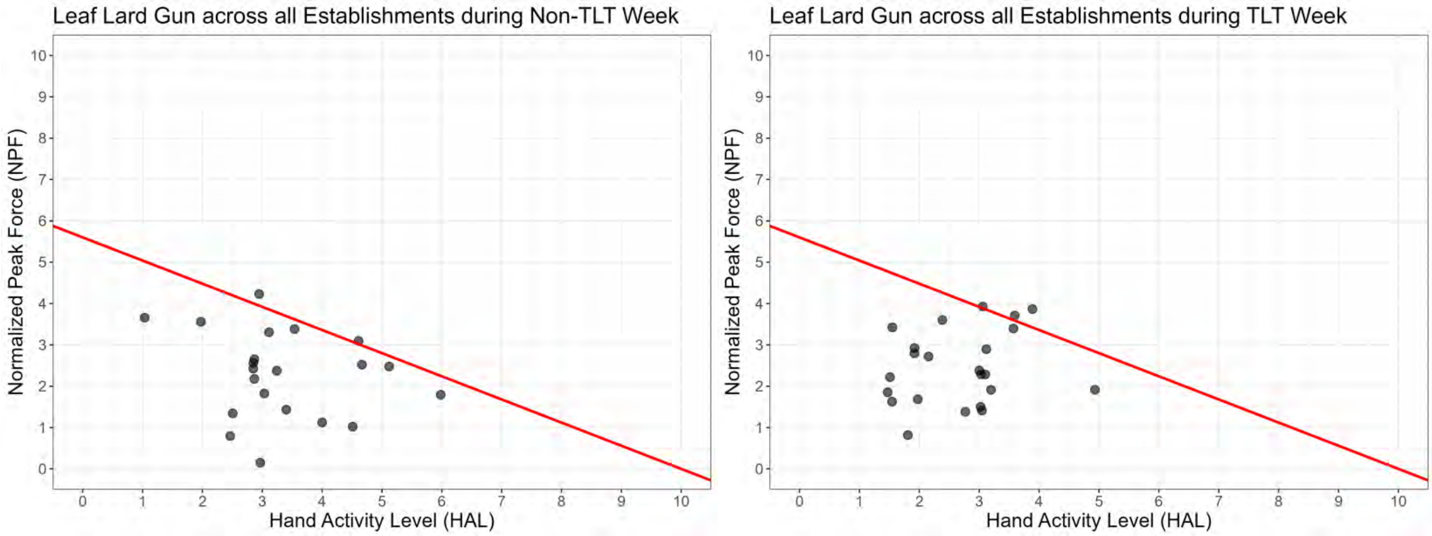


Figure. A.7.2.H. Scatter plots of PFI-TLV scores for the Tongue Pull job

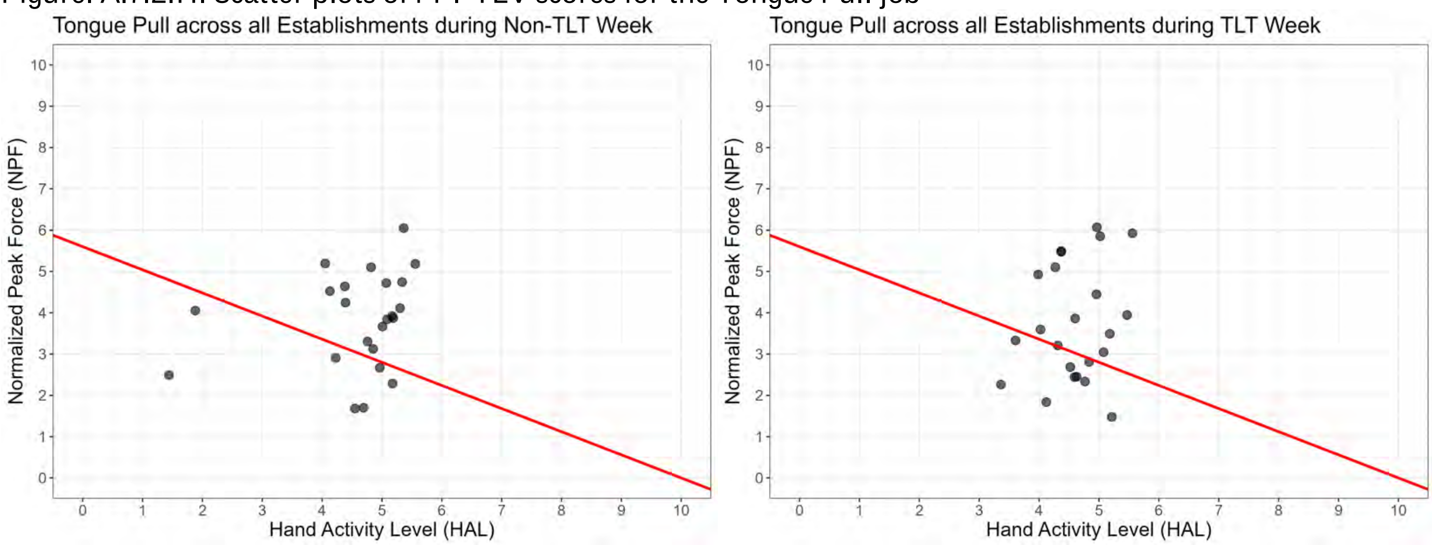


