Poultry Processing Line Speed Evaluation Study (PULSE)

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List of Terms and Abbreviations

ACGIH: American Conference of Governmental Industrial Hygienists

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

BLS: Bureau of Labor Statistics

BPM: Birds per Minute

CTS: Carpal Tunnel Syndrome

evisceration line speed: the number of birds per minute being eviscerated, as reported by each establishment to the USDA

FSIS: Food Safety and Inspection Service

GAO: Government Accountability Office

HA TLV: Hand Activity Threshold Limit Value (ACGIH)

Job-Specific Line Speed: the number of shackles, cones, or conveyors 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 Disorders

%MVC: percent of Maximum Voluntary Contraction

NPF: Normalized Peak Force defined as the %MVC normalized to a 0 to 10 scale

NPIS: New Poultry Inspection System

PAA: Peracetic Acid

PFI: Peak Force Index

PFI-TLV Score: Peak Force Index Threshold Limit Value

Piece Rate: the number of items (whole birds, pieces, parts) handled by a worker per minute

RSI: Revised Strain Index

STEL: Short Term Exposure Limit

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

In November of 2022, the USDA Food Safety and Inspection Service (FSIS) funded a research team from the University of California, San Francisco (UCSF) 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 scope of work included evaluating the impact of evisceration line speed on the risk of (i) acute and chronic work-related musculoskeletal disorders (MSDs) and (ii) antimicrobial-related respiratory exposure. Between November 2023 and April 2024, the Poultry Processing Line Speed Evaluation (PULSE) study team enrolled 1,047 poultry processing establishment workers at eleven New Poultry Inspection System (NPIS) establishments operating at evisceration line speeds between 140 and 175 birds per minute (BPM). The study team conducted surveys and medical interviews and took measurements of ergonomic exposures and airborne peracetic acid (PAA) concentrations. Data from the surveys, interviews, and exposure measures were analyzed and the key findings are presented in this report.

Key Findings

- 81% of workers were at increased risk of musculoskeletal disorders across all establishments.
- Musculoskeletal disorder risk was greater among workers who worked at a higher *piece rate*, a job-level measure of work pace.
- For most jobs, establishments operating at higher evisceration line speeds were observed to have piece rates similar to establishments operating at lower evisceration line speeds; thus, musculoskeletal disorder risk scores were similar among workers at establishments operating over a range of evisceration line speeds.
- Models indicate that reducing piece rate, by increasing job-specific staffing or decreasing job-specific line speed, may reduce musculoskeletal disorder risk for workers.
- 40% of workers across all establishments reported experiencing moderate to severe work-related pain during the past 12 months. Such pain was not reported more frequently at establishments with higher evisceration line speeds.
- Peracetic acid (PAA) airborne exposures in one in five jobs sampled across all establishments exceeded the ACGIH Short Term Exposure Limit (STEL) of 0.4 ppm.

81% of evaluated workers were at high risk for musculoskeletal disorders (MSDs) (i.e., PFI-TLV score > 1.0).[1]

- The highest mean PFI-TLV scores were observed among workers performing Breast Processing, Shoulder Processing, and Trim/Rework jobs.
- The PFI-TLV scores observed for many of the evaluated poultry processing jobs were similar in magnitude to the PFI-TLV scores of jobs in industries such as large appliance manufacturing, crop harvesting, and furniture assembly. Prior prospective epidemiological studies found elevated rates of carpal tunnel syndrome and other upper extremity musculoskeletal disorders among workers in such industries.

Piece rate, *i.e.*, the number of chicken parts handled per minute by a worker, was associated with MSD risk (PFI-TLV score).

- Analyses were conducted to examine (i) unstratified associations between piece rate and PFI-TLV score among all workers included in the study and (ii) separate associations between piece rate and PFI-TLV score stratified by job across all establishments. Associations were observed for both analyses.
- Piece rate had little or no association with evisceration line speed.
- Piece rate was determined predominantly by the job-specific line speed and staffing level.

Evisceration line speed category (≤145 BPM, >145 to <175 BPM, 175 BPM) was not associated with the *Peak Force Index -Threshold Limit Value* (PFI-TLV score), the primary metric of upper extremity MSD risk.

- Analyses were conducted to examine (i) unstratified associations between evisceration line speed category and PFI-TLV score among all workers included in the study and (ii) separate associations between evisceration line speed category and PFI-TLV score stratified by job across all establishments. No associations were observed for either of the analyses.
- For some jobs (Live Hang, Chiller Rehang, Coning) increased staffing levels or reduced job-specific line speed at establishments operating at higher evisceration line speeds attenuated increases in MSD risk.

40% of workers across all establishments reported experiencing moderate to severe work-related upper extremity pain during the 12-month period prior to the site visit.

- Analyses were conducted to examine (i) unstratified associations between evisceration line speed category and the prevalence of moderate to severe work-related pain during the past 12 months among all workers across all jobs and sites and (ii) associations between evisceration line speed category and the prevalence of moderate to severe work-related pain during the past

[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.

12 months stratified by job across all sites. No associations were observed for either of the analyses.

- Analyses were conducted to examine (i) unstratified associations between piece rate category and the prevalence of moderate to severe work-related pain during the past 12 months among all workers across all jobs and sites and (ii) associations between piece rate category and the prevalence of moderate to severe work-related pain during the past 12 months stratified by job across all sites. No associations were observed for either of the analyses.
- Among the study participants who reported experiencing moderate to severe work-related MSD pain in the last 12 months, one-quarter (27%) reported difficulty in maintaining their expected work pace or quality of work, more than one-third (38%) considered quitting or changing lines or had work-related pain or discomfort that interfered with activities outside of work, and approximately 1 in 5 took time off work because of their work-related pain.
- Among the study participants who reported moderate to severe work-related pain in the past 12 months at work, 44% did not report their pain to their supervisor or the establishment nurse.
- Most (70%) workers reported experiencing moderate to severe work-related pain within the first three months of hire at their respective establishments.

Airborne concentrations of PAA did not differ by evisceration line speed category.

- At 5 of the 11 establishments, airborne PAA concentrations of at least one job exceeded the recommended ACGIH STEL of 0.4 ppm.
- Airborne PAA concentrations of 13 (21%) of the 61 establishment-specific jobs measured exceeded the ACGIH STEL of 0.4 ppm.

Conclusions

Evisceration line speed was not associated with MSD risk. Rather, piece rate, a metric of job-specific line speed and staffing level, was associated with MSD risk. The absence of an association between evisceration line speed and job-specific MSD risk was due in part to higher job-specific staffing levels, lower job-specific line speed, or both, at establishments operating at higher evisceration line speeds in comparison to those operating at lower evisceration line speeds. Despite the absence of an observed association between evisceration line speed category and MSD risk, a substantial majority of workers across all facilities (81%) had a high MSD risk (i.e., PFI-TLV score >1.0), indicating that current risk mitigation efforts are insufficient.

A substantial proportion of workers who were surveyed reported experiencing moderate to severe levels of work-related pain causing some to have difficulty maintaining the pace of their work or to consider quitting their job. Further, pain interfered with some workers' activities outside of work and resulted in others taking time off from work. These survey findings were confirmed by the medical interviews conducted by physician members of the PULSE study team.

Airborne PAA concentrations were greater than the ACGIH STEL among 1 in 5 jobs that were sampled, indicating that current risk mitigation efforts are insufficient.

Recommendations

Poultry processing establishments should mitigate MSD risk by fully implementing ergonomic program guidelines for poultry processing and meat packing establishments published by the US Department of Labor (US DOL, 1993; US DOL, 2004; US DOL, 2013). 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 poultry processing establishments:

- Reduce the PFI-TLV score to ≤ 1.0 for all poultry processing jobs.
    - Implement job-specific piece rates as presented in this report to achieve a PFI-TLV score <1.0.
- Implement established meat packing best practices to reduce hand exertion force to achieve a PFI-TLV score of ≤1.0.
- Establishments should 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 reduce 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

From October 2018 to April 2020, the U.S. Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS) granted 53 evisceration line speed waivers to poultry establishments that allowed qualifying New Poultry Inspection System (NPIS) establishments to operate at evisceration line speeds up to 175 birds per minute (BPM). The USDA FSIS requested contracting support to design and conduct a study to assess the impact of increased evisceration line speeds in young chicken establishments on work-related musculoskeletal disorders (MSDs) and 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 work-related 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 of increased work pace and lack of recovery time, commonly experienced with “just in time” manufacturing, showed an association 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 work-related 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. Another study of poultry processing found that differences in MSDs and work-related pain between establishments were attributed to differences in evisceration line speed and pace of work (Rosenblum et al., 2014).

1.3. Risk Assessment for Work-Related Musculoskeletal Disorders

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

The ACGIH is a North American, nongovernmental 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) that are 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). The ACGIH TLVs are analogs of 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 occupational 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 and persistent work-related 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 use of both exposure characteristics to calculate the final TLV value. Specifically, the TLV uses *Normalized Peak Force* (NPF) to quantify forceful exertions 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 score* (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 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. 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 minimal 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 value into context [Yung et al., 2019]. Specifically, the study's authors explored the relationship between the PFI-TLV score value and carpal tunnel syndrome risk among 4,321 manufacturing workers. Workers performing tasks with a PFI-TLV score greater than 1.0 (i.e., an exposure 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

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[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.

PFI-TLV score greater than 1.0 than among workers in the lowest exposure strata. Analyses of an international cohort (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 score and relative risk (i.e., 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* (LI). A LI <1.0 indicates that most workers are able to 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 low back 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 is used widely by North American industries and safety professionals.

Table 1.3.2. Risk implications for "low back pain duration > 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 and not on the frequency of lifts. FILI scores are helpful in evaluating 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. Exposure and Risk Assessment of MSDs in Poultry Processing

Multiple studies of poultry workers describe musculoskeletal symptoms and MSDs in poultry workers (Quandt, 2006; Lipscomb, 2007; Lipscomb, 2008; Cartwright, 2012). Two recent Health Hazard Evaluations from the National Institute for Occupational Safety and Health (NIOSH) substantiated high numbers of MSD symptoms and MSDs in poultry workers resulting from excessive exposure to ergonomic hazards (Musolin, 2012; Ramsey, 2015). In these studies, NIOSH documented high carpal tunnel syndrome (CTS) prevalence in poultry workers using nerve conduction studies and linked CTS and musculoskeletal symptoms to elevated ergonomic risks using the American Conference of Governmental Industrial Hygienists (ACGIH)'s Hand Activity Level measurements (Musolin, 2017).

Repetitive and forceful hand exertions are common to many poultry processing jobs, including live hang, chiller rehang, trim, debone, and other processing tasks. A review of ergonomic hazards in the poultry industry reported that poultry processing workers repeated thousands of repetitive and forceful motions per shift, sometimes completing more than 2,000 cuts or hanging more than 1,000 birds (Harmse et al., 2016). Some tasks were typically repeated every 10 seconds or less, up to 30,000 times per day with limited breaks. In addition to hand injuries, Rosenbaum et al. (2014) reported an increase in low back pain, shoulder injuries (rotator cuff syndrome), and elbow injuries (tendinitis) among Latino poultry workers, particularly those working in receiving, hanging, plucking, and killing. The authors concluded that "tasks performed in the processing line" were significantly associated with both low back pain and rotator cuff syndrome and that "line speed and work pace may account for these differences [in injury across the three employers] and provide an opportunity for regulation and intervention to protect the health of workers." A recent study highlighted the importance of cold exposure as an additional risk factor in the poultry industry (Altunas and Cankaya, 2020).

1.5. Work Organizational Stress

Extended work shifts with mandatory overtime can increase exhaustion, work-related 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 work-related 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 Work-related pain and Injury may result in an Underestimate of MSD Incidence and Prevalence

Several studies have highlighted the underreporting of injuries in the meat and poultry industry (GAO, 2005; Quandt, 2006; GAO, 2016). The Government Accountability Office (GAO) 2016 report highlighted the challenges of gathering data on injury and illness rates for meat and poultry workers due to underreporting and inadequate data collection. Factors for underreporting cited by the GAO include the vulnerable status of undocumented or foreign-born workers, fear of losing their jobs, and employers underreporting because of concerns about potential costs. The OSHA log, which employers use to respond to the Bureau of Labor Statistics (BLS) Survey of Occupational Injury and Illness, also does not specifically classify recorded injuries or illnesses as MSDs.

In contrast, early recognition and appropriate treatment of MSDs are essential in improving outcomes for injured workers. Researchers from the State of Washington Department of Labor and Industry evaluated workers' compensation CTS claims from 1990-2000 (Daniell et al., 2005). They found that delayed diagnosis of CTS resulted in increased workers' compensation costs, increased lost time away from the job, delays in surgical treatment, and increased permanent disability. Further, an Australian study found that early intervention in poultry worker injuries decreased workers' compensation claims, costs, and lost workdays (Donovan et al., 2017). Workplace interventions in the poultry industry have reduced the risk of MSDs (Tirloni et al., 2020).

1.7. Mitigation of MSD Risk Resulting 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.

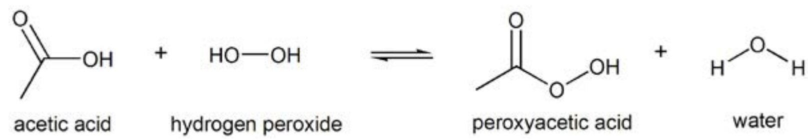
Workplace safety and health programs rely on ergonomics and established public health principles to reduce the risk and severity of work-related MSDs. Such programs typically involve (i) a review of existing injury data to identify tasks that place workers at high risk of injury, (ii) an ergonomic hazard 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, the training of supervisors and employees on ergonomic principles, and the assigning of 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 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 Poultry Processing

Peracetic Acid (PAA) is a powerful oxidizing agent used as an antimicrobial processing aid in poultry establishments. PAA is an organic peroxide that is flammable above 40.5°C (105°F) and has an 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 aqueous concentrations that may be used for specific purposes in meat, poultry, and egg product establishments. Aqueous PAA solutions are currently approved for use in PAA concentrations ranging from 50 to 2,000 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 evisceration line speed waivers, establishments were not required to assess "baseline" ergonomic or PAA exposures before implementing higher poultry processing speeds. To our knowledge, no establishment has made such data available to the FSIS. After further discussion with the USDA and participating companies, we concluded that a "within establishment" study design was not feasible due to the inability of establishments to operate at two different line speeds on separate occasions. Consequently, the study team proceeded with a "between establishment" design with six companies, each with two "matched pair" establishments (n=12 establishments), where one establishment was operating the evisceration line at or close to 140 BPM and the "matched pair" establishment was operating the evisceration line at or close to 175 BPM. Workers at six of the twelve establishments were represented by the United Food and Commercial Workers International Union. Data collection was conducted between November 2023 and April 2024. After the study began, one company declined participation for one of their establishments and withdrew this site from the USDA waiver program. Therefore, 11 establishments with evisceration line speeds between 140 BPM and 175 BPM were enrolled.

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 poultry processing workers. The study team identified five specific aims, 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 establishments operating over a range of evisceration line speeds and piece rates.

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

Aim 3: Estimate the effect of evisceration line speed on airborne antimicrobial concentrations (PAA) in establishments operating over a range of evisceration line speeds.

Aim 4: Estimate the prevalence of respiratory symptoms among workers in establishments operating over a range of 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 establishments operating over a range of evisceration line speeds.

4. Methods

4.1. Study Design

Sixteen US companies (47 establishments) with at least one establishment operating under a line speed waiver allowing for evisceration line speed greater than 140 BPM, were contacted by email in late August 2023. Establishment representatives were asked to complete a brief Qualtrics survey about product types, average daily volume of products, production shifts per day, number of hourly production workers, number of slaughter lines, days per week for slaughter, maximum and minimum evisceration line speeds, whether the establishment could change evisceration line speeds for the study, days per week for second processing, weekly range (pounds) of product in second processing, second processing jobs, and gallons of concentrated PAA purchased per month. Based on survey responses and guidance from the USDA, six companies with two establishments each (n=12 establishments) were selected, where one establishment was typically running the evisceration line at or close to 140 BPM and the other at or close to 175 BPM. At six of the establishments, employees had a collective bargaining agreement with the establishment designating the UFCW as their representative.

This was a cross-sectional study of the impact of evisceration line speed on musculoskeletal and respiratory health outcomes among poultry processing workers employed by establishments operating over a range of evisceration line speeds greater than 140 BPM. Eligible poultry processing establishments were those granted an evisceration line speed waiver allowing them to operate at greater than 140 BPM. All participating establishments agreed to allow researchers to enter the establishment for three days and provided additional information on operations and injury prevention and management programs as requested by the investigators.

Before each site visit, the PULSE team held video meetings with company corporate representatives, site managers, and UFCW representatives to explain the study and finalize logistical details. At each establishment, study data were collected over a three-day period by a team led by a senior occupational medicine physician, a senior ergonomist, and a senior industrial hygienist, and assisted by UCSF and UCB graduate students and UCSF occupational medicine residents. In February 2024, after the study began, one company withdrew one of its establishments from the USDA waiver program. Therefore, eleven establishments ultimately participated in this study.

For purposes of comparing poultry establishments by reported evisceration line speed, establishments were categorized into three groups by evisceration line speed tertile. The first tertile included four establishments with evisceration line speeds of ≤145BPM; the second tertile included three establishments with evisceration line speeds >145BPM and <175BPM; and the third tertile included four establishments with evisceration line speeds of 175BPM.

The pace of work for any individual worker is dependent on both the speed of the line on which they work and the number of workers doing that specific job. Therefore, using video analysis, we quantified the “piece rate,” i.e., the number of pieces or items that each worker handled per minute. In this study, we use “piece rate” to assess the pace of work and not to describe the monetary compensation rate at which a worker is paid for the number of tasks performed or units of work completed. Since the piece rate varied for each job, workers were assigned to low, medium, or high piece rate categories based on a tertile split of piece rate for their particular job. The overall and job-specific relationship between piece rate and MSD risk was evaluated.

4.2. Job and Participant Selection

Because differential effects of evisceration line speed on study outcome measures were possible, we sampled 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 pre-data collection site visits (Appendix 1 - Phase 1) and during the initial walk-through of the three-day data collection site visits (Phase 2). A mix of jobs throughout the production process was included to evaluate the impact of evisceration line speed on workers prior to, and following, the evisceration area. Ten upper extremity intensive jobs (Table 4.2.1), performed at most or all participating establishments, were selected for inclusion in the MSD risk assessment component of this study; additional jobs, when evaluated at fewer establishments, were combined for analysis purposes into an “other” category.