Figure. A.7.2.I. Scatter plots of PFI-TLV scores for the Tongue Trim job

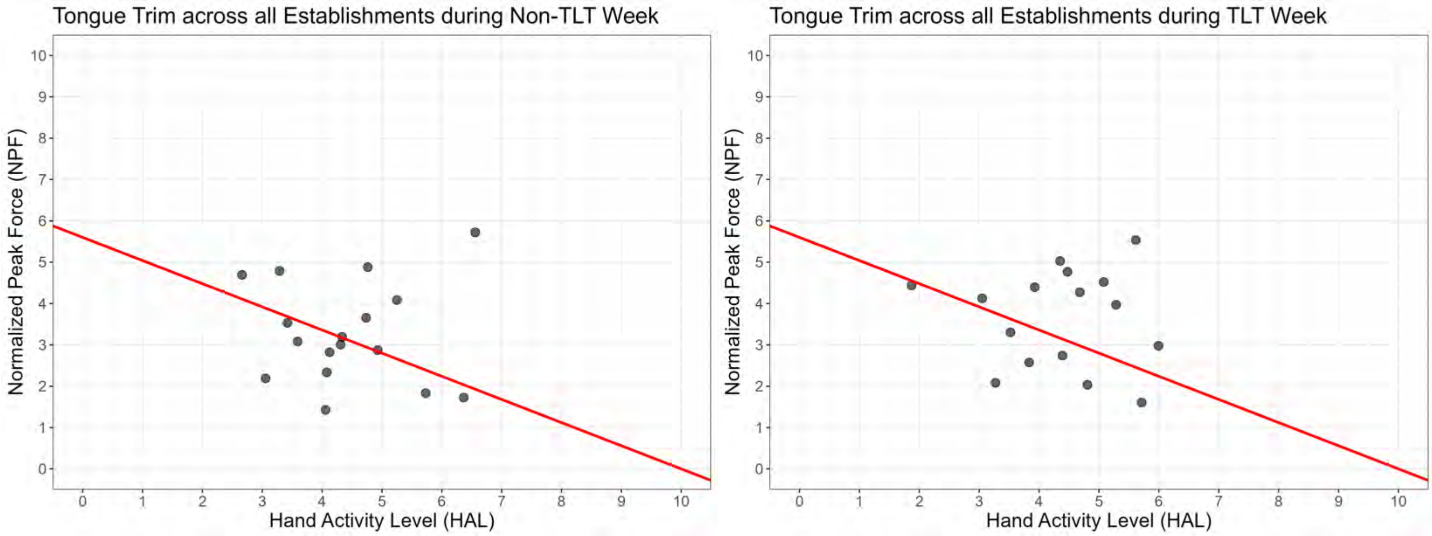


Figure. A.7.2.J. Scatter plots of PFI-TLV scores for the Head Round job

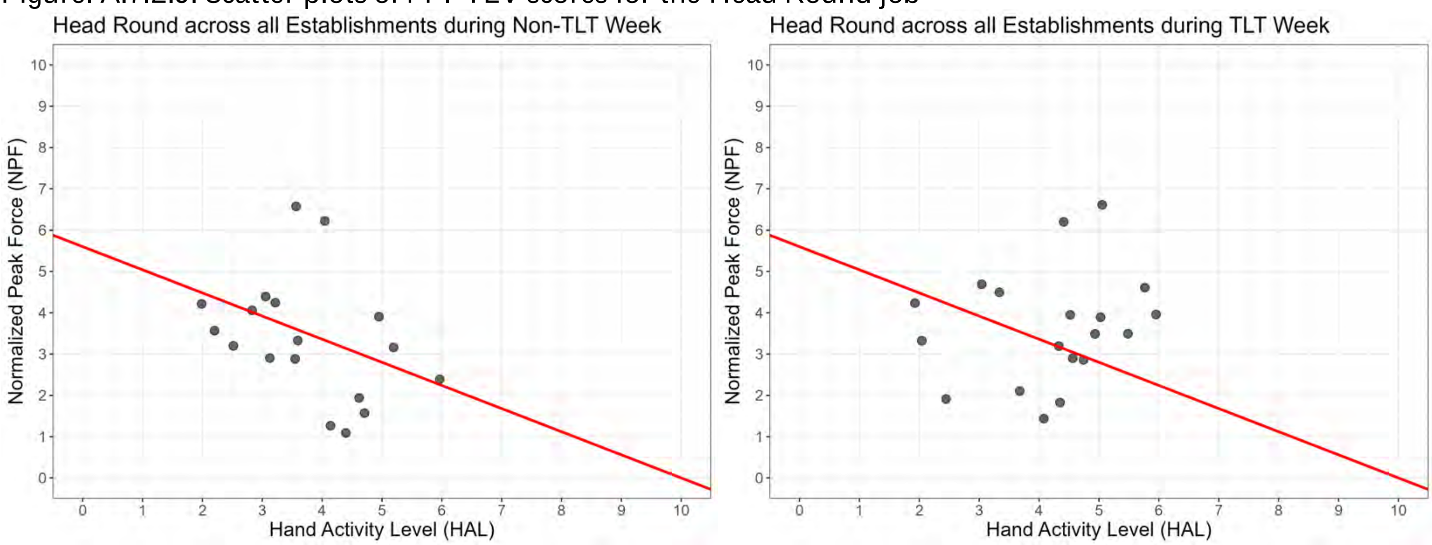


Figure. A.7.2.K. Scatter plots of PFI-TLV scores for the Ear Trim job

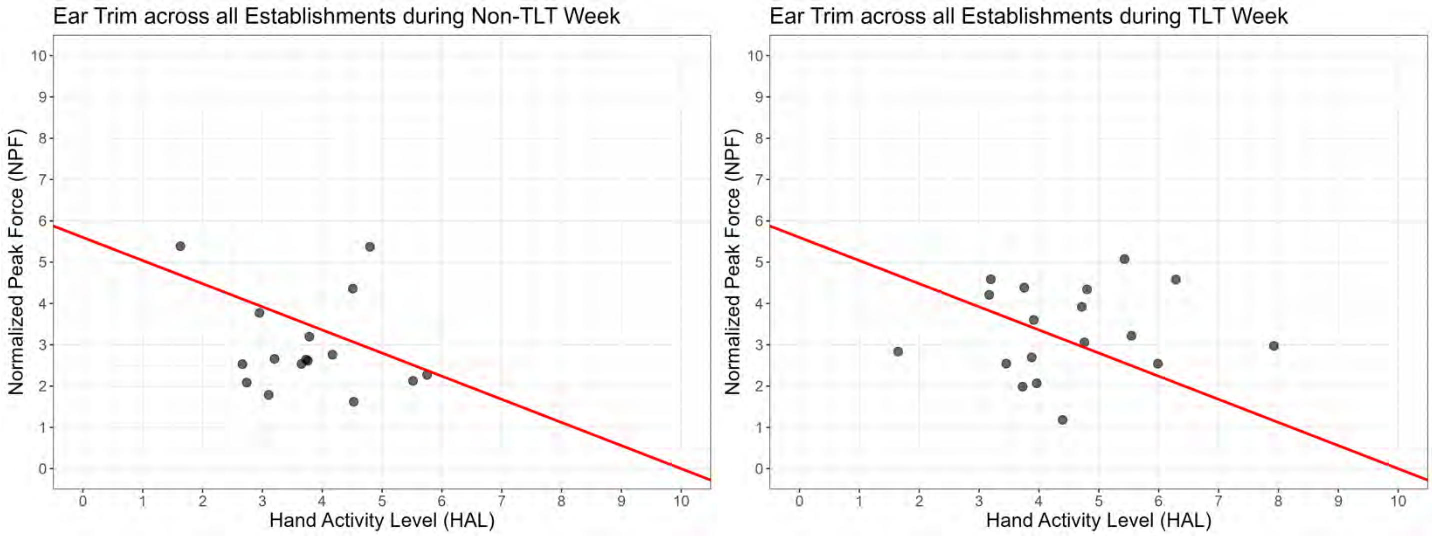


Figure. A.7.2.L. Scatter plots