Workers over 18 years of age who performed the selected jobs during the site visits were chosen randomly 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. The goal was to evaluate ten workers per job, half of whom were administered the Work and Health Survey and a medical interview and half of whom were administered the Work and Health Survey and an ergonomic assessment. If there were fewer than ten workers for any particular job at an establishment, all available workers for that job at that establishment were invited to participate in the Work and Health Survey, medical interview and ergonomic evaluation. If there were more than ten workers in a particular job, workers were selected (i) using a random number generator; (ii) by an ergonomic team researcher who ensured that at least one person each of shorter (<66”), medium (66-70”), and taller (>70”) heights were included, if possible; or (iii) by convenience, depending on who could leave the line at a particular time. Study participants were paid their normal hourly rates by the company during time spent participating in the study.

Each prospective study participant met with a research team member who explained the study in detail before obtaining written informed consent. The research team member explained that no identifying information (name, address, telephone number, email, etc.) would be collected and results of individual interviews would not be shared with managers, union representatives or co-workers. Workers had a choice of not consenting at all, consenting to part of the study, or consenting to all parts. For example, those who did not consent to be videotaped did not receive an ergonomic assessment and were allocated to receive the survey and medical interview. 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 study protocol was approved by the University of California at San Francisco Institutional Review Board.

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

Job Category	Job Line Speed	Job Staffing	Worker Piece Rate
Live Hang Chiller Rehang	Number of shackles on one line that pass by a fixed point, per minute	Number of staff hanging birds onto the same shackle line	Number of birds hung on shackles by one worker, per minute
Coner Breast Processing Shoulder/Wing Processing Tender Processing	Number of cones on one line that pass by a fixed point, per minute	Number of staff performing the same job, working along the same the cone line	Number of birds processed (i.e., placed, cut, pulled, trimmed) by one worker, per minute
Thigh Debone Trim/Rework	N/A (product is delivered to worker via conveyer, or a bin fed from a conveyer)	Number of staff performing the same job (i.e., sharing the same flow of conveyed/binned product)	Number of pieces (e.g., thighs, breasts) processed (i.e., trimmed, deboned) by one worker, per minute
Packing	N/A (product is delivered to worker via conveyor, or a bag fed from a conveyor)	Number of staff performing the same job, working along the same pack line	Number of pieces (e.g., thighs, breasts) or units (e.g., bags, boxes) handled by one worker, per minute
Stacking	N/A (product is delivered to worker via conveyor)	Number of staff stacking boxes onto the same pallet	Number of boxes handled by one worker, per minute

* For reporting purposes, one shackle holds one bird (i.e., one shackle holds two legs)

4.3. Work and Health Survey (“survey”)

A survey was administered to study participants by a trained study team member in a private room during work hours, regardless of worker assignment to an ergonomic assessment or medical interview. The survey instrument was a structured electronic questionnaire (Qualtrics, Seattle, WA) designed to collect information about health outcomes and ergonomics hazards among poultry processing workers. The survey included questions on demographics (age, gender, tenure at the establishment, and job title), work-related ergonomic hazards (e.g., perceived hand force), work organization (work schedule, overtime, line staffing, job rotation), and work-related discomfort and pain (self-reported musculoskeletal discomfort and pain in various body regions, rated using a Likert scale). Work-related pain was defined as any pain or discomfort over the past 12 months that was worse at work and lasted for more than one day, as reported by the study participant. *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). Prior feedback on survey content was solicited from multiple stakeholders, including union members and USDA staff. The survey instrument is provided in Appendix 2. Surveys were administered in the worker’s preferred language utilizing telephonic interpretation services when needed. Due to technical issues, some survey questions were not administered at the first study site.

4.4. Medical Interview

A supplemental medical interview was conducted to evaluate medical treatment among workers who reported musculoskeletal or respiratory symptoms during the work and health survey. Workers who indicated they had experienced work-related musculoskeletal pain or respiratory symptoms were asked additional open-ended questions about their experience of receiving first aid and medical care. A study team medical professionals conducted the medical interviews at each establishment.

4.5. Manager and Union Representative Interviews

Managers were interviewed to collect information about establishment operations, the ergonomics program, and the injury prevention and treatment program. Interviews were conducted (when available) among 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 (e.g., maintenance, knife sharpening). Union representatives were interviewed, when applicable.

4.6. Ergonomic Assessment of Workers

After completion of the survey, workers were allocated to a video-only assessment or a video-and-wearable device assessment of the biomechanical demands of their jobs based on (i) whether they provided consent for wearable device assessment; (ii) the number of workers performing the same job; (iii) the number of workers (video-only versus video-and-wearable) who had already participated; and (iv) the amount of time left in their shift. Every effort was made to include a minimum of five workers performing a job, however, some jobs did not have five workers to include. Biomechanical exposure measurements included force, repetition, duty cycle, and wrist kinematics (posture and velocity).

4.6.1. 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 50th and 90th 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 (RSI) (Appendix 3). Median and peak sagittal plane velocity values were calculated as the 50th and 90th 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 risk assessment tools. The primary upper extremity 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 90th 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 ≤1.0) and unacceptable risk jobs (PFI-TLV score > 1.0) (Kapellusch et al., 2014; Yung et al., 2019). A complete description of risk assessment calculations is presented in Appendix 5.

For one job (Stacking), the primary activity was lifting and the RNLE was used to estimate work-related low back pain risk. A CLI score was calculated and compared to a limit of 1.5 based on a systematic review of prospective and cross-sectional studies (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 from video analysis and the work duration was based on worker self-report. 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

Workers with video-based measurements but no wearable data were assigned imputed APDF values using the site and job-specific means adjusted for worker age and sex. Summary statistics were generated for all workers included in the study and summarized by evisceration line speed category. For purposes of ascertaining the effect of evisceration line speed on study outcome, analyses were conducted with evisceration line speed categorized into tertiles (≤145BPM, between >145BPM and <175BPM, and 175BPM). To evaluate the effect of job-specific workload on study outcome, analyses were conducted with piece rate categorized into tertiles (low, medium, high), where tertiles were performed by job category.

Thirty unique tasks were evaluated across the eleven establishments; the thirty tasks were collapsed into ten job categories (with one to four tasks per category) based on line area, similarity of purpose, and rotation strategy (Table 4.2.1). Each worker was evaluated while performing their primary task; thus, their exposure was based on that primary task performed.

Generalized linear models (GLM) with fixed and random effects were used to evaluate the relationship between three categories of evisceration line speed (≤145BPM, >145BPM to <175BPM, and 175BPM) and the PFI-TLV score or the RNLE CLI (for the Stacker job). All models included the establishment as a random effect to account for differences in measured and unmeasured establishment factors such as size, age, automation, and unionization. All models also included worker characteristics to control for potential confounding of associations between the evisceration line speed category and MSD risk score. The following possible confounders were included in each model: job category, work tenure, sex, primary language spoken (a proxy for immigrant status), and age (using splines to account for its non-linear effect). Bird weight was evaluated for confounding. Logistic regression models with fixed and random effects were also used to evaluate the relationship between the three categories of evisceration line speed and moderate to severe work-related pain or respiratory symptoms. Job-specific estimates of association were estimated by including job category (Table 4.2.1) as a fixed effect in each model.

The above analyses were repeated using piece rate (tertiles of low, medium, high based on job category) as the independent variable to model the relationship between job-specific workload and MSD risk (PFI-TLV score), moderate to severe work-related pain, and respiratory symptoms. Piece rate categorized into tertiles (low, medium, high), where tertiles were performed by job category. A sensitivity analysis (Appendix 6) was performed using a smaller dataset of workers who had complete exposure information (EMG, goniometer, and video data).

4.6.4. Risk Mitigation

Video analysis was used to quantify the job line speed, staffing level, and worker pace (piece rate) for each job (Table 4.2.1); a complete description of video analysis methods is provided in Appendix 3.

Within any particular job, the risk for MSDs varies by piece rate. Consequently, companies have at least two approaches to mitigating hazardous exposures: slowing the line or adding additional workers to jobs where such hazardous exposures occur. The anticipated joint effect of job line speed and staffing level can be estimated using actual measures of biomechanical exposure measurements collected during Phase 2 establishment visits in combination with hypothetical investigator-designated job line speeds and staffing levels. The result, presented in tabular and graphical form, provides companies with detailed information on the risk mitigation they can achieve with specific job line speed and staffing level changes. The specific approach used to model job line speed and staffing level reductions on changes in the PFI-TLV score can be found in Appendix 7.

4.7. Antimicrobial Hazard Assessment

4.7.1. PAA Exposure Measurement

To measure airborne concentrations of PAA, we used the direct-reading ChemDAQ SafeCide Portable Monitoring Envirocell Sensor Module (ChemDAQ, Pittsburg, PA, USA). The ChemDAQ system is comprised of a passive electrochemical sensor that is sensitive to PAA vapors. Before reaching the sensor, the gas 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 digital tablet computer to log the PAA concentration data generated using a proprietary sampling strategy and a one-second logging interval. The ChemDAQ 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). We used an Atmotube Pro (ATMOTECH Inc., San Francisco, CA, USA) to collect temperature, relative humidity (%), and atmospheric pressure information. We also used an Aranet4 (SAF Tehnika, Riga, Latvia) to measure CO2 concentrations to understand ventilation conditions. The Atmotube Pro, and Aranet4 logged data at one-minute or shorter intervals. A video camera (Go-pro, San Mateo, CA) was used to record activities in the vicinity of the sensors when air contaminant measurements were made.

4.7.2. Sample Collection Method

Selection of jobs and areas for sampling. To select the areas and jobs where workers may have been exposed to airborne PAA concentrations, we evaluated records of PAA sampling data provided by each establishment and maps of each establishment's buildings that identified the locations of the primary PAA sources. We used this information as a reference during an initial walk-through of the establishment where we collected preliminary air samples to confirm the areas and jobs prioritized for sampling. During the walk-through we monitored airborne PAA concentrations using the ChemDAQ instrument (Figure 4.7.1) to identify areas and jobs that required more extensive sampling. Workers in some job categories were not exposed to PAA; therefore, we did not sample all possible establishment-specific jobs (for example, Live Hang workers were not exposed to PAA).

Personal-level samples. To characterize near-field personal-level exposures, we collected at least one short-term (1-15 minute) sample while wearing instrumentation (Figure 4.7.1) and standing at each workstation (as close as possible to where the worker would stand) for each job measured (Table 4.7.3). For example, when evaluating airborne PAA concentrations at the Chiller Rehang workstation, we stood in the same location as one of the Chiller Rehang workers on the line. This method did not interfere with the workers' work processes or workflow and allowed us to collect samples that were representative of employee exposures standing in the same location, performing the same job. Sampling did not occur over an entire 8-hour period for each job category; instead, the sampling approach for the personal level measurements included short samples collected randomly throughout the day for each job category. This sampling approach was appropriate since most jobs had short cycle times, (e.g., hanging a chicken in the Chiller Rehang job takes less than 15 seconds, and the same action is repeated over an entire shift). Therefore, short duration samples collected at random times during the workday represented short-term exposures to airborne PAA concentrations at different time points throughout the work shift.

Figure 4.7.1. Sampling instrument setup

Area samples. We also collected short-term (1-15 minute) area samples in parts of the establishments where PAA was used and could potentially expose some establishment workers to PAA for brief periods of time. These areas included the PAA storage and mixing areas and drainage systems

There was significant variation in the construction and ventilation of the PAA mixing and storage rooms at the 11 establishments. Some of the rooms were located within the establishment's main building, but off the production floor. Other establishments had PAA stored in a separate building. PAA solutions need to be mixed with water to attain the concentrations desired for product application. Some establishments mixed the PAA solutions before the PAA was piped into the production areas while others mixed the PAA solutions direction at the site of production.

Sampling Logs. All sampling activity was recorded on field sheets with the time, location, and activity for each minute of sampling. When possible, we videoed our sampling location during PAA sampling. The videos were used to confirm field sheet notes and assign proximity metrics to a subset of samples (e.g., identifying the distance from the sample to the closest dip tank).

4.7.3. Job Category Determination for Personal-Level Samples

In order to understand where high-risk exposures may occur and compare airborne PAA concentrations across establishments, we collected personal-level samples at 11 PAA job categories that were relatively consistent across sites. This approach protected the anonymity of individual establishments, as every job is not present at every establishment. Video recordings and paper field data sheets were used to assign consistent standard jobs across sites. Table 4.7.1 shows the 11 job categories and the description of the work performed in each job category.

4.7.4. PAA Data Analysis

All data were downloaded from the instruments into analysis files and synchronized with the video by time of collection. Each sample was assigned a PAA job category. All raw data was processed as follows: (i) negative values were set to 0.00 ppm, and (ii) missing values were removed. There was less than one minute of raw sample data with negative PAA concentrations. To smooth the short-term fluctuations in our PAA concentration time series data, we calculated one-minute averages of all sampling data for use in further analysis. Data management was done using Microsoft Excel 360 (Seattle, WA), and statistical analyses were performed using SAS 9.3 (Cary, NC).

Table 4.7.1. Description of PAA exposure job categories used in the PAA analysis

PAA Job Sampling Category	Description
Evisceration: Live Hang	Workers are hanging live chickens on manacles
Evisceration: Auto Rehang	Chicken carcasses are transferred from the manacle chain to a second chain within the evisceration department
Evisceration Inspector	Establishment workers who are inspecting the chicken carcasses prior to the USDA/FSIS inspection stations
Evisceration Trim	Workers are cleaning up chicken carcasses that have broken bones, are dirty or other problems. Done prior to USDA/FSIS inspection
Chiller Rehang	Rehanging the whole bird without giblets (WOGs) after they have been through the chiller
Debone (Dark)	Deboning dark meat (thigh or leg)
Debone (White)	Deboning white meat (breast, tenders, wings)
Portioning	Portioning white meat
Grader	Grading breast, leg, thigh, tender, or wing
Product Wash	Cleaning chicken or chicken parts that have been dropped on the floor or otherwise need washing in the 2nd processing area
Bagger/Packout	Bagging or packing chicken for shipping or retail sale

Personal-level samples. We calculated the mean airborne PAA concentration for each job category within each establishment to represent the job-specific worker exposure to airborne PAA concentrations. We averaged the 1-minute data (post-processing) for each PAA job category by establishment. We used the job and establishment-specific average as the short-term (15-minute) average. All short-term averages were compared to the American Conference of Governmental Industrial Hygienists (ACGIH) 15-minute Short-Term Exposure Limit (STEL) of 0.4 ppm.

Area Samples. We calculated the mean airborne PAA concentration for each area within each establishment to represent area airborne PAA concentrations. We averaged the one-minute data (post-processing) for each area by establishment. We used the establishment-specific average as the short-term (15-minute) average. All short-term averages were compared to the American Conference of Governmental Industrial Hygienists (ACGIH) 15-minute Short-Term Exposure Limit (STEL) of 0.4 ppm.

Comparison of antimicrobial exposure measures by job category and evisceration line speed. To compare the airborne PAA exposures by evisceration line speed, short-term exposure averages were averaged across establishments in each of the three evisceration line speed categories.

4.7.5. Respiratory Symptoms

During administration of the survey described in Section 4.3, workers were asked whether they experienced respiratory symptoms during the year prior to the survey and, if yes, to rate them by frequency and severity. Frequency responses were rated as often", sometimes or never. Severity responses were rated as very mild, mild, moderate, moderate-severe, or severe.

5. Results

Primary study results are provided in Section 5. Secondary results are provided in tabular and graphic form in Appendices 5 - 9. No additional descriptions or discussion of secondary results are provided.

5.1. Establishment Overview

Eleven establishments (sites) participated in the study. Each site reported to the USDA its three-day average evisceration line speeds for the days of our visit. In addition, the study team also measured Live Hang line speeds (Table 5.1). The establishment-reported three-day average establishment evisceration line speed was strongly correlated with the measured Live Hang Line Speed (r^2=0.92). For this report, the 11 participating establishments were categorized into three evisceration line speed categories: (i) four establishments with evisceration line speeds of ≤145 BPM, (ii) three establishments with evisceration line speeds of >145 BPM to <175 BPM, and four establishments with evisceration line speeds of 175 BPM. evisceration line speed category, mean bird weight, average three-day mean evisceration line speed, and measured Live Hang line speed are presented in Table 5.1. A difference of 33.3 BPM was observed between the average evisceration line speed of the four plants operating at evisceration line speeds of ≤145 BPM and the four plants operating at an evisceration line speed of 175 BPM. Mean bird weight ranged from 7.6 lbs. to 9.1 lbs. across the three evisceration line speed categories.

Table 5.1. Bird Weight, evisceration line speed, and Live Hang Line Speed

Establishment	Evisceration Line Speed Category (BPM)	Bird Weight[1] (lbs.) Mean (SD)	evisceration line speed (BPM)[1] Mean (SD)	Live Hang Line Speed (BPM) Mean (SD)
A	≤145 BPM	7.6 (1.3)	142 (2.2)	149.0 (4.2)
B				
C				
D				
E	>145 to <175 BPM	9.1 (0.3)	162 (9.3)	158.0 (7.9)
F				
G				
H	175 BPM	8.3 (1.4)	175 (0)	182.3 (3.4)
I				
J				
K				

1 Three-day mean during the site visit as provided by each establishment to the USDA

The effect of evisceration line speed on study outcomes was analyzed by comparing average results of the establishments across three line speed categories.

5.2. Participant Overview

The primary worker survey was completed by 1047 participants across the 11 participating establishments. The participation rate was 96.6% (37 individuals declined participation). Among participants, 375 were employed by establishments operating at an evisceration line speed of ≤145 BPM, and 409 were employed by establishments operating at 175 BPM (Table 5.2.1.). About half of the participants also completed a medical interview, 46% were videotaped to analyze movements, and 25% wore wearable devices to collect electromyography (EMG) and goniometer measurements (i.e., “wearable data”). After single imputation using within-establishment, job-specific data adjusted for sex and age, complete biomechanical exposure information of 456 participants was included in exposure-effect analyses (Section 6). Between 62 and 155 workers contributed biomechanical exposure information to the analyses of each job, with varying numbers of workers contributing to medical interviews, repetitive motion exposure metrics (measured using video), and force and posture exposure metrics (measured using wearable devices). Job-specific results are presented in Section 7.