of PFI-TLV scores for the Chiseler job

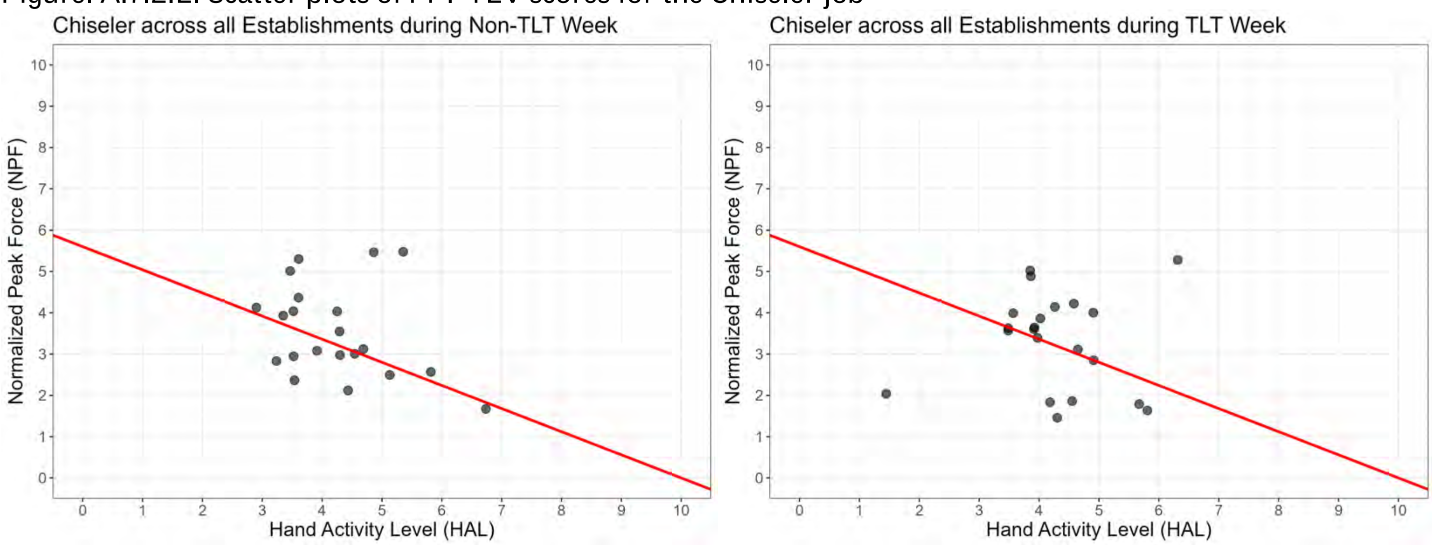


Figure. A.7.2.M. Scatter plots of PFI-TLV scores for the Cheeks job

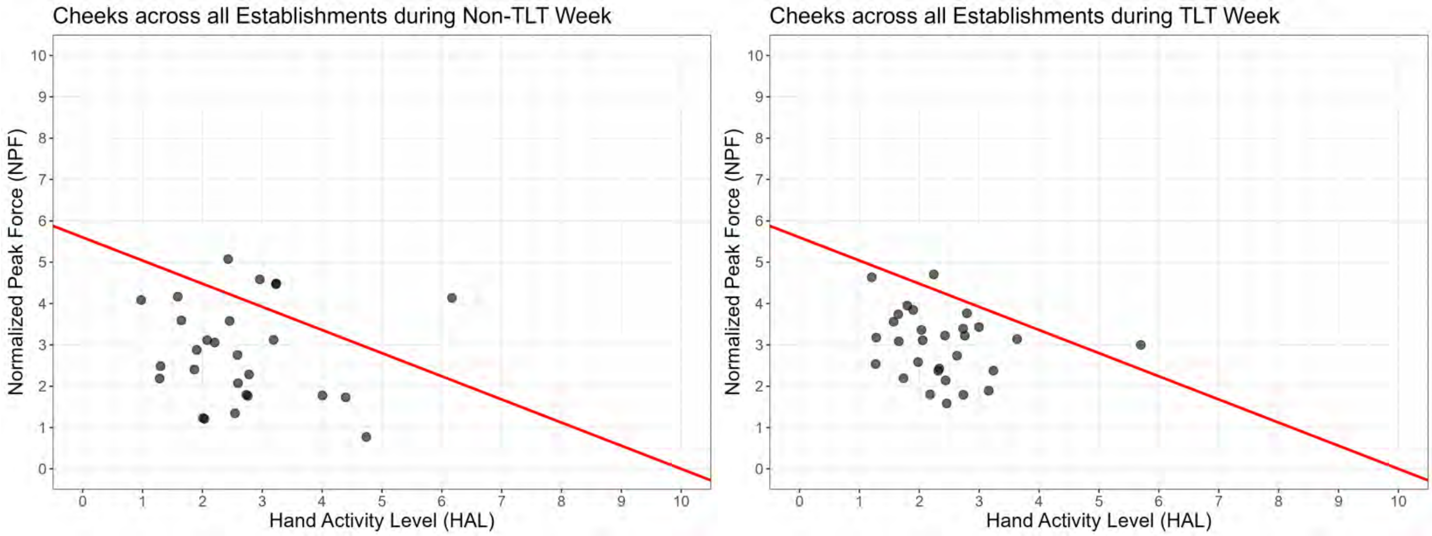


Figure. A.7.2.N. Scatter plots of PFI-TLV scores for the Trim Head Meat job

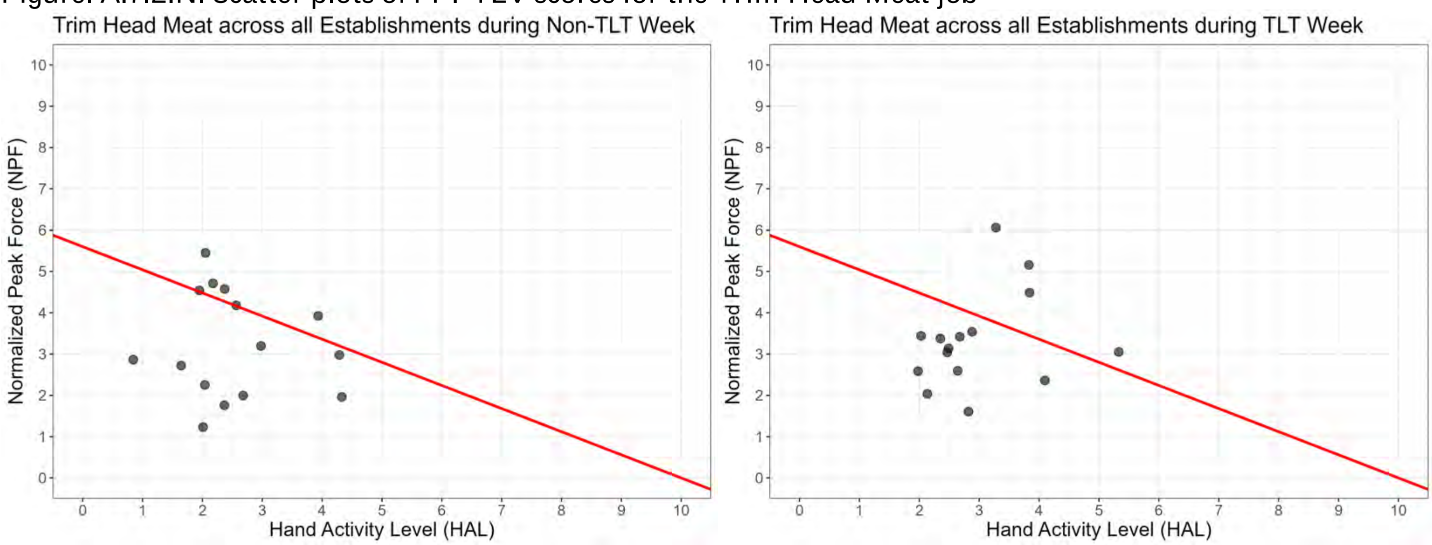
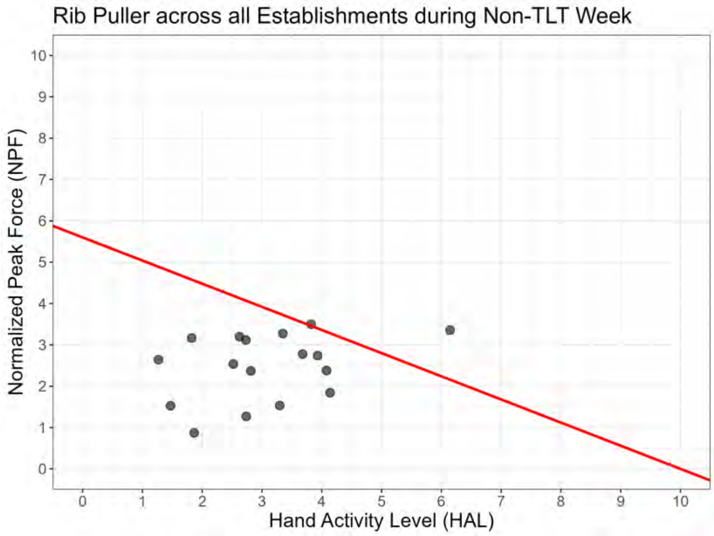