Table 5.2.1. Number of workers by data type and evisceration line speed category

	≤145BPM (N)	>145 to <175 (N)	175 BPM (N)	Overall (N)
Survey	375	263	409	1047
Medical Interview	199	108	201	508
Video[1]	167	134	179	480
EMG and Goniometer[1]	89	74	114	277
EMG after imputation[2]	155	127	174	456

1 See section 4.6.1 for more detail
2 See section 4.6.3 for more detail

The mean age of the 1047 study participants was 38.4 (SD=12.3) years, with little difference between the three evisceration line speed categories (Table 5.2.2). More than half of the study participants were male (55%), with a negligible difference between the evisceration line speed categories. Thirty-six percent of participants identified as Black or African American and 37% identified as Hispanic. About 13% identified as White/Non-Hispanic and a similar proportion self-identified as another race. A smaller proportion of participants in the lowest evisceration line speed category reported Black or African American race/ethnicity than the proportion of participants in the highest evisceration line speed category (25% versus 43%). Roughly half of the participants spoke English as their primary language (48%). A larger proportion of study participants in the lowest evisceration line speed category reported being born outside of the United States (63% versus 47%). Two-thirds of study participants were employed in their respective poultry processing establishments for one or more years. Work tenure differed modestly across establishments operating at different evisceration line speeds. Specifically, about 29% of workers in ≤145 BPM establishments worked less than one year compared to 38% of workers in the 175 BPM establishments. Additionally, nearly twice as many workers in the ≤145 BPM establishment category worked at their establishment (i.e., work tenure) for more than five years in comparison to workers in the 175 BPM establishment category.

Overall, study participants reported working an average of 8.2 hours per day and 4.9 days per week (data not shown). Study participants in the 175 BPM category reported working an average of twelve minutes more per day and 0.1 fewer days per week than participants in the ≤145 BPM category. Sixty-eight percent of study participants reported usually working on the day shift, with the remainder reporting working night, swing, evening, or other shifts. The distribution of shifts did not vary appreciably by evisceration line speed category. Sixty-one percent of workers in the ≤145 BPM category reported "typically" working mandatory or voluntary overtime (i.e., more than 40 hours per week), whereas 34% of workers in the 175 BPM reported "typically" working mandatory or voluntary overtime.

Table 5.2.2. Demographic and work tenure summary of participants at all establishments and by evisceration line speed group

	Evisceration Line Speed			
	≤145BPM	>145 to <175 BPM	175 BPM	Overall
Age, Mean (SD)	37.0 (11.7)	39.6 (12.4)	38.7 (12.7)	38.3 (12.3)
Gender				
Male, N (%)	214 (55.3%)	146 (54.37%)	223 (54.0%)	583 (54.5%)
Female, N (%)	146 (37.7%)	116 (43.1%)	184 (44.5%)	446 (41.7%)
Race/Ethnicity				
Black or African American, N (%)	95 (24.5%)	105 (39.0%)	176 (42.6%)	376 (36.0%)
White/Caucasian, N (%)	45 (11.6%)	28 (10.4%)	61 (14.8%)	134 (12.8%)
Hispanic, N (%)	165 (42.6%)	80 (29.7%)	137 (33.2%)	382 (36.6%)
Other, N (%)	66 (17.1%)	49 (18.2%)	33 (8.0%)	148 (14.2%)
Primary Language Spoken				
English, N (%)	167 (43.2%)	130 (48.3%)	208 (50.4%)	505 (48.2%)
Other, N (%)	208 (53.8%)	133 (49.4%)	201 (48.7%)	542 (51.8%)
Born outside the US				
Yes, N (%)	242 (62.5%)	128 (47.6%)	194 (47.0%)	542 (51.8%)
No, N (%)	145 (37.5%)	141 (52.4%)	219 (53.0%)	505 (48.2%)
Work Tenure				
<90 days, N (%)	50 (13.3%)	21 (7.8%)	33 (8.0%)	105 (10.0%)
≥ 90 days but < 1 year, N (%)	58 (15.5%)	64 (23.8%)	123 (29.8%)	247 (23.5%)
≥ 1 year and < 5 years, N (%)	131 (33.9%)	89 (33.1%)	179 (43.3%)	399 (37.9%)
≥ 5 years, N (%)	136 (35.1%)	88 (32.7%)	73 (17.7%)	299 (28.4%)

BPM = birds per minute
When the percentages provided do not add up to 100%, the remaining percentage represents missing data

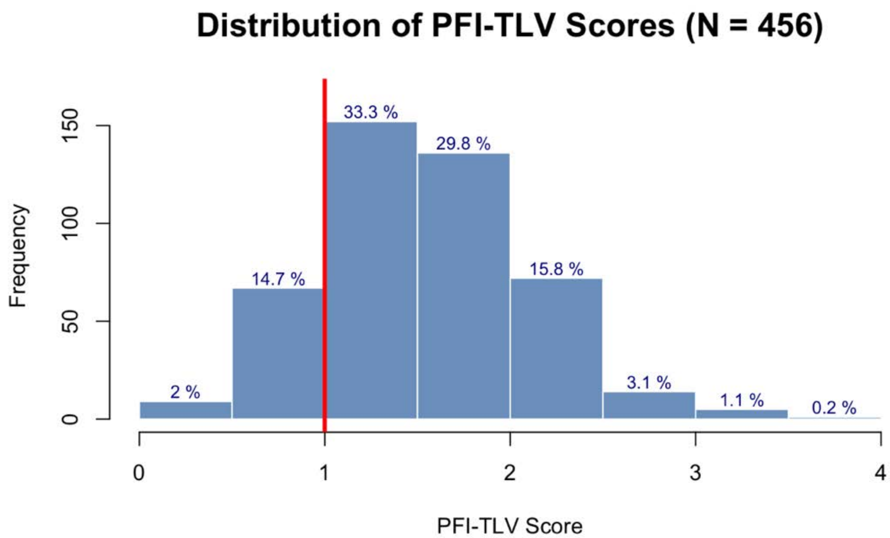
> Just over one-third of workers identified as Black or African-American, and just over one-third of workers identified as Hispanic. About half of the workers reported a language other than English as their primary language and about half of the workers were born outside of the United States.

5.3. Associations between Evisceration Line Speed, Piece Rate and PFI-TLV score

Across all establishments and jobs, 83% of the 456 workers for whom a PFI-TLV score could be calculated exceeded a PFI-TLV score of 1.0 (Figure 5.3.1.); thus, more than four of every five such workers were at a meaningfully increased risk of developing a MSD compared to workers with PFI-TLV scores of less than 1.0.

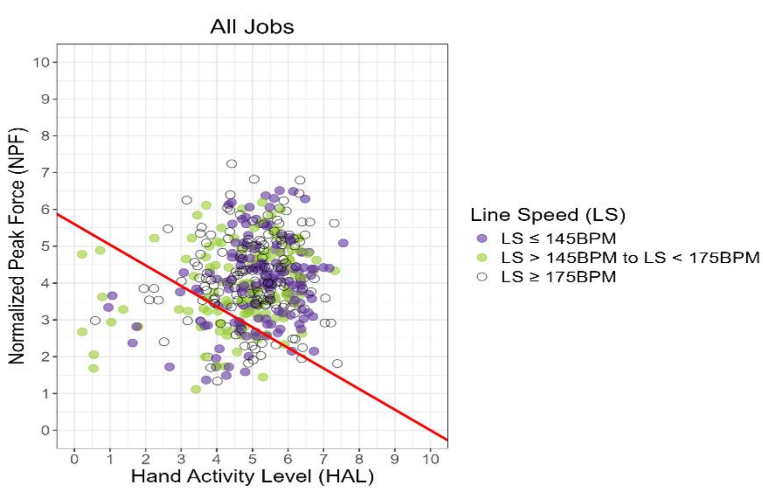
The scatter plots (Figure 5.3.2) show the PFI-TLV scores stratified by evisceration line speed and Piece Rate. These plots show the contributions of exposures (NPF and HAL) that result in the PFI-TLV score. Points above the red line have a PFI-TLV score>1.0 indicating increased MSD risk.

Figure 5.3.1. Distribution of PFI-TLV scores across all workers and all establishments (N=456)



> Four of five workers evaluated had a PFI-TLV score >1.0.

Figure 5.3.2. Scatter plots of PFI-TLV scores stratified by evisceration line speed and piece rate. 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 mean PFI-TLV score was not associated with evisceration line speed category (Table 5.3.1). In contrast, the mean PFI-TLV score increased monotonically with increasing piece rate category (test of trend p=0.01). Further, for piece rate the difference in mean PFI-TLV score between workers in the ≤145 BPM evisceration line speed category and workers in the 175 BPM evisceration line speed category was statistically significant (p<0.02) (Table 5.3.1).

Table 5.3.1. Association between evisceration line speed, piece rate, and PFI-TLV score

	All, N	PFI-TLV Score[1] Estimate (SE)	Difference (SE)	Adjusted p-value
Evisceration Line Speed	480			
≤145 BPM	167	1.4 (0.20)	referent	
>145 to <175 BPM	134	1.2 (0.20)	-0.2 (0.1)	0.30
175 BPM[3]	179	1.4 (0.20)	-0.01 (0.1)	0.96
Piece Rate[2]	477			
Low	158	1.1 (0.21)	referent	
Medium	159	1.2 (0.21)	0.18 (0.09)	0.04
High[4]	160	1.3 (0.22)	0.24 (0.09)	0.02

1 Adjusted for age, sex, primary language, job tenure (fixed effects) and establishment (random effects)
2 Each worker's piece rate was assigned to a low, medium, or high category based on a tertile split by job
3 p=0.9 for test of trend of PFI-TLV score across the three line speed categories
4 p=0.01 for test of trend of PFI-TLV score across the three piece rate categories

5.4. Job-specific Line Speed and Staffing levels: Two Case Studies

The results presented above show no association between evisceration line speed and MSD risk (as quantified by the PFI-TLV score). However, there was an association between piece rate and MSD risk. This is because, for most jobs in poultry processing establishments, evisceration line speed is an inaccurate estimator of upper extremity workload and consequent MSD risk whereas piece rate, because it accounts for both the job-specific line speed *and* the number of workers performing that specific job, is a more accurate estimator of upper extremity workload and consequent MSD risk. Thus, the piece rate is driven by the job-specific line speed *and* the allocation of staff intended to meet the increased demand from higher bird throughput. Further, it is important to note that MSD risk will increase or decrease based on changes in job-specific line speed and staffing levels.

Ultimately, what determines a worker's MSD risk while performing a particular job is whether the number of pieces processed by that worker's line is offset adequately by the number of workers performing that job on that line. An increase in evisceration line speed results in a higher throughput of birds being processed per eight-hour shift. The higher number of birds being eviscerated can be processed by (i) extending the work shift beyond eight hours, (ii) adding more lines downstream of evisceration (e.g., more cone lines), (iii) automation, (iv) increasing the speed of processing the birds downstream of evisceration (i.e., increasing job-specific line speed), (v) adding staff, or (vi) any combination thereof. Given any particular evisceration line speed, efforts to mitigate MSD risk for a specific job must account for both job-specific line speed and job-specific staffing level; ignoring either one (or worse, both) is expected to result in an increase in MSD risk when evisceration line speed increases. The first case study below (5.4.1) demonstrates the effect of higher job-specific *staffing* on MSD risk and the second case study below (5.4.2) demonstrates the effect of lower job-specific *line speed* on MSD risk.

5.4.1. Reducing MSD risk (PFI-TLV score) by increasing job-specific staffing levels: A case-study of Live Hang workers

Live Hang was chosen for this case study because higher average Live Hang staffing levels among establishments in the high evisceration line speed category resulted in lower Live Hang piece rates, thereby mitigating the expected increase of MSD risk (i.e., PFI-TLV score) among Live Hang workers. The relationships between (i) evisceration line speed and MSD risk among Live Hang workers and (ii) piece rate and MSD risk among Live Hang workers are shown in Table 5.4.1.A. and the mean Live Hang line speed, staffing, and piece rates are shown in Table 5.4.1.B. The higher evisceration line speed workers have approximately the same MSD risk as the lower evisceration line speed workers (Table 5.4.1.A.) due to the combinations of Live Hang line speed and the number of workers performing Live Hang observed during our visit. As shown in Table 5.4.1.B., the establishments operating at higher evisceration line speeds (175 BPM) had both (i) a *higher* mean Live Hang line speed (181.8 BPM) and (ii) a *higher* mean staffing level (7.8 workers) whereas the plants operating at lower evisceration line speeds (≤145 BPM) had (i) a *lower* mean Live Hang line speed (148.9 BPM) and (ii) a *lower* mean staffing level (6.1 workers). This resulted in a lower mean piece rate among Live Hang workers in plants operating at higher evisceration line speeds (175 BPM) than would be expected had the staffing levels not changed. To summarize, greater MSD risk levels among Live Hang workers in plants operating at higher evisceration line speeds were not observed due to the compensatory effect of higher Live Hang staffing levels at the higher evisceration line speeds.

Table 5.4.1.A. The relationship between evisceration line speed and MSD risk (mean PFI-TLV score) and piece rate and MSD risk (mean PFI-TLV) score for Live Hang workers

Live Hang	N	PFI-TLV Score Mean (SE)[1]	PFI-TLV Score Difference (95% CI)[1]	Adjusted p-value
Evisceration Line Speed	56			
≤145 BPM	22	1.2 (0.2)	Referent	
>145 to <175 BPM	14	1.3 (0.2)	0.1 (-0.2 to 0.5)	0.99
175 BPM	20	1.2 (0.2)	<0.1 (-0.3 to 0.3)	>.99
Piece Rate [2]	56			
Low	19	0.9 (0.2)	Referent	
Medium	18	1.3 (0.2)	0.3 (-0.1 to 0.7)	0.60
High	19	1.8 (0.2)	0.8 (0.4 to 1.3)	0.01

1 Adjusted for age, sex, primary language, job tenure
2 Each worker's piece rate was assigned to a low, medium, or high category based on a tertile split

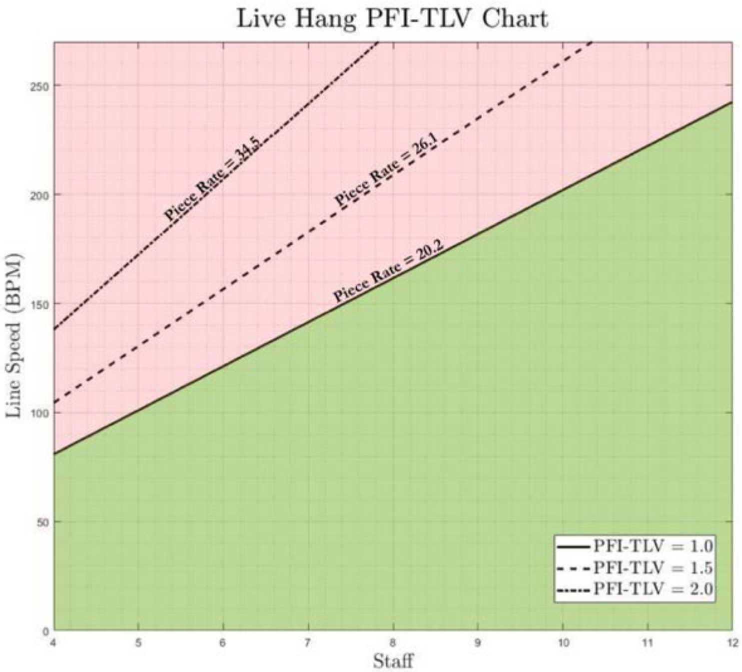
Table 5.4.1.B. The number of workers and mean job-specific line speed, staffing, and piece rate by evisceration line speed category

		Evisceration Line Speed		
		≤145BPM	>145 to <175 BPM	175 BPM
Live Hang	N	22	14	20
	Mean Job Line Speed[1] (SD)	148.9 (6.1)	156.3 (7.6)	181.8 (5.0)
	Mean Staff per Line (SD)	6.1 (1.8)	6.9 (1.5)	7.8 (1.7)
	Mean Piece Rate[2] (SD)	27.8 (6.8)	25.3 (8.3)	25.7 (8.1)

1 Number of shackles on one line that pass by a fixed point, per minute
2 Number of birds hung on shackles by one worker, per minute

With the example above, we show that staffing level can mitigate MSD risk (i.e., PFI-TLV score), even when the evisceration line speed is operating at 175 BPM. To guide decisions about Live Hang staffing levels and line speed, the number of staff needed at any given Live Hang line speed necessary to achieve a PFI-TLV score of less than 1.0 is shown in Figure 5.4.1. Any combination of staff level and Live Hang line speed below the solid diagonal line yields a PFI-TLV score of less than 1.0. For example, establishments with a Live Hang line speed of 145 BPM require seven or more workers to achieve a PFI-TLV score of less than 1.0 whereas establishments operating at 175 BPM require nine or more workers to achieve a PFI-TLV score of less than 1.0. As shown in Figure 5.4.1, every acceptable combination of Live Hang line speed and staffing has an associated piece rate no greater than 20.2 BPM (solid line). As noted above, regardless of evisceration line speed, efforts to mitigate MSD risk must account for both job-specific line speed and staffing level.

Figure 5.4.1. The relationship between staffing, Live Hang line speed, and risk of MSD (i.e., PFI-TLV score)



5.4.2. Reducing MSD risk (i.e., PFI-TLV score) by decreasing job-specific line speed: A case study of Chiller Rehang workers

Chiller Rehang was chosen for this case study because lower Chiller Rehang line speeds among establishments in the high evisceration line speed category resulted in lower Chiller Rehang piece rates that mitigated the expected increase of MSD risk (i.e., PFI-TLV score). The relationships between (i) evisceration line speed and MSD risk among Chiller Rehang workers and (ii) piece rate and MSD risk among Chiller Rehang workers are shown in Table 5.4.2.A. and the mean Chiller Rehang line speed, staffing, and piece rates are shown in Table 5.6.2.B. The higher evisceration line speed Chiller Rehang workers have lower MSD risk compared to the lower evisceration line speed Chiller Rehang workers (Table 5.4.2.A.). This seemingly paradoxical relationship is due to *lower* Chiller Rehang line speed among the *higher* evisceration line speed facilities. Specifically, as shown in Table 5.4.2.B., the plants operating at 175 BPM evisceration line speed had a mean Chiller Rehang line speed of 100.5 BPM whereas the plants operating at ≤145 BPM evisceration line speed had a mean Chiller Rehang line speed of 113.1 BPM. Interestingly, even though the establishments operating at 175 BPM evisceration line speed had an average of one less person on the line than the establishments operating at ≤145 evisceration line speed (3.6 workers versus 4.9 workers), their piece rates were nearly equivalent. To summarize, despite the higher evisceration line speeds, establishments with a lower Chiller Rehang line speed had similar piece rates and MSD risks.