Figure. A.7.2.O. Scatter plots of PFI-TLV scores for the Rib Puller job



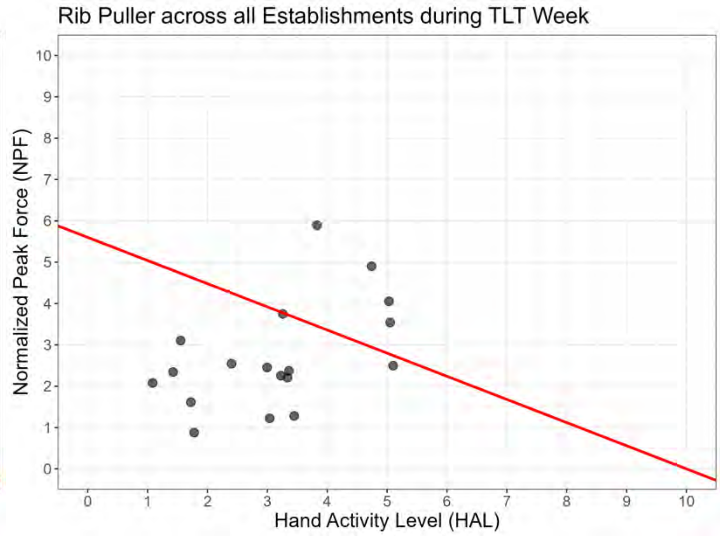
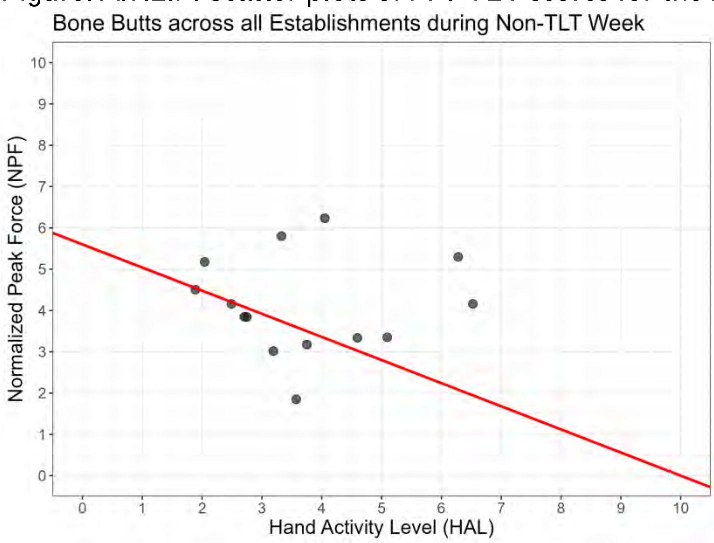


Figure. A.7.2.P. Scatter plots of PFI-TLV scores for the Bone Butts job



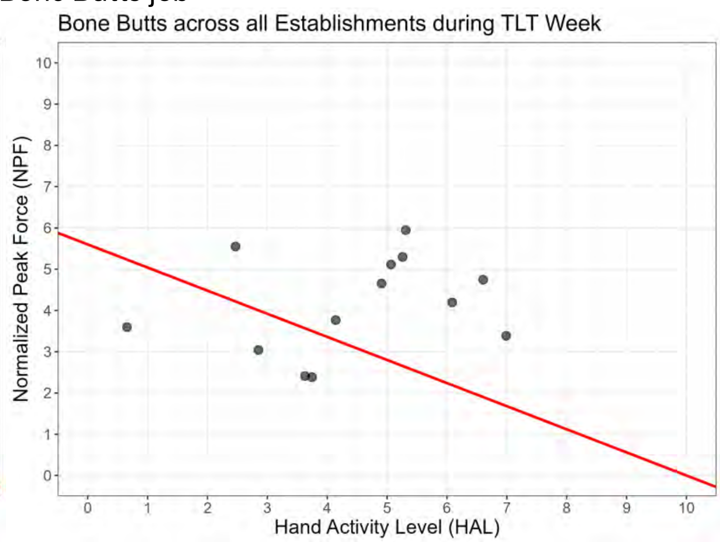


Figure. A.7.2.Q. Scatter plots of PFI-TLV scores for the Neckbone Lifters job

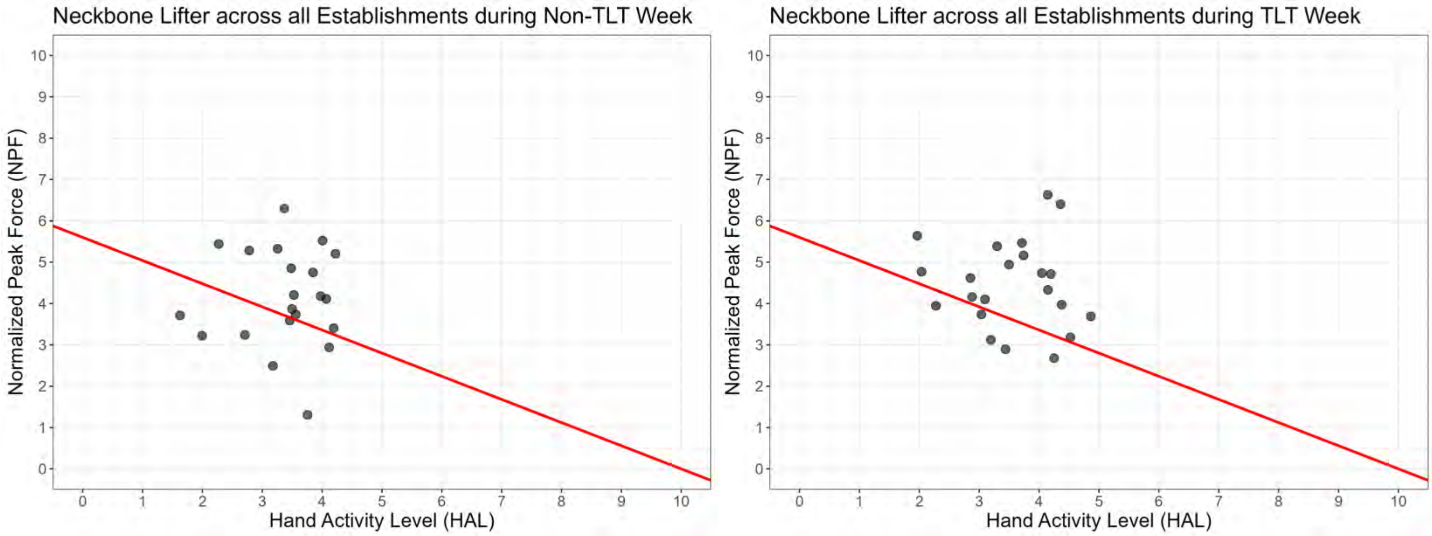


Figure. A.7.2.R. Scatter plots of PFI-TLV scores for the Picnic job

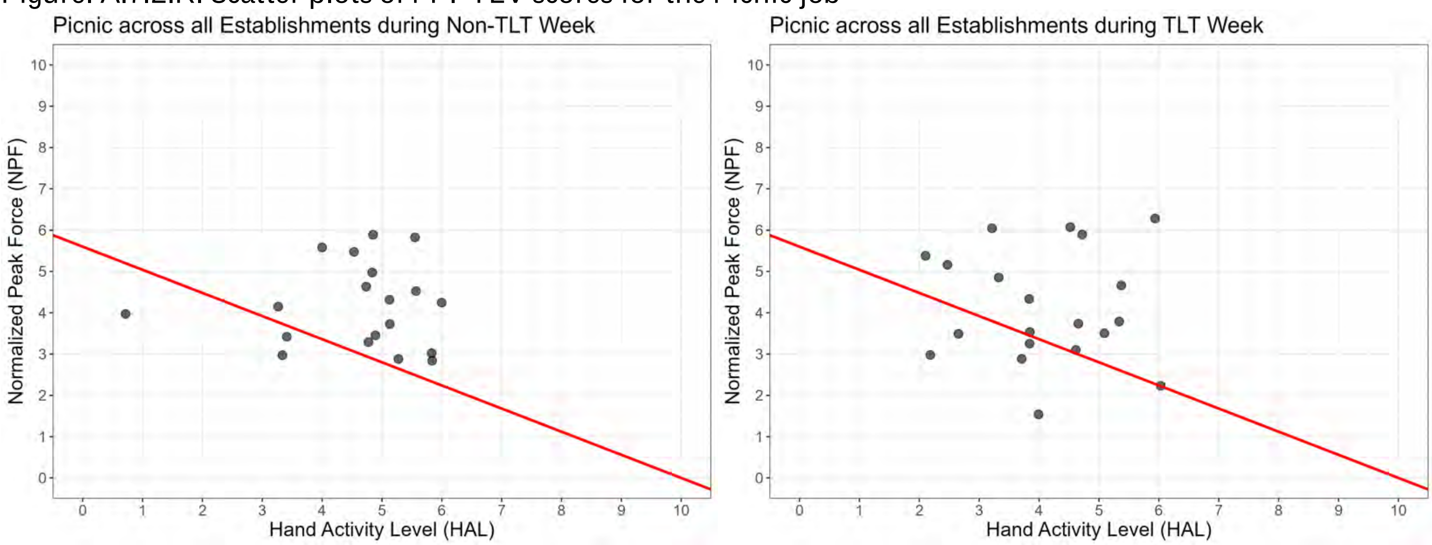
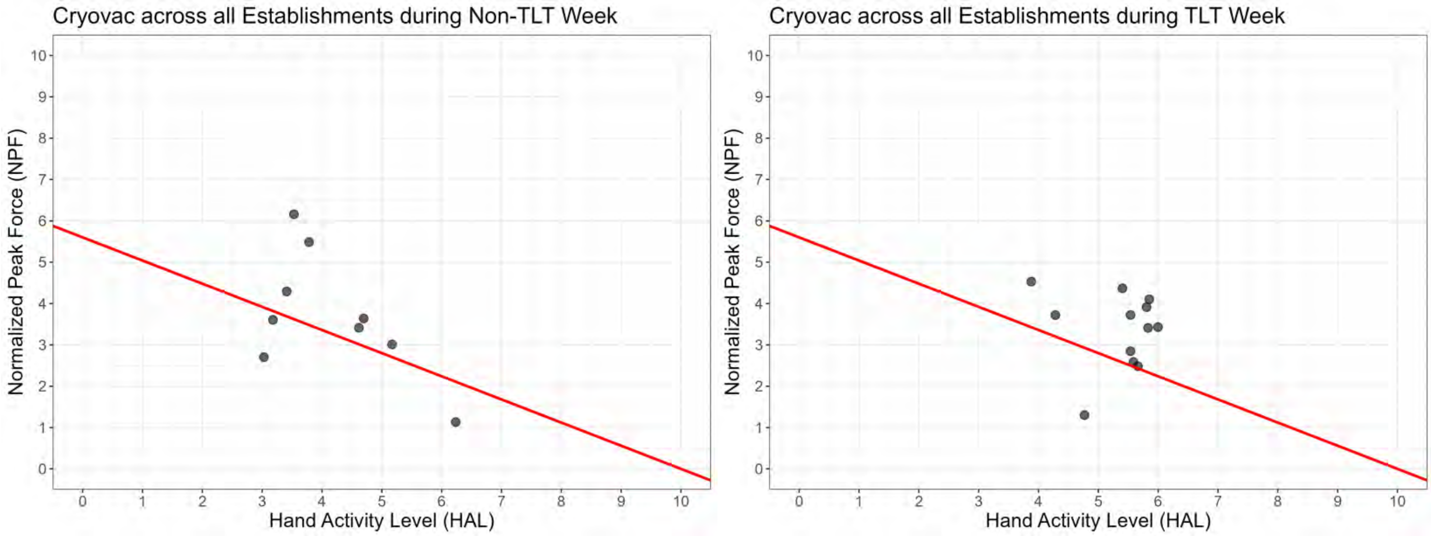


Figure. A.7.2.S. Scatter plots of PFI-TLV scores for the Cryovac job



1 The NPF value is calculated from the 90th percentile of the amplitude probability distribution function of a worker's EMG data, and the HAL value is calculated from the repetition rate and duty cycle calculated from the video analysis of each worker's video. See section 4.6.2. for additional detail.