Table 5.4.2.A. The relationship between evisceration line speed and risk of MSDs and piece rate and risk of MSDs for Chiller Rehang workers

Chiller Rehang	All N	PFI-TLV Score Mean Estimate (SE)[1]	PFI-TLV Score Difference (95% CI) [3]	Adjusted p-value
Evisceration Line Speed	54			
≤145 BPM	20	1.6 (0.2)	Referent	
>145 to <175 BPM	15	1.2 (0.2)	-0.4 (-0.8 to –0.1)	0.04
175 BPM	19	1.2 (0.2)	-0.4 (-0.7 to –0.04)	0.07
Piece Rate [2]	54			
Low	18	1.0 (0.2)	Referent	
Medium	18	1.5 (0.2)	0.5 (0.1 to 0.9)	0.20
High	18	2.0 (0.2)	0.9 (0.5 to 1.3)	>0.00

1 Adjusted for age, sex, primary language, job tenure
2 Each worker's piece rate was assigned to a low, medium, or high category based on a tertile split
3 Adjusted for age, sex, primary language, job tenure

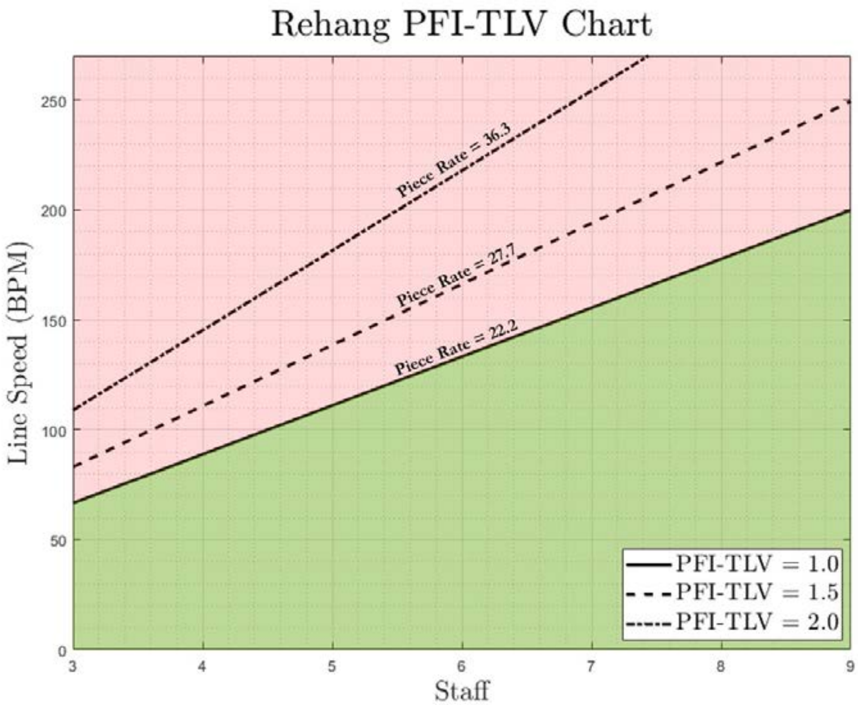
Table 5.4.2.B. A summary of the number of workers and mean job-specific line speed, staffing, piece rate, and PFI-TLV scores by evisceration line speed category

		Evisceration Line Speed		
		≤145BPM	>145 to <175 BPM	175 BPM
Chiller Rehang	N	20	15	19
	Job Line Speed[1]	113.1 (34.0)	99.7 (23.1)	100.5 (11.7)
	Staff per Line	4.9 (0.9)	3.0 (1.0)	3.6 (0.8)
	Piece Rate[2]	30.7 (9.6)	29.1 (5.4)	28.8 (11.3)

1 Number of shackles on one line that pass by a fixed point, per minute
2 Number of birds hung on shackles by one worker, per minute

With the Chiller Rehang case study, we have demonstrated that MSD risk (mean PFI-TLV score) is, at least in part, a function of job-specific line speed. Therefore, to achieve a PFI-TLV score of 1.0 or less, job-specific line speed is one factor (in addition to staffing level) that can be adjusted to mitigate MSD risk. To guide decisions about Chiller Rehang staffing levels and line speed, the number of staff needed at any given Chiller Rehang line speed necessary to achieve a PFI-TLV score of less than 1.0 (i.e., below the solid line) is shown in Figure 5.4.2. For example, establishments with a Chiller Rehang line speed of 145 BPM require seven or more workers to achieve a PFI-TLV score of less than 1.0 whereas establishments operating at 175 BPM require eight or more workers to achieve a PFI-TLV score of 1.0 or less (see Figure 5.4.2.). As shown in Figure 5.4.2, every acceptable combination of Chiller Rehang line speed and staffing is associated with a piece rate no greater than 2.2 BPM (solid line). As noted above, regardless of evisceration line speed, efforts to mitigate MSD risk must account for both job-specific line speed and staffing level.

Figures 5.4.2. The relationship between staffing, Chiller Rehang line speed, and risk of MSD (PFI-TLV score)



Musculoskeletal disorder risk is dependent on the job-specific line speed and the number of workers (staffing level) performing that job.

Independent of other mitigation factors, the increase in musculoskeletal disorder risk that can result from increase in throughput (e.g., higher evisceration line speed) should be mitigated by adjusting job-specific line speeds and staffing levels to maintain acceptable musculoskeletal disorder risk (PFI-TLV score <1.0).

5.5. Associations between Evisceration Line Speed, Piece Rate, and MSD risk by job

Upper extremity MSD risk. As stated above, the work pace of an individual worker (i.e., the worker's piece rate) is dependent, in part, on the line speed of that worker's job and the number of workers performing that job (i.e., staffing level). The average job-specific line speed, staffing level, and piece rate empirically observed from video recordings of participating poultry processing workers are presented by job in Appendix 5. Across the jobs, the highest piece rate was not always observed in the highest evisceration line speed category. For example, the lowest Live Hang piece rate was observed in the establishments operating at 175 BPM.

When analyzing each poultry processing job individually, the sample sizes per cell were small and, for some jobs, led to unstable estimates of the association between (i) evisceration line speed and PFI-TLV score and (ii) piece rate and PFI-TLV score. There were no statistically significant associations between evisceration line speed and PFI-TLV score (Appendix 5) whereas piece rate was statistically significantly associated with PFI-TLV score among workers performing the Live Hang and Chiller-Rehang jobs.

Low back MSD risk. The risk of work-related low back pain and disorder among Stacking job workers was analyzed using the RNLE at nine of the eleven establishments. Details of the RNLE methodology are provided in Section 4.6.2., above. The number of workers analyzed, average lift frequency, Composite Lift Index (CLI) value, and FILI value by evisceration line speed category are provided in Table 5.5.1.

The average CLI of Stackers within each of the nine establishments evaluated for low back MSD risk exceeded 1.5 (a result indicating moderate or greater low back pain hazard and the need for task redesign); only one of 32 workers had a CLI less than 1.5. The mean CLI among establishments in each evisceration line speed category also exceeded 1.5 (Table 5.5.1.). The primary elements of manual material handling contributing to the low back injury hazard among Stackers were (i) the torso bending, shoulder flexion and shoulder elevation required to stack boxes on pallets, (ii) the weight of boxes lifted (the typical load lifted was 40 lbs., with one exception of 20-lb. boxes), (iii) the hours of exposure per day (8 hours), and (iv) the lifting frequency. Based on the physical lifting conditions (i.e., the biomechanical criterion) of the lifts, the highest Frequency Independent Lifting Index (FILI) also exceeded 1.5 at establishments in each evisceration line speed category.

Table 5.5.1. The association between the line speed rate and the NIOSH Cumulative Lifting Index for the Stacking job

Job	N	Lift Frequency[1] Mean (SD)	CLI Mean (SD)	CLI Range	Highest FILI[2] Range
Stacking	32				
≤145 BPM	12	4.1 (1.4)	3.2 (1.0)	2.1 - 5.1	1.3 - 1.6
>145 to <175 BPM	12	3.0 (1.3)	2.3 (0.6)	1.3 - 3.2	0.8 - 1.6
175 BPM	8	4.5 (1.6)	3.5 (1.5)	1.9 - 6.5	1.0 - 1.7

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

5.6. Peracetic Acid Airborne Concentrations

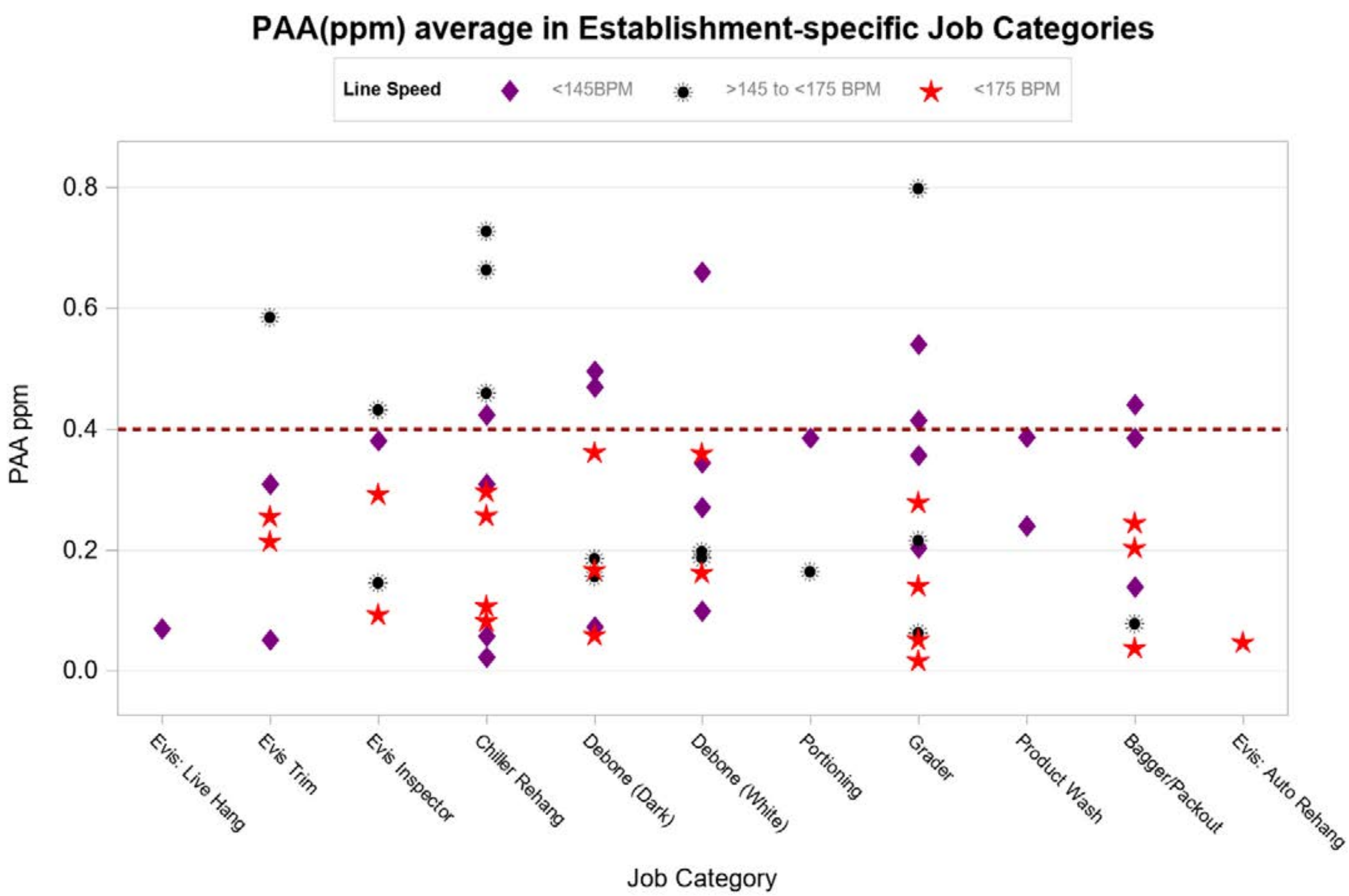
We collected 2680 minutes of airborne PAA concentration samples at the 11 establishments. Of these 2680 minutes, 90% (2473 minutes) were personal-level samples, and 10% (257 minutes) were area samples.

5.6.1. Personal-level Samples

We collected one personal-level sample for 61 of the 121 possible establishment-specific job categories (11 establishments by 11 job categories). The average exposure across all establishments was 0.29 ppm, ranging from 0.05-0.50 ppm. The average exposure at establishments with evisceration line speeds of ≤145 BPM, >145 to <175 BPM, and 175 BPM were 0.26 ppm, 0.24 ppm, and 0.47 ppm, respectively.

For each of the 11 job categories, the distribution of average airborne PAA concentration by evisceration line speed category is shown in Figure 5.6.1. Thirteen (21%) of the 61 personal-level airborne PAA concentrations exceeded the proposed ACGIH 0.4 ppm STEL. A detailed description of the airborne PAA concentrations for each establishment-specific job category can be found in Appendix 9.

Figure 5.6.1. Average airborne PAA concentration (ppm) by job category (each point is one of the 61 average personal-level exposure concentrations). The dashed red line shows the ACGIH guideline value for the 15-minute short-term exposure limit (STEL) of 0.4 ppm



> One in five establishment-specific job categories (N=61) exceeded the ACGIH 0.40ppm STEL.

5.6.2. Comparison of personal-level antimicrobial exposure measures by job category and evisceration line speed

Mean personal-level airborne PAA concentrations by evisceration line speed category and PAA job category are presented in Table 5.6.2. Comparisons are based on PAA job categories at different establishments and are not direct comparisons made at the same establishment. Four of the 11 PAA job categories were excluded because PAA exposures were not available in one or more of the evisceration line speed Groups. Establishments in the two <175 evisceration line speed categories tended to have greater PAA exposures than establishments in the 175 BPM evisceration line speed category. Factors such as local ventilation, age of establishment, size of establishment, proximity to PAA dips, and number of birds processed per job were not controlled for across establishments.

Table 5.6.2. Personal-level airborne PAA concentrations by job category and evisceration line speed[1]

PAA Job Category[1]	Overall		≤145 BPM		>145 to <175 BPM		175 BPM	
	N[2]	Mean (SD)	N[2]	Mean (SD)	N[2]	Mean (SD)	N[2]	Mean (SD)
Evisceration Trim	5	0.29 (0.19)	2	0.18 (0.18)	1	0.58 (--)	2	0.24 (0.03)
Evisceration Inspector	5	0.27 (0.15)	1	0.38 (--)	2	0.29 (0.20)	2	0.20 (0.14)
Chiller Rehang	11	0.31 (0.24)	4	0.21 (0.19)	3	0.62 (0.14)	4	0.19 (0.11)
Debone (Dark)	8	0.25 (0.17)	3	0.35 (0.24)	2	0.18 (0.02)	3	0.20 (0.15)
Debone (White)	8	0.29 (0.18)	4	0.35 (0.23)	2	0.20 (0.01)	2	0.26 (0.14)
Grader	11	0.28 (0.24)	4	0.38 (0.14)	3	0.36 (0.39)	4	0.13 (0.12)
Bagger/Packout	7	0.22 (0.15)	3	0.32 (0.16)	1	0.08 (--)	3	0.16 (0.11)

1 See Table 4.7.1 in methods for the definition of PAA job categories.
2 N is the number of establishment-specific job category airborne PAA mean concentrations.

> Airborne PAA concentrations were higher at establishments operating at <175 compared to establishments operating at 175 BPM.

5.6.3. Area Samples

We collected 58 minutes of airborne PAA concentration samples at five establishments; the average airborne PAA concentration was 0.12 ppm with a range of 0.01-0.18 ppm. These area airborne PAA concentrations do not necessarily reflect exposures expected to occur during specific worker activities, such as connecting a new tote of PAA working solution or collecting Quality Assurance titration samples in these areas, which may have resulted in higher exposure levels than those collected. Therefore, these area sampling results may be underestimates of actual worker exposures.

5.7. Case Studies: Mitigation Strategies to reduce Airborne PAA Concentrations

5.7.1. Case Study 1: PAA Dip Tank Proximity

We evaluated the relationship between worker proximity to a PAA dip tank and airborne PAA concentration to guide mitigation recommendations. We collected data for the Grader PAA job category at two workstations (purple circles, Figure 5.7.1), one four ft. "upstream" of the PAA dip tank and one 0.5 ft. "downstream" of the PAA dip tank. Data was also collected approximately two ft. away from the workstations in the "off-line sampling" position (blue circle, Figure 5.7.1). The mean airborne PAA concentration in all three locations exceeded the ACGIH STEL of 0.4 ppm and the highest airborne PAA concentration was measured directly "downstream" of the dip tank (Table 5.7.1).

Figure 5.7.1. Example of workstations for grading at one establishment

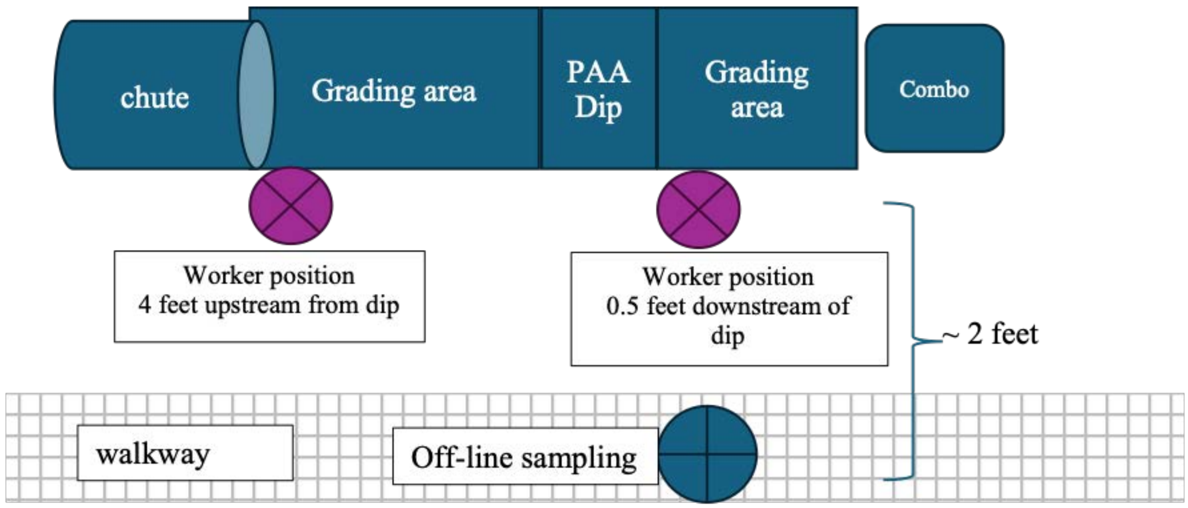


Table 5.7.1. Concentrations of PAA (ppm) by proximity to the dip tank at one establishment

Location	Number of Measurements (# minutes)	Mean PAA Concentration (ppm) (SD)	Median PAA Concentration (ppm)	Range PAA Concentration (ppm)
Worker position - 0.5' downstream	34	0.92 (0.27)	0.92	0.03 -1.79
Worker position - 4' upstream	7	0.66 (0.28)	0.61	0.18-1.14
Off line sampling - 2' off-line	5	0.79 (0.11)	0.79	0.58-1.01

Notably, the worker positioned 0.5 ft. from the PAA dip tank reported experiencing daily burning sensations and eye-watering for the first month they worked in that location. Additionally, the researcher who collected samples in this location experienced a maximum exposure of 1.79 ppm accompanied by temporarily disabling eye-watering and "throat" burning for 10 minutes and skin irritation that lasted for approximately 18 hours.

5.7.2. Case Study 2: Chiller Rehang Ventilation Management

At one establishment, we examined the effect of mechanical ventilation on airborne PAA concentrations among Chiller Rehang workers. At all establishments, the Chiller Rehang area was directly adjacent to large chillers tanks containing working PAA solution. The Chiller Rehang area was also often adjacent to a facility wall or located in an area without substantial air movement. Some establishments had large fans either permanently installed on the walls or ceiling or free-standing on the floor to control Chiller Rehang worker exposure to airborne PAA vapor. In the scenario we observed, large fans were incorporated into the air recirculation unit above the Chiller Rehang table. We worked with the enterprise management to measure airborne PAA concentrations to which Chiller Rehang workers would be exposed during the conditions of fan use and no fan use. We found that fan use in the Chiller Rehang area of the case study establishment decreased the airborne concentrations of PAA vapor to which Chiller Rehang workers would be exposed (Table 5.7.2). The decrease of airborne PAA concentration was statistically significant ($p<0.001$).

Table 5.7.2. PAA concentrations compared under different uses of general ventilation

Ventilation above Chiller Rehang	Number of Measurements (# minutes)	mean PAA Concentration (ppm) (SD)	Median PAA Concentration (ppm)	Range PAA Concentration (ppm)
Fans off	15	0.82 (0.17)	0.78	0.38-1.15
Fans on	28	0.60 (0.25)	0.51	0.21-1.19

This case study highlights the importance of ventilation that circulates “clean air” (i.e., contains negligible to no PAA) to areas where elevated PAA vapor concentrations occur. The personal level samples taken in the Chiller Rehang areas of most establishments had the highest job level airborne PAA concentrations and should be prioritized for PAA sampling and, depending on the results, ventilation improvement.

5.8. Health Effects

5.8.1. Associations of evisceration line speed and piece rate with pain

Forty percent (N=380) of 840 participants reported experiencing moderate to severe upper extremity pain during the 12 months prior to the site visit. The prevalence of moderate to severe upper extremity pain among workers in the ≤145 BPM evisceration line speed category (48%) was virtually the same as the prevalence of moderate to severe upper extremity pain among workers in the 175 BPM evisceration line speed category (47%) (Table 5.8.1). The prevalence of moderate to severe upper extremity pain was similar across workers in the three piece rate categories. None of the differences in the prevalence of moderate to severe upper extremity pain during the 12 months prior to the site visit across evisceration line speed or piece rate categories were statistically significant.

Among all workers performing palletizing (stacking boxes), 22% had moderate to severe back pain during the past 12 months (data not shown), with a higher prevalence of workers experiencing moderate to severe low back pain in establishments operating at 175 BPM (40%) compared to those operating at ≤145 BPM (15%) (Table 5.8.1.). Workers at the higher evisceration line speed establishments (i.e., 175 BPM) had more than a three-fold increase in the odds of experiencing moderate to severe low back pain in comparison to workers in establishments with evisceration line speeds of ≤145 BPM, although the confidence intervals were wide and the pain prevalence differences between evisceration line speed groups were not statistically significant.

Table 5.8.1. Association between evisceration line speed, piece rate, and moderate to severe pain over the past 12 months

	All, N	Pain[1] N (%)	OR[2] (95% CI)	Adjusted p-value
Moderate to severe upper extremity pain during the past 12 months				
Evisceration Line Speed				
≤145 BPM	319	153 (48%)	1.0	
>145 to <175 BPM	202	78 (39%)	0.6 (0.3 to 1.2)	0.14
175 BPM	319	149 (47%)	0.8 (0.4 to 1.4)	0.71
Piece Rate[3]				
Low	143	59 (41%)	1.0	
Medium	142	61 (43%)	1.2 (0.7 to 2.0)	0.60
High	142	57 (40%)	0.9 (0.5 to 1.5)	0.84
Moderate to severe low back pain among stackers during the past 12 months				
Evisceration Line Speed				
≤145 BPM	20	3 (15%)	1.0	
>145 to <175 BPM	13	1 (8%)	--	--
175 BPM	25	10 (40%)	3.4 (0.7 to 17.8)	0.15

1 Includes all workers with survey data who responded to the pain question
2 Adjusted for age, sex, primary language, job tenure
3 Each worker with video data had a piece rate that was assigned to a low, medium, or high category based on a tertile split by job

> Nearly half (45%) of all workers reported experiencing moderate to severe upper extremity pain during the 12 months preceding the site visit.
>
> There was no statistically significant association between evisceration line speed category and moderate to severe upper extremity pain prevalence
>
> There was no statistically significant association between piece rate category and moderate to severe upper extremity pain prevalence.
>
> There was no statistically significant association between evisceration line speed category and moderate to severe low back pain prevalence among stackers (palletizers).

5.8.2. New hire "break-in" 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. The reported prevalence of break-in pain and the duration of break-in pain is provided by evisceration line speed category in Table 5.8.2. About 70% of all participants reported experiencing break-in pain with a slightly higher proportion of workers in the ≤145BPM evisceration line speed category reporting break-in pain in comparison to the 175BPM evisceration line speed category (75% versus 69%). About one in five workers at both, establishments in the ≤145 BPM evisceration line speed category and establishments in the 175 BPM evisceration line speed category, reported that the pain they experienced when they first started working had not resolved at the time of the site visit. About one in three (31.0%) workers in the >145BPM to <175 BPM evisceration line speed category reported experiencing unresolved break-in pain at the time of the site visit.

Table 5.8.2. Prevalence of "break-in" pain and duration of "break-in" pain by evisceration line speed

	≤145BPM N (%)	>145 to <175 BPM N (%)	175 BPM N (%)	Overall N (%)
Pain or discomfort when first started working[1]				882
Yes	196 (74.5%)	145 (68.7%)	280 (68.6%)	621 (70.4%)
No	58 (22.1%)	64 (30.3%)	127 (31.1%)	249 (28.2%)
I don't recall	9 (3.4%)	2 (0.9%)	1 (0.2%)	12 (1.4%)
Reported duration of break-in pain[2]				619
Resolved in <2 weeks	49 (25.3%)	40 (27.6%)	77 (27.5%)	166 (26.8%)
2- 4 Weeks	57 (29.4%)	28 (19.3%)	78 (27.8%)	163 (26.3%)
1-3 Months	38 (19.6%)	31 (21.4%)	59 (21.1%)	128 (20.7%)
Still have pain[1]	42 (21.6%)	45 (31.0%)	59 (21.1%)	146 (23.7%)
I don't recall	8 (4.1%)	1 (0.7%)	7 (2.5%)	16 (2.5%)

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 less than 90 days

> Break-in pain experienced at the time of hire was reported by 70% of all interviewed workers. Break-in pain had not resolved as of the site visit for 24% of interviewed workers who reported experiencing it.

5.8.3. Work-related pain reporting behavior

Pain-reporting behavior and some characteristics of care provided to workers who reported any work-related pain are provided in Table 5.8.3. Among the 593 workers who reported experiencing any work-related pain during the 12 months prior to the site visit, 260 (44%) did not report their pain to their supervisor or company health care provider. Of those workers, about half reported that their pain was very mild or that they were able to take care of their pain themselves, almost three-fourths of those reporting any pain received first-aid treatment from the company clinic or nurse, and only one-fourth of those reporting any pain were seen by a doctor. A higher proportion of respondents in the highest evisceration line speed category received first-aid care for their pain for more than ten weeks.

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 poultry establishment workers (regardless of current employment status) during the year prior to the site visit who had experienced pain.

Table 5.8.3. Work-related pain reporting behavior by evisceration line speed category

	Evisceration Line Speed			
	≤145BPM N (%)	>145 to <175 BPM N (%)	175 BPM N (%)	Overall
Reported any work-related pain in the past during twelve months that lasted > 1 day[1]				1039
No, N (%)	133 (34.4%)	130 (48.3%)	163 (39.5%)	426 (41.0%)
Yes, N (%)	238 (61.5%)	131 (48.7%)	244 (59.1%)	613 (59.0%)
Reported pain to supervisor or company nurse[1]				593
No, N (%)	102 (46.8%)	51 (38.9%)	107 (43.9%)	260 (43.8%)
Yes, N (%)	116 (53.2%)	80 (61.1%)	137 (56.1%)	333 (56.2%)
Reason pain was not reported[2]				258
It was very mild, N (%)	21 (20.8%)	11 (22.0%)	21 (19.6%)	53 (20.5%)
I can take care of myself, N (%)	32 (31.7%)	20 (40.0%)	33 (30.8%)	85 (32.9%)
I didn't know how to report the problem, N (%)	11 (10.9%)	3 (6.0%)	14 (13.1%)	28 (10.9%)
I didn't think the company would help me, N (%)	2 (1.9%)	0 (0%)	1 (0.9%)	3 (1.2%)
I was afraid of getting in trouble, N (%)	4 (4.0%)	0 (0%)	3 (2.8%)	7 (2.7%)
I was afraid of losing my job, N (%)	4 (4.0%)	0 (0%)	7 (6.5%)	11 (4.3%)
Other, decline to answer, N (%)	27 (26.7%)	16 (32.0%)	28 (26.2%)	71 (27.5%)
Received first aid from onsite health care practitioner[3]				371
No, N (%)	51 (33.1%)	15 (18.8%)	36 (26.3%)	102 (27.3%)
Yes, N (%)	103 (66.9%)	65 (81.3%)	101 (73.7%)	269 (72.7%)
Duration of first aid from onsite company health care practitioner[4]				261
<2 weeks, N (%)	72 (72.0%)	43 (67.2%)	67 (69.1%)	182 (69.7%)
> 2 week but < 6 weeks, N (%)	21 (21.0%)	7 (10.9%)	16 (16.5%)	44 (16.9%)
> 6 weeks and < 10 weeks, N (%)	4 (4.0%)	5 (7.8%)	2 (2.0%)	11 (4.2%)
> 10 weeks, N (%)	3 (3.0%)	9 (14.1%)	12 (12.4%)	24 (9.2%)
Evaluated (onsite or offsite) by any doctor[1]				593
No, N (%)	144 (66.1%)	96 (73.4%)	170 (69.7%)	410 (69.1%)
Yes, N (%)	43 (19.7%)	30 (22.9%)	62 (25.4%)	135 (22.8%)
Other, decline to answer, N (%)	31 (14.2%)	5 (3.8%)	12 (4.9%)	48 (8.1%)

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

5.8.4. Effects of work-related pain on function at work and outside of work

As reported in Section 5.8.1, above, 613 study participants reported experiencing any pain lasting one or more days during the 12 months prior to the site visit. Among the participants who reported experiencing 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 5.8.4. Over one-fourth of the 582 workers who reported upper extremity pain during the 12 months prior to the site visit also reported experiencing moderate to severe difficulty in maintaining their expected work pace or quality of work because of their pain, with only small differences across evisceration line speed categories. The proportion of workers who considered either changing lines or quitting because of pain was substantial (38%) and varied little by evisceration line speed. About one in five respondents took time off work because of pain, with a slightly higher proportion in the ≤145 BPM establishments in comparison to the 175 BPM establishments (27.8% v 21.7%).

Table 5.8.4. Effects of any reported pain during the 12 months prior to the site visit on work pace or work quality, consideration of quitting, outside activities, and time off work by evisceration line speed

	Evisceration Line Speed			
	≤145BPM N (%)	>145 to <175 BPM N (%)	175 BPM N (%)	Overall N (%)
Difficulty maintaining expected work pace or quality of work[1]				582
No difficulty, N, %	96 (46.2%)	73 (55.7%)	128 (52.7%)	297 (51.0%)
Mild difficulty, N, %	53 (25.5%)	27 (20.6%)	49 (20.2%)	129 (22.2%)
Moderate difficulty, N, %	39 (18.7%)	20 (15.3%)	53 (21.8%)	112 (19.2%)
Severe difficulty, N, %	20 (9.6%)	11 (8.4%)	13 (5.3%)	44 (7.6%)
Considered quitting or changing lines because of pain[1]				580
No, N, %	122 (59.2%)	84 (64.6%)	152 (62.3%)	358 (61.7%)
Considered changing lines, N, %	44 (21.4%)	26 (20.0%)	50 (20.5%)	120 (20.7%)
Considered quitting, N, %	40 (19.4%)	20 (15.4%)	42 (17.2%)	102 (17.6%)
Pain or discomfort prevents important activities outside of work[1]				561
No, N, %	115 (61.2%)	93 (71.5%)	164 (67.5%)	372 (66.3%)
Yes, N, %	73 (38.8%)	37 (28.5%)	79 (32.5%)	189 (33.7%)
Time off work[2] because of pain or discomfort[1]				569
No, N, %	107 (55.2%)	105 (80.2%)	158 (64.8%)	370 (65.0%)
No, but I wanted to, N, %	33 (17.0%)	13 (9.9%)	33 (13.5%)	79 (13.9%)
Yes, N, %	54 (27.8%)	13 (9.9%)	53 (21.7%)	120 (21.1%)

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 reporting pain, one-quarter of workers reported having moderate to severe difficulty maintaining their expected workplace.

One-third of workers reported considering changing lines or quitting due to their pain. One-third of workers also reported that their pain prevents them from performing important activities outside of work.

One-fifth of workers took time off of work (paid or unpaid) due to pain.

Over 40% of all respondents *did not* report their pain to the supervisor or nurse.

5.8.5. Medical interviews

A total of 508 medical interviews were completed by faculty and resident physicians at the University of California, San Francisco. One physician (RH) reviewed all interview notes and information about evisceration line speed, staffing, musculoskeletal symptoms, injuries, and medical management was summarized. The nature of the open-ended responses elicited during the medical interviews did not allow for comparative analyses of medical interviews across establishments or by evisceration line speed category.

Fatigue and pain were common among interviewed workers. Workers reported that pain was "part of the job" and had to be tolerated to continue working. One worker noted, "When the chickens are bigger, people get tired." Workers also reported that being short-staffed led to increased difficulty performing their jobs. For example, one worker noted, "It is hard to keep doing [the work] over and over when we are not fully staffed."

Reporting of pain and injuries. Although all establishments had policies that encouraged early reporting of symptoms, many workers perceived limited value from onsite first aid treatment and did not report their pain. Several workers noted that they often treated their pain with over-the-counter medications after work. Some representative comments included, "I do not report my pain so I can keep working to maintain my pay" and "We just have to get used to [pain]."

Satisfaction with company provided care. Workers who received treatment from their company for pain or injury were generally satisfied with the care they received. Participants reported that onsite treatment was commonly provided with topical agents (e.g., BioFreeze, heat) or over-the-counter anti-inflammatory medications.

Ergonomic interventions following injury. Workers reported that their jobs were not modified or "fixed" after they reported pain or injury to facility managers, supervisors, or health care providers. In some cases, workers underwent treatment (including surgery) for a work-related injury and were returned to the same unmodified job that they believed had caused their pain.

Suggestions for changes to the work environment and work processes. When asked about improvements to their work, participants often had few ideas, perhaps reflecting the common perception of one worker who stated, "The job is not so bad once you get used to it." Several workers mentioned their supervisors' focus on productivity with a few articulating their sense of being "overworked and underpaid." While most workers reported that while they could keep up with the demands of their jobs, some wanted to make their work easier by slowing the speed of work and increasing the number of staff who do their jobs. Many workers, however, echoed the opinion of one worker who noted, "I do not see how to make the job easier; workers just have to adapt."

5.8.6. Respiratory Symptoms

Overall, 17.2% of all participants reported respiratory symptoms during the past 12 months (Table 5.9.1.). The prevalence of workers with complaints of respiratory symptoms during the past 12 months was similar in establishments with evisceration line speeds of ≤ 145 BPM and of 175 BPM (19.2% vs 19.2%), and nearly equivalent across piece rate exposure groups. This analysis includes all workers regardless of their proximity to PAA.

Table 5.9.1. Association between evisceration line speed, piece rate, and moderate to severe respiratory symptoms over 12 months

	All, N	Symptoms[1] N (%)	OR[2] (95% CI)	p-value
Moderate or Severe Respiratory Symptoms during past 12 months (n=976)				
Evisceration Line Speed				
≤145 BPM	313	60 (19.2%)	1.0	
>145 το <175 BΠM	262	31 (11.8%)	0.5 (0.2 to 1.2)	0.1
175 BPM	401	77 (19.2%)	1.0 (0.4 to 2.1)	0.9
Piece Rate[3]				
Low	150	25 (16.7%)	1.0	
Medium	144	26 (18.1%)	0.9 (0.5 to 1.8)	0.9
High	147	27 (18.4%)	0.9 (0.5 to 1.8)	0.8

1 Includes all workers with survey data who responded to the pain question
2 Adjusted for age, sex, primary language, job tenure
3 Each worker with video data had a piece rate that was assigned to a low, medium, or high category based on a tertile split by job

Chiller Rehang workers had the highest overall exposures to PAA (Table 5.6.2) and had the highest prevalence of moderate to severe respiratory symptoms (29.9%, data not shown). Comparing the prevalence of symptoms across jobs was challenging due to the differences in PAA concentrations between establishments.

6. Conclusions

6.1. Evisceration line speed category was not associated with MSD risk among poultry processing workers. Rather, piece rate, a metric of job-specific line speed and staffing level, was associated with MSD risk.

Evisceration line speed, in the absence of information about job-specific line speed and staffing level, was not associated with musculoskeletal disorder risk. For some jobs (Live Hang, Chiller Rehang, Coning) higher staffing levels or lower job-specific line speed at establishments with higher evisceration line speeds attenuated potential job-specific increases in PFI-TLV score compared to lower evisceration line speeds, but for other jobs (Breast Processing, Shoulder/Wing Processing, Tender/Wing Processing) increased staffing levels were not enough to reduce piece rate to levels measured in establishments operating at slower evisceration line speeds. Piece rate, a proxy for job line speed and staffing levels, was statistically significantly associated with MSD risk. Job-specific line speeds and staffing levels are important drivers of MSD risk.

6.2. Regardless of evisceration line speed category, poultry establishments have failed to protect most workers from MSD risk (PFI-TLV score ≤1.0; CLI≤1.5).

The majority (81%) of the poultry plant workers in the jobs evaluated had an unacceptably high MSD risk (PFI-TLV score >1.0) regardless of evisceration line speed category. Consequently, all establishments should mitigate MSD risk by increasing job-specific staffing levels and/or job-specific line speeds to ensure that all jobs are designed to achieve a PFI-TLV score <1.0. Further, any establishment anticipating an increase in evisceration line speed should proactively mitigate MSD risk by increasing job-specific staffing levels and/or decreasing job-specific line speeds to maintain a PFI-TLV score ≤1.0.

Increased MSD risk levels were substantial. For example, the 81% of workers performing a job with a PFI-TLV score >1.0 had at least a two-fold increase in risk of CTS (a benchmark musculoskeletal disorder known to be associated with forceful and repetitive exertions). The 20% with a PFI-TLV score greater than 2.0 had a three-fold increased risk of CTS. 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.). Further, 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. A large proportion of workers reported moderate to severe work-related pain; nearly half did not report it to their employer.

Forty percent of workers across all establishments reported experiencing moderate to severe work-related upper extremity pain during the prior 12 months. Among those workers who experienced moderate to severe work-related pain in the past year, 43% did not report their pain to their employer. For those who did report moderate to severe work-related pain, 30% received only first aid care for more than 2 weeks, with 9% receiving only first aid care for more than 10 weeks.

6.4. Evisceration line speed category was not associated with PAA exposure. However, some poultry establishments have not adequately mitigated excessive PAA exposure.

Peracetic acid (PAA) airborne concentrations in one in five jobs sampled across all establishments (N=61 jobs) exceeded the ACGIH STEL of 0.4 ppm. At 5 of the 11 establishments, PAA airborne concentration in at least one job exceeded the ACGIH STEL of 0.4 ppm. The PAA exposure levels found in this study were independent of evisceration line speed. Other factors, such as establishment layout and ventilation system performance, may have accounted for the observed variations in exposure concentrations.

Our findings on PAA were based on short-term measurements and we did not evaluate the risk to poultry processing workers who may have repeated exposures. At concentrations of PAA exposure above the ACGIH STEL, poultry processing workers may experience acute respiratory irritation. The ACGIH STEL has not been set for repeated exposures over months to years that may result in chronic respiratory effects. Any establishment anticipating an increase in evisceration line speed should proactively mitigate the risk of acute health effects from PAA by reducing worker exposures to less than the ACGIH STEL.

7. Strengths and Limitations

There were numerous strengths to this study, including:

- A large study worker sample size recruited from multiple poultry processing establishments.
- This study had a high participation rate (96.6%).
- Ergonomic exposure measurements that were highly detailed, and used validated and objective methods to quantify hand force, hand repetition rate, and duty cycle.
- The inclusion of participants from jobs that were representative of work performed by poultry processing workers.
- A quantitative approach to using job-specific line speed and staffing levels to model MSD risk and provide guidance for MSD risk reduction.

There were some study limitations, including:

- As a result of the high turnover rate[3], the study sample was likely healthier than the sample of all previously exposed workers. Those who left employment due to work-related pain or the inability to keep up with the high pace of work were underrepresented. Such a healthy worker survivor effect likely leads to an underestimate of reported work-related pain and an underestimate of associations.
- Of all workers with video data, a subset also had EMG data. Consequently, single imputation was used to estimate the NPF of workers without EMG data. This may have led to measurement error. Since the single imputation ignored the uncertainty involved in imputation, the standard errors and p-values may be underestimated. For this reason, a sensitivity analysis using only non-imputed data was performed to ensure consistency with the single imputation models. The standard error and p-values of the models using non-imputed data were virtually identical to those of the models using imputed data.
- Despite trying to select study subjects randomly, there may have been some selection bias at establishments resulting from the researcher or supervisor convenience sampling of workers.
- Interviews were conducted onsite and in multiple languages using telephone interpreters, and some survey questions may have been misunderstood.
- The ability to detect the effect of evisceration line speed on MSD risk would have been greater if establishments had operated at only 140 *or* 175 BPM and not at any other speeds.

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[3] Seven of the eleven establishments provided annual turnover rates. The 2023 mean(SD) turnover rate was 86% (18%) and the 2024 mean (SD) turnover rate was 69% (33%).

8. Recommendations

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

The PFI-TLV score is a well established and validated measure of risk for upper extremity MSDs. 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 PFI-TLV score of 1 or greater had a two-fold or more increase in risk of upper extremity MSDs compared to workers with a PFI-TLV of less than 1 (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 one is 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, across all poultry processing jobs, should be the minimal threshold used by the industry for achieving acceptable upper extremity MSD risk.

8.1.1. Implement target job-specific piece rates presented in this report to achieve a PFI-TLV score of one or less.

Workers with a PFI-TLV score >1.0 are exposed to a combination of work pace (HAL) and hand force (NPF) that, together, 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. Establishments can use the graphs in this report to identify the combination of job-specific line speed and staffing levels to achieve a PFI-TLV score ≤1.0 (Appendix 7). In order to decrease the risk of MSDs, the piece rate, or number of chickens (or pieces) handled per minute, can be lowered. The primary approach to reducing the frequency and duration of hand exertions is to reduce the pace of work (i.e., the job-specific piece rate) by either slowing the job-specific line speed, increasing staff, or both. For some jobs, like Live Hang and Chiller Rehang, increasing staffing is the only effective approach for reducing the PFI-TLV score to one or less.

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 similar 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 poultry 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 for that job while keeping the PFI-TLV score to less than 1.0, particularly for jobs that require the use of cutting tools.

Integrate MSD risk scores into 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 MSD risk. However, fatigue allowances can 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.

8.1.2. Implement long-established meat packing best practices.

Every decade since 1993, OSHA has published guidelines that established best practices for meat packing. In 1993, OSHA published Ergonomic Program Management Guidelines for Meat Packing Plants (OSHA 1993). In 2004, OSHA published Guidelines for Poultry Processing- Ergonomics for the prevention of musculoskeletal disorders. In 2013, OSHA published Prevention of Musculoskeletal Injuries in Poultry Processing. Furthermore, in 2012, NIOSH completed a health hazard evaluation of poultry processing (HHE 2012-0125-3024) and made 15 recommendations, the first of which was to design job tasks so they are below the ACGIH TLV for Hand Activity to minimize the risk of developing carpal tunnel syndrome. Yet, our study found that 81% of workers evaluated still exceeded the PFI-TLV score of 1.0, and despite decades of published best practices, many best practices have not been implemented uniformly or comprehensively across establishments regardless of line speed.

In this study of eleven poultry processing establishments, there were some examples of effective practices reflecting the implementation of the previously referred guidelines. One company (two establishments) had a Certified Professional Ergonomist who had facilitated numerous effective interventions. Most other companies had safety team members with minimal ergonomics training overseeing ergonomic assessments and interventions. Some establishments had robotic knife sharpening systems while others relied on manual sharpening of knives. Some establishments had automated cone lines or reduced the pace of work by using every other cone, while other establishments relied purely on manual cone lines. In summary, there are numerous opportunities for establishments to improve their ergonomic programs to mitigate the MSD risks described.

To facilitate the implementation of best practices, one option is to develop an industry and labor safety and health consortium. Examples from the automobile manufacturing industry are the United States Council for Automotive Research (USCAR) and the Automotive Industry Action Group (AIAG). These consortia include Ford Motor Company, General Motors, and Stellantis. They facilitate the legal collaboration of their participants to address safety and health challenges in their industry. Solutions come from collaborative efforts to develop and implement industry best practices. The evaluation of automated knife sharpening, optimal knife rotation schedules, and using wearable devices to assist in ergonomic risk and exposure assessment and training of workers are examples of factors that could be researched collaboratively through such a consortium. Optimizing the integration of the PFI-TLV score into 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.

8.2. Reduce worker exposure to PAA to below the ACGIH 0.4 ppm STEL.

All poultry processing establishments using PAA should implement an industrial hygiene program to maintain worker exposures below the ACGIH 0.4 ppm STEL. Establishments should utilize an industrial hygienist to identify appropriate mitigation strategies such as (i) increasing the distance between workers and PAA source, (ii) covering of dip and chiller tanks, (iii) increasing ventilation that delivers clean air to workers (general ventilation) or removes airborne PAA (e.g. local exhaust ventilation), and (iv) substitution of approved antimicrobials that are safer for workers, if available.

8.3. 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 emphasizing collaboration with workplace safety and health programs (US DOL 2024). Findings from this study, such as, (i) the proportion of workers not reporting their work-related 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 Poultry Processing Establishments.

Poultry processing employers should utilize first aid only to precede definitive assessment of the need for medical care and should not require multiple first aid encounters of the same worker presenting the same symptoms. Additionally, poultry processing employers should ensure timely referral of workers with work-related 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 work-related 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." Poultry 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 other 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 Medicine physician. OSHA also recommends that medical management programs collaborate with safety and health programs by tracking information about first-aid visits, injuries, illnesses, incidents, and near misses.

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Appendix 1: Planning and Implementation of PULSE

A.1.1. Study Planning ("Phase 1")

The FSIS provided the PULSE Team with a list of the 49 chicken slaughter establishments with evisceration line speed waivers greater than 140 BPM during Phase 1 study planning. Meta-data included establishment number, name, location, number of lines, union status, number of shifts, inauguration year, evisceration line speed waiver year of issuance, and evisceration line speed. The PULSE team visited six poultry establishments from six companies between November 2022 and February 2023 that varied in production volume, union representation, and location (state). The PULSE team spent two days at each establishment to evaluate all aspects of facility operations. 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 PULSE team selected specific areas and work processes for observation and videotaping. In addition, the PULSE team interviewed the facility manager, safety/ergonomics manager(s), industrial hygienist, line leaders, supervisors, human resources representative, medical department staff, and union representative (s) where present. The PULSE team also reviewed written documents about the core elements of their ergonomics, safety, and health, antimicrobial agents (PAA), and medical management programs.

Before the Phase 1 site visits, our null hypothesis was that the higher evisceration line speeds would not change the risk of MSDs and respiratory diseases throughout the facility. During our 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 I 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 evisceration 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.

Ergonomic hazards and risk for MSDs

During Phase 1 the PULSE Team conducted walk-throughs, obtained videos, and interviewed numerous managers, worker representatives, and frontline workers at each facility. When interviewing workers, the PULSE Team focused on a qualitative assessment of whether tasks had changed due to automation or became more/less physically demanding due to the increased evisceration line speed. Workers consistently mentioned that although automation can make the job "easier," training, staffing, and turnover were primary determinants of work demands. Although most workers could not tell if evisceration line speed affected the demands of their jobs, many felt that the pace of their jobs was too fast. Onsite observation and videos confirmed that all facilities had implemented automated technology to decrease hand-intensive tasks in evisceration line speed. The PULSE team found that slaughter and other automated technologies may not have eliminated the risk for MSDs, as several jobs are still manually performed (upstream and downstream from the automated slaughter process) and may potentially be at increased risk for hand/wrist, upper extremity, and low back injuries especially if process flow increases and there is inadequate staffing.

Two establishments had ergonomic and industrial hygiene consultants available to evaluate specific ergonomic issues as needed. However, none of the establishments appeared to have employed either in-house or external scientific research teams to document the ergonomic or respiratory exposures before and after the implementation of increased evisceration line speeds between 141 and 175 BPM.

According to management interviews, the evisceration line speed waivers increased slaughter output through automated technologies, allowed for flexibility in meeting customer demand, and increased efficiencies in operations. Ideally, the risk of manual hand-intensive or materials-handling tasks could be minimized by automation (such as deboning) or by adding lines and workers as needed for second processing. The workers whom the PULSE Team interviewed could not describe whether increased evisceration line speed consistently affected job demands. Again, insufficient staffing levels were mentioned as the most critical contributor to overall workload.

Exposure to antimicrobial agents used as processing aids.

Potential personal and area exposure to PAA was observed to occur during 1) off-gassing from chillers; 2) over-spray from spray cabinet openings and high nozzle pressure; 3) lack of local exhaust ventilation on spray cabinets; 4) inadequate ventilation in kill floor areas; 5) direct discharge of waste solution from cabinets and tanks directly onto the floor; 6) inadequate control of solution pH; 7) chemical mixing in floor drains; and 8) hand application with spray tanks. The PULSE team theorized that increased evisceration line speed could potentially result in increased exposure to PAA as a result of:

- mixing and testing the titration of PAA tanks;
- volatilization from chiller tanks, spray cabinets, and spray nozzles;
- Waste production and drainage systems with unusual events, such as blocked drains and
- Entrainment from air currents and/or poultry on conveyors

Medical Management and Injury Record Keeping

Increased exposure to ergonomic hazards from higher evisceration line speeds may result in more first aid visits and OSHA recordable injuries. Onsite clinics provided first aid and were staffed by nursing personnel with variable medical oversight and protocols. At one establishment, certified nursing assistants utilized a 24/7 service for registered nurse consultation, and there was no corporate medical director or clinical oversight of the nursing staff. At another establishment, onsite nurses followed medical directives signed by a local physician and reviewed by the corporate occupational medicine consultant. The nursing staff at this establishment were clinically supervised by an experienced occupational health nurse who performed an annual audit at all company onsite medical clinics. At another site, nurses were available during both shifts for treatment and had access to local clinics for medical care. The PULSE team found that evaluating information on treatment and reporting protocols would be critical to understanding whether there has been an increase in first aid visits and recordable injuries due to increased evisceration line speed.

Appendix 2: Survey Instrument

Q1 We are here upon request from the USDA to evaluate the impact of line speed on workload. I am a university researcher and would like to ask you some questions about your work using this questionnaire. Your responses will be anonymous and maintained confidentially. Your participation is completely voluntary.

Q2 Indicate the facility Study Site number: Site 1 (1) Site 2 (2) Site 3 (3) Site 4 (4) Site 5 (5) Site 6 (6) Site 7 (7) Site 8 (8) Site 9 (9) Site 10 (10) Site 11 (11) Site 12 (12) Site 13 (13) Site 14 (14) Site 15 (15) Site 16 (16).

Q3 Participant ID (write "Decline" if a worker declines to participate):

Q4 This week, have you PREVIOUSLY participated in any of the following? (Choose all that apply): No (0), Medical Interview (1), Work Survey (2), Video (3), Wearables and Video (4).

Q5 Will you be participating in task evaluation (video or wearable devices)? No (0), Yes, videotaped (1), Yes, devices while videotaped (2).

End of Block: Intro

Start of Block: Work Organization

Q6 How long have you worked at this company? <90 days (1), ≥90 days but <1 year (2), ≥1 year and <5 years (3), ≥5 years and <10 years (4), ≥10 years (5).

Q7 Which shift do you work? Day (1), Swing/Evening (2), Night (3), Other (4)

Q8 What jobs do you perform most often? Live Hang (1), Evisceration Line (2), Organ Sorting (3), Trimming (4), Quality Control (5), Rehang (6), Debone white meat (7), Debone dark meat (8), Manual rework (9), Breast/Tender puller (10), Marinate (11), Packing/Packout (12), CVP Stackout (13), Line Supervisor (14), Other (15)

Q9 How often do you rotate positions? Never/Rarely (0), Once per day (1), Two or more times per day (2).

Q10 How many HOURS PER DAY do you TYPICALLY work here? Hours: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14.

Q11 How many DAYS PER WEEK do you TYPICALLY work here? Days: 0 1 2 3 4 5 6 7.

Q12 Do you work overtime (more than 40 hours per week)? No (0), Yes, voluntary (1), Yes, mandatory (2), Yes, both (3).

Q13 What is the most number of hours you have ever worked in a week? ___________

Q14 How many workers are on your line when it is FULLY staffed? Workers: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15.

Q15 When fully staffed, is it comfortable to work your job? No (0), Yes (1).

Q16 How many days during a week or month is your line understaffed? Days/week ___________, Days/month ___________.

Q17 How many birds per minute (line speed) do you process? ___________

Q18 Is the LINE SPEED for this job: Much too slow (1), A little too slow (2), Just about right (3), A little too fast (4), Much too fast (5).

Q19 Do you ever have difficulty keeping up with your work? Rarely/Never (0), Sometimes (1), Most of the time (2), Always (3).

Q20 Any other comments? ___________

Start of Block: Task Evaluation

Q21 What is the job that you will perform TODAY while being videotaped? Live Hang (1), Evisceration Line (2), Organ Sorting (3), Trimming (4), Quality Control (5), Rehang (6), Debone white meat (7), Debone dark meat (8), Manual rework (9), Breast/Tender puller (10), Marinate (11), Packing/Packout (12), CVP Stackout (13), Line Supervisor (14), Other (15) __________.

Q22 Please rate the AVERAGE HAND FORCE (squeezing, gripping, pinching) that you use for this job. (SHOW CARD) 0 Nothing at All (0), 0.5 Extremely Weak (0.5), 1 Very Weak (1), 2 Weak (2), 3 Moderate (3), 4 (4), 5 Strong (5), 6 (6), 7 Very Strong (7), 8 (8), 9 (9), 10 Extremely Strong (10).

Q23 Please rate the HIGHEST HAND FORCE (squeezing, gripping, pinching) that you use for this job. (SHOW CARD) 0 Nothing at All (0), 0.5 Extremely Weak (0.5), 1 Very Weak (1), 2 Weak (2), 3 Moderate (3), 4 (4), 5 Strong (5), 6 (6), 7 Very Strong (7), 8 (8), 9 (9), 10 Extremely Strong (10).

Q24 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 (3), A few less people (4), A lot less people (5).

Q25 Is your line today 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).

Q26 Do you have any productivity requirements (weight of meat processed, birds per minute, etc.)? No (0), Not sure (1), Yes (2).

Q27 Please describe your productivity requirements. ___________

Q28 Do you receive any bonus or incentive pay for your work? No (0), Yes (1).

Q29 Please describe any bonus or incentive pay for your work. ___________

Q30 If you had a magic wand, how would you make your work EASIER? (choose all that apply): Knife sharpening program (1), More job rotation (2), More training (3), More team members on the line (4), Better-trained workers (5), Flexible hours (6), Shorter workday (7), Slower line speed (8), Supervisors who listen (9), Supervisors who care (10), Fewer machine breakdowns (11), More space (12), Redesign workstation (13), Change tools (14), Other (15) ___________.

Q31 Thinking back to when you first started at this company, did you have any pain or discomfort that lasted more than a day in your hands, arms, neck, back, legs, or feet related to your work? No (0), Yes (1), I don’t recall (2).

Q32 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 (2), 4 weeks to less than 8 weeks (3), 8 weeks to less than 12 weeks (4), Always had pain (5), I don’t recall (6).

Q33 Have you had pain or discomfort in the past 12 months that was worse at work and lasted more than a day in your neck, shoulders, arms, hands, wrists, or legs? No (0), Yes (1).

Q34 For each of the body parts where you had pain or discomfort, rate your pain on a scale of 0 to 10: Neck (0–10), Shoulders (0–10), Arms/Elbows/Forearms (0–10), Hands/Wrists (0–10), Back (0–10), Hips/Knees/Legs (0–10).

Q35 Were you performing the same job that you have today? No (0) ___________, Yes (1).

Q36 Did you have difficulty maintaining your expected pace or quality of work because of your pain? No (0), Mild difficulty (1), Moderate difficulty (2), Severe difficulty (3).

Q37 How often did you take medication (prescription or over-the-counter) for pain relief? Daily (1), 2-3 times this week (2), At least once this week (3), Rarely/Never (4).

Q38 Have you ever considered quitting or changing lines because of pain? No (0), Yes, considered changing lines (1), Yes, considered quitting (3).

Q39 In the past year, have you been injured by safety hazards (knives, forklift, tripping hazards, etc.)? No (0), Yes (1).

Q40 In the past year, have you experienced respiratory symptoms (burning eyes, nose, throat, or lungs at work)? No (0), Yes, sometimes (1), Yes, often (2).

Q41 If respiratory symptoms were often, how severe were they (0–4 scale)? ___________.

Q42 What job or task were you performing when you experienced symptoms? ___________.

Q43 Did you report your pain to your supervisor or company nurse? No (0), Yes, to supervisor/manager/lead (1), Yes, to company nurse/healthcare provider (2).

Q44 If you didn't report pain, why not? Mild pain (1), Could manage myself (2), Didn't think the company would help (3), Didn't know how to report (4), Afraid of getting in trouble (5), Afraid of losing my job (6), Other (7) ___________.

Q45 Did you receive treatment or first aid from the company clinic or nurse? No (0), Yes (1).

Q46 What first aid or treatment did you receive? None (0), Ice (1), Ibuprofen (2), Aspirin (3), Stretches (4), Exercises (5), Training (6), Other (10) ___________.

Q47 How many weeks did you receive first aid or treatment for? Less than 2 weeks (1), 2-6 weeks (2), 6-10 weeks (3), More than 10 weeks (4).

Q48 Were you seen by a doctor? No, didn't want to (1), No, should have (2), Yes, referred by company (3), Yes, saw own doctor (4), Other (5) ___________.

Q49 Was your job or work tasks changed because of pain? No (1), Yes, additional rest time (2), Yes, changed processes (4), Yes, changed jobs permanently (5).

Q50 If job or tasks were modified, how many days until you returned to regular work? ___________.

Q51 During the past year, did you take any time off work because of the pain? No (0), No, but wanted to (1), Yes (2).

Q52 If yes, how many days? ___________.

Q53 Did the pain prevent you from doing important activities outside of work? No (0), Yes (1).

Q54 If yes, which activities? ___________.

Start of Block: Demographics

Q55 What is your age (years)? ___________.

Q56 Are you male, female, or non-binary? Female (1), Male (2), Non-binary (4), Decline to answer (3), Other (5) ___________.

Q57 What best describes your race or ethnicity? White/Caucasian (1), White Latino/Hispanic (2), Black Latino/Hispanic (3), Black/African American (4), Asian (5), Pacific Islander (6), Native American/Indigenous Alaskan (7), Decline to answer (8), Other (9) ___________.

Q58 What is the primary language spoken at home growing up? English (1), Spanish (2), Chinese (3), Tagalog (4), Vietnamese (5), Arabic (6), Chuukese (8), Other (7) ___________.

Q59 What level of education have you completed? Didn't complete 5th grade (1), Elementary school (2), Middle school (3), High school (4), Two years of college (5), Bachelor's degree (6) ___________, Graduate education (7) ___________, Decline to answer (8).

Q60 What country were you born in? ___________.

Q61 If born in another country, 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).

Q62 Height (inches) ___________.

Q63 Weight (lbs) ___________

Q64 Anthropometric Measurements: Forearm (cm) ___________, Grip span (cm) ___________, Wrist to fingertip (cm) ___________, Grip diameter (cm) ___________.

Q65 MVC Measurements: 100% MVC Trial 1 ___________, Trial 2 ___________, Trial 3 ___________, Average ___________, 75% MVC Target ___________, 50% MVC Target ___________, 25% MVC Target ___________.

Appendix 3: Methodology

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). Generally, 3 of the 5 participants being videotaped 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 (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.a.) and the type of hand exertion (Figure A.3.1.b.), as defined below (Tables A.3.1.a. and b.).

Figure A.3.1.a. Example of video analyzed in MVTA by tool used

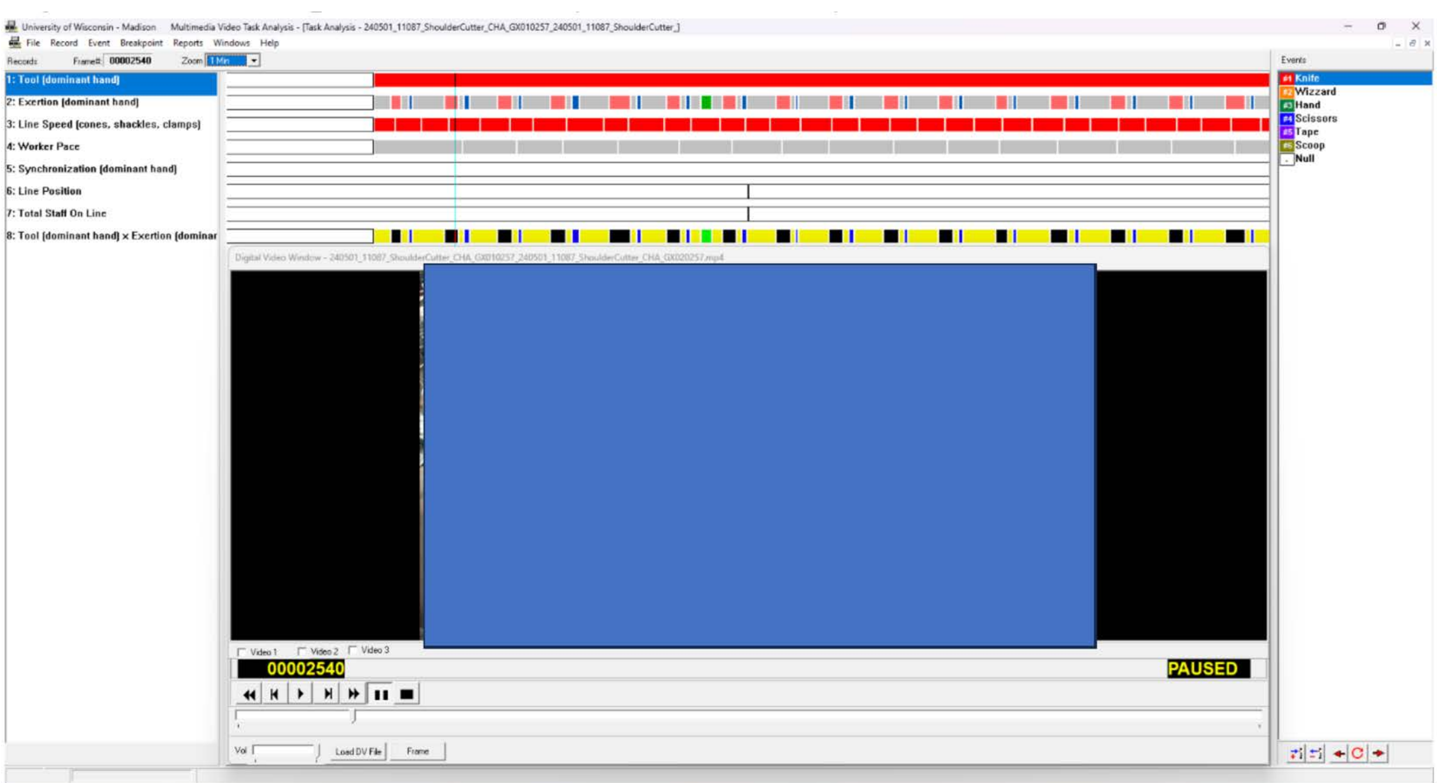


Figure A.3.1.b. Example of video analyzed in MVTA by type of hand exertion

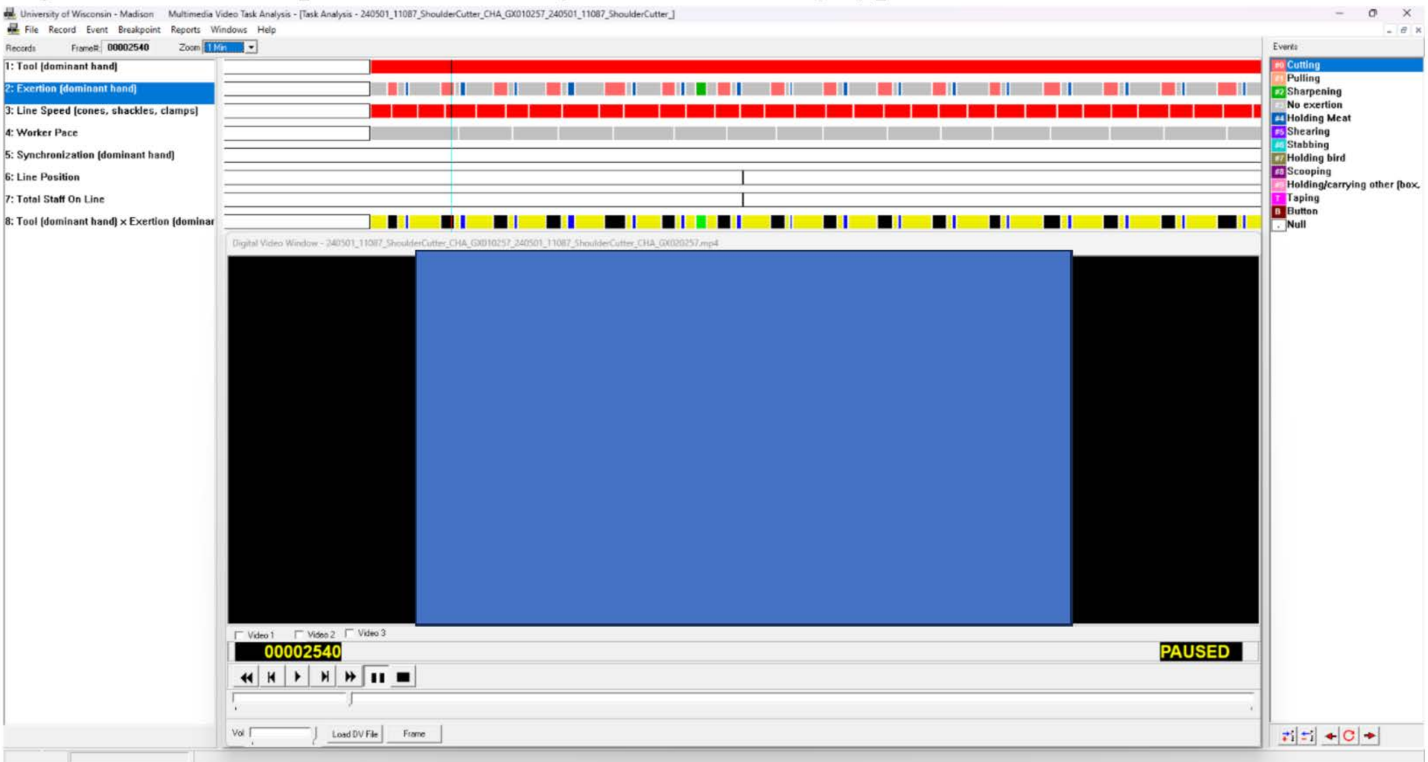


Table A.3.1.a. List of definitions used to classify hand exertions

Category	Event	Definition
Tool	Knife	Single or double, straight blade
	Whizard	Electric circular blade, various size
	Hand	While wearing gloves
	Scissors	Standard scissors
	Tape	Packing tape or adhesive label
	Scoop	Metal scoop for dry ice
Exertion	Cutting	Knife, scissor or whizard
	Pulling	Using hand to pull meat
	Sharpening	Using blade sharpener with knife or scissors
	Holding Meat	Using hand to hold meat
	Shearing	Pushing scissors, without closing the blades
	Stabbing	Using end of knife or scissors to move meat
	Holding Bird	Hand holding whole bird (live hang, rehang, coning)
	Scooping	Scooping dry ice during for packing
	Holding/Carrying	Holding non-meat object (box, bag, etc.)
	Taping	During packing
	Button	During bagging
	No Exertion	None of the above exertions
	Null	Hand not clearly in view

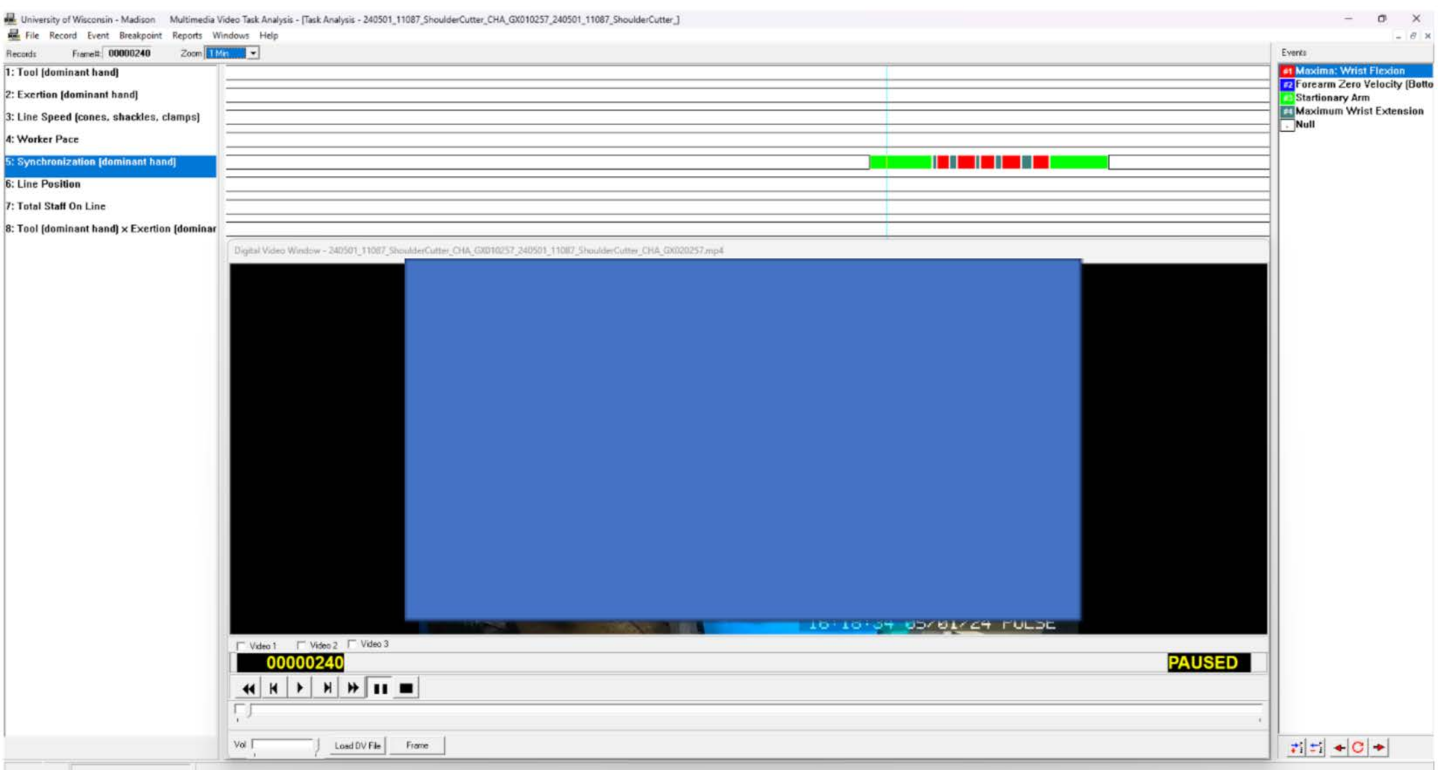
One minute of work from each video was analyzed by first categorizing the tool used, and then the type of hand exertion identified in every frame, for one hand only. The hand holding the tool was analyzed, or when no tool was present, the worker's dominant hand was used and identified by the presence 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.3.1.c.). 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.

Table A.3.1.b. List of definitions used to quantify piece rate per worker

Job Name	Piece Rate Definition
Live Hang	Hang one bird
Chiller Rehang	Hang one bird
Shoulder Cut	Cut one bird
Wing Round	Cut one bird
Breast Pull	Pull breast from one bird
Breast Trim	Cut one bird
Tender Cut	Cut one bird
Tender Pull	Pull tender from one bird
Thigh Debone	Cut one piece
Cone Line (Coner)	Load one bird
White Trim	Cut one piece
Dark Trim	Cut one piece
White Rework	Cut one piece

Figure A.3.1.c. 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

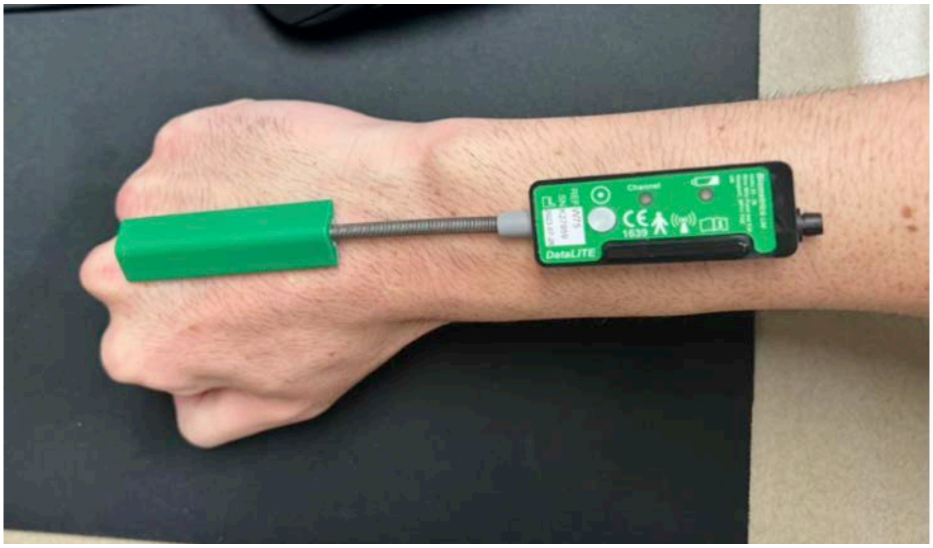
Maximum voluntary contractions were elicited using a hand grip dynamometer (Biometrics, Ltd., Cwmfelinfach, Wales) which collected data at 500 Hz. For instances in which the dynamometer collected data at 100 Hz (n=48), the data was resampled to 500 Hz using linear interpolation. Three maximum voluntary 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 work-related 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 research team member, then transferred to a hard drive and different computer for data processing. EMG data was processed using a 5^{th}-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 on the dorsal side of the hand over 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 research 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 A.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. This wearable data was then brought into the temporality of the video using Multimedia Video Task Analysis (MVTA; NexGen Ergonomics, Inc., Pointe-Claire, QC, Canada) 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 score ≤1) and unacceptable jobs (PFI-TLV score >1). The PFI-TLV score 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 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.

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

The ULLF TLV uses two exposure measures to categorize work tasks as acceptable or unacceptable: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 that an acceptable task will protect 75% of female workers and almost all male workers from persistent upper extremity fatigue and work-related 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: Biomechanical Exposure and Risk Assessment by Job

A.5.1. Job Categories and Titles

Across the 11 plants there were 30 jobs that were evaluated, grouped into six distinct job categories (Table A.5.1). Job categories were primarily composed of jobs that were in a certain area or line that had a distinct purpose such as (i) hanging birds for processing before slaughter; (ii) hanging birds for initial processing/separation after being chilled; (iii) harvesting of white meat via a cone line (manual and automatic); (iv) trimming or reworking white meat post cone line; (v) harvesting dark meat; (vi) packing chicken products; and (vii) other miscellaneous job titles. All job categories and titles were evaluated for biomechanical exposure and risk of WRMSDs. However, 14 of the 30 jobs included enough workers (N>5 per plant) to allow for comparisons between evisceration line speed categories. Live Hang and Chiller Rehang included similar biomechanical exposures but were separated since their relative line speeds and staffing levels differed considerably. Coning was separated into automatic and manual lines for the same reason. Breast Trim and Pull were divided based on whether a knife (Breast Trim) was used.

Table A.5.1.a. Number of measurements by Job Category and Title

Job Category and Title	Video Data	Wearable Data	Wearable Data Single Imputation	Total (N)
Live Hang[1]	55	32	54	55
Chiller Rehang[1]	53	29	54	53
Cone Line				203
Coning - Auto[1]	*16*	10	16	*16*
Coning - Manual[1]	*29*	*14*	27	*29*
Shoulder Cut[1]	*42*	*24*	40	*42*
Wing Round[1]	*37*	*19*	33	*37*
Breast Trim[1]	*23*	*12*	21	*23*
Breast Pull[1]	*7*	*6*	8	*7*
Tender Cut[1]	*32*	*16*	33	*32*
Tender Pull[1]	*17*	*6*	16	*17*
Trim/Rework				61
X-Ray Trim	*5*	*3*	5	*5*
White Trim	*28*	*14*	27	*28*
White Rework[1]	*15*	*10*	15	*15*
Dark Trim[1]	*13*	*7*	12	*13*
Thigh Debone				40
Thigh Hang	*12*	*7*	13	*12*
Leg Load	*4*	*3*	4	*4*
J-Cut	*4*	*3*	4	*4*
Thigh Debone[1]	*20*	*12*	20	*20*
Pack				42
Bag	*9*	5	8	*9*
Scale	*3*	*1*	3	*3*
Pack	*4*	*3*	5	*4*
Tray Pack	*5*	*3*	5	*5*
Saddlepack (White)	*6*	*4*	6	*6*
Saddlepack (Dark)	*8*	*6*	8	*8*
Whole Bird Bag	*6*	*4*	5	*6*
Vacuum Pack	*1*	*1*	1	*1*
Other				50
Wing Load	*5*	3	5	*5*
Stack	*43*	6	6	*43*
Whole Bird Hang	*1*	1	1	*1*
Style	*1*	1	1	*1*
Total	235	112	456	504

1: included in the comparison of exposure and risk assessment by line speed

Table A.5.1.b. Line speed, staffing, and piece rate by job at plants operating at three categories of evisceration line speed

		Evisceration Line Speed		
		≤145BPM	>145 to <175 BPM	≥175 BPM
Live Hang	N	20	14	20
	Job Line Speed [min-1]	148.9 (6.1)	156.3 (7.6)	181.8 (5.0)
	Staff per Line	6.1 (1.8)	6.9 (1.5)	7.8 (1.7)
	Piece Rate[1] [min-1]	27.8 (6.8)	25.3 (8.3)	25.7 (8.1)
Chiller Rehang	N	20	15	19
	Job Line Speed [min-1]	99.5 (15.8)	119.2 (41.5)	100.5 (11.7)
	Staff per Line	3.6 (1.5)	3.9 (1.1)	3.6 (0.8)
	Piece Rate[1] [min-1]	30.6 (8.4)	29.2 (7.7)	28.8 (6.8)
Coning	N	12	17	14
	Job Line Speed [min-1]	36.9 (4.9)	42.9 (6.6)	43.3 (5.4)
	Staff per Line	1.2 (0.4)	1.5 (0.5)	1.3 (0.5)
	Piece Rate[1] [min-1]	40.4 (12.6)	29.3 (7.1)	39.1 (16.9)
Breast Processing	N	11	9	9
	Job Line Speed [min-1]	36.1 (2.6)	37.5 (3.2)	39.3 (1.6)
	Staff per Line	3.2 (1.9)	2.2 (0.7)	3.9 (2.8)
	Piece Rate[1] [min-1]	17.3 (3.3)	16.9 (6.1)	17.6 (8.5)
Shoulder/ Wing Processing	N	33	19	21
	Job Line Speed [min-1]	35.8 (2.2)	37.2 (1.9)	39.8 (2.0)
	Staff per Line	2.8 (1.3)	2.7 (1.0)	2.9 (1.5)
	Piece Rate[1] [min-1]	24.7 (11.3)	27.4 (11.8)	30.9 (10.2)
Tender Processing	N	26	9	14
	Job Line Speed [min-1]	36.1 (2.3)	38.9 (4.9)	39.0 (2.5)
	Staff per Line	1.6 (0.5)	2.3 (0.7)	1.7 (0.7)
	Piece Rate[1] [min-1]	25.0 (10.6)	16.5 (5.5)	27.2 (11.7)
Trim/ Rework	N	6	31	22
	Job Line Speed[2] [min-1]	N/A	5.2 (7.3)	20.0 (34.6)
	Staff per Line	2.5 (1.0)	2.5 (1.2)	3.2 (1.9)
	Piece Rate[min-1]	13.1 (6.3)	16.5 (23.3)	16.8 (9.2)
Thigh Debone	N	13	2	13
	Job Line Speed[2] [min-1]	44.4 (6.8)	N/A	N/A
	Staff per Line	3.7 (2.4)	1.5 (0.7)	2.7 (1.6)
	Piece Rate [min-1]	25.0 (15.9)	36.1 (0)	13.6 (5.7)
Pack	N	9	7	25
	Job Line Speed[2] [min-1]	N/A	N/A	34.3 (6.4)
	Staff per Line	1.3 (0.5)	1.0 (0)	3.7 (1.9)
	Piece Rate [min-1]	28.3 (33.1)	16.2 (16.9)	30.0 (20.4)

1 piece rate defined by job in Table 4.2.1 and summarize in Table A.3.1.b.
2 job line speed defined by job in Table 4.2.1

A.5.2. Biomechanical Exposure and Risk of MSDs by Job Category

Table A.5.2.A. Mean and Standard Deviation of Biomechanical Exposures by 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)
Live Hang	54	1.6 (0.9)	28.8 (10.3)	67.4 (8.8)	4.6 (1.0)	24.4 (9.7)	39.4 (14.3)	-13.8 (7.3)	71.2 (30.7)	245.7 (95.1)
Chiller Rehang	54	1.2 (0.4)	34.9 (12.0)	60.8 (9.7)	5.0 (1.0)	25.4 (11.3)	41.6 (14.0)	-15.4 (10.2)	60.0 (20.9)	196.9 (58.0)
Coning	43	1.4 (0.5)	29.2 (6.76)	64.0 (12.4)	4.6 (0.7)	21.1 (7.7)	34.9 (11.1)	-14.5 (12.2)	50.3 (11.7)	178.5 (39.2)
Breast Processing	29	0.5 (0.2)	56.2 (18.2)	47.1 (11.8)	5.7 (1.1)	25.6 (8.5)	42.2 (11.9)	-11.7 (10.0)	53.5 (22.9)	178.2 (57.8)
Shoulder/Wing Processing	73	0.5 (0.2)	48.4 (11.1)	42.1 (12.6)	5.3 (0.7)	26.5 (8.9)	41.7 (13.6)	-5.3 (16.7)	51.0 (18.2)	167.1 (59.2)
Tender Processing	49	0.5 (0.2)	64.0 (21.0)	45.66 (10.0)	5.9 (0.7)	26.84 (9.1)	41.4 (12.0)	-13.6 (8.6)	47.2 (12.1)	157.4 (49.7)
Trim/Rework	59	0.5 (0.3)	49.4 (17.4)	37.42 (14.6)	5.0 (1.2)	26.7 (9.1)	45.6 (11.4)	-7.0 (9.5)	38.0 (13.3)	135.7 (43.1)
Thigh Debone	28	0.5 (0.3)	48.1 (12.9)	36.37 (19.6)	4.9 (0.8)	25.6 (10.0)	39.5 (13.5)	1.5 (10.5)	34.4 (9.9)	112.4 (34.6)
Packing	41	1.3 (0.7)	25.3 (13.6)	47.71 (21.7)	3.71 (1.8)	20.2 (9.9)	37.2 (11.2)	-9.2 (7.6)	40.9 (17.6)	158.1 (56.5)
Stacking	6	1.5 (0.8)	16.1 (14.9)	27.27 (18.6)	2.3 (2.2)	14.1 (8.2)	33.4 (10.6)	-11.9 (13.4)	32.5 (16.7)	137.1 (63.3)
Other	20	1.1 (0.7)	44.0 (13.7)	72.37 (12.0)	5.8 (0.9)	25.1 (12.5)	38.2 (13.0)	-15.5 (15.4)	50.6 (31.1)	176.3 (88.7)

1 Peak value is defined as the 90th% value of the distribution

Table A.5.2.B. MSD Risk Summary by Job Category

	N	Revised Strain Index (RSI)	ACGIH PFI-TLV Score[1]	ACGIH ULLF[2] (%MVC)	ULLF Ratio[3]
Live Hang	54	34.2 (15.2)	1.4 (0.5)	12 (2)	2.0 (0.7)
Chiller Rehang	54	37.8 (14.5)	1.5 (0.5)	14 (2)	1.9 (0.6)
Coning	43	28.4 (9.6)	1.2 (0.4)	13 (3)	1.7 (0.7)
Breast Processing	29	51.5 (23.6)	1.9 (0.6)	18 (5)	1.5 (0.4)
Shoulder/Wing Processing	73	44.0 (17.8)	1.6 (0.5)	20 (4)	1.5 (0.7)
Tender Processing	49	51.8 (23.3)	1.9 (0.6)	18 (3)	1.5 (0.5)
Trim/Rework	59	45.4 (18.4)	1.7 (0.5)	22 (7)	1.4 (0.6)
Thigh Debone	28	42.1 (18.3)	1.5 (0.4)	23 (7)	1.3 (0.6)
Packing	41	24.3 (14.3)	1.1 (0.5)	19 (9)	1.3 (0.9)
Stacking	6	13.9 (12.2)	0.9 (0.4)	29 (13)	0.6 (0.5)
Other	20	45.4 (27.1)	1.7 (0.8)	11 (3)	2.4 (1.2)

1 PFI-TLV Score: Peak Force Index Threshold Limit Value
2 ULLF: Upper Limb Localized Fatigue
3 ULLF Ratio: %MVC divided by the Median Muscle Activity

A.5.3. Differences in Hand Activity Level and Normalized Peak Force by Job Category and Line Speed

Table A.5.3.1. Prevalence of PFI-TLV Score>1.0 by job for workers in establishments operating at all evisceration line speeds (N=456)

	N	PFI-TLV Score>1, N (%)	PFI-TLV Score Mean (SD)
Live Hang	54	39 (72.2%)	1.4 (0.5)
Chiller Rehang	54	47 (87.0%)	1.5 (0.5)
Coning	43	31 (72.1%)	1.2 (0.4)
Breast Processing	29	26 (89.7%)	1.8 (0.5)
Shoulder/Wing Processing	73	67 (91.8%)	1.6 (0.5)
Tender Processing	49	46 (93.9)	1.9 (0.5)
Trim Rework	59	55 (93.2%)	1.7 (0.4)
Thigh Debone	28	25 (89.3%)	1.5 (0.4)
Packing	41	23 (56.1%)	1.1 (0.5)
Stacker	6	2 (33.3%)	0.9 (0.4)
Other	20	19 (95.0%)	1.8 (0.7)

Figure A.5.3.1.A. Scatter plot of Normalized Peak Force and Hand Activity Level for Live Hang workers in establishments operating at three different evisceration line speed Groups (N=54)

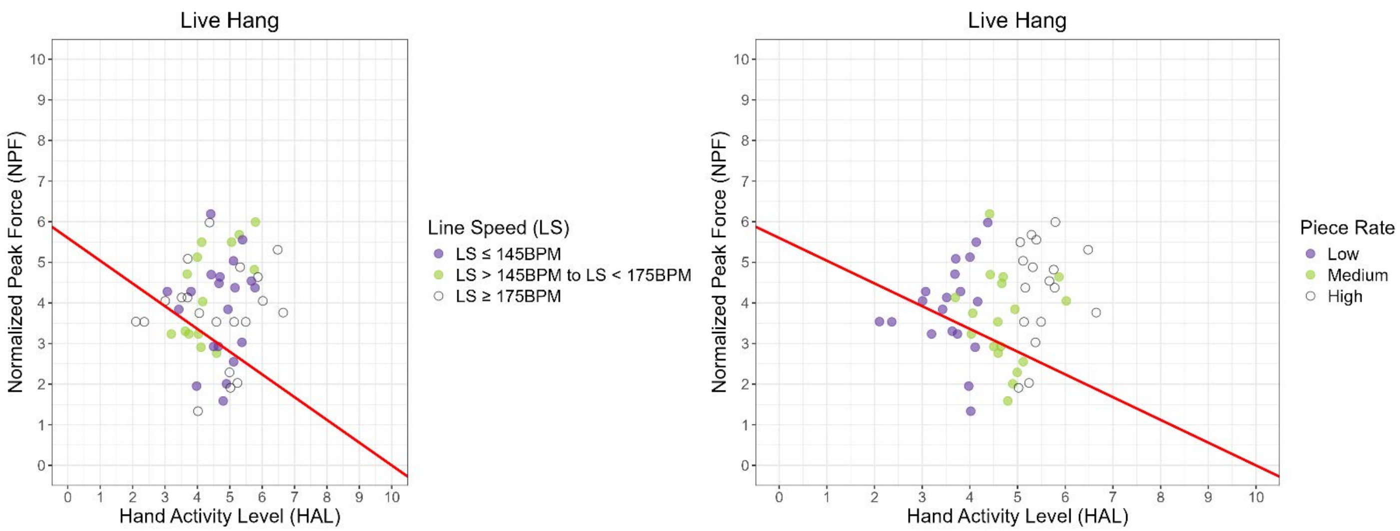


Figure A.5.3.1.b Scatter plot of Normalized Peak Force and Hand Activity Level for Chiller Rehang workers in establishments operating at three different evisceration line speed Groups (N=54)

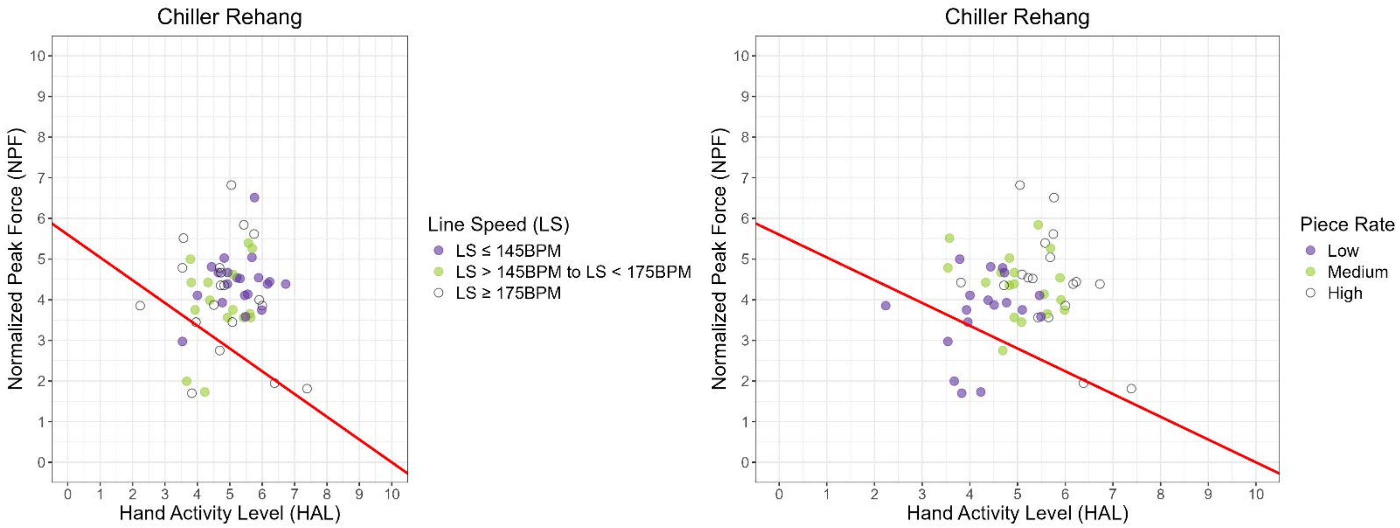


Figure A.5.3.1.c Scatter plot of Normalized Peak Force and Hand Activity Level for Coners in establishments operating at three different evisceration line speed Groups (N=43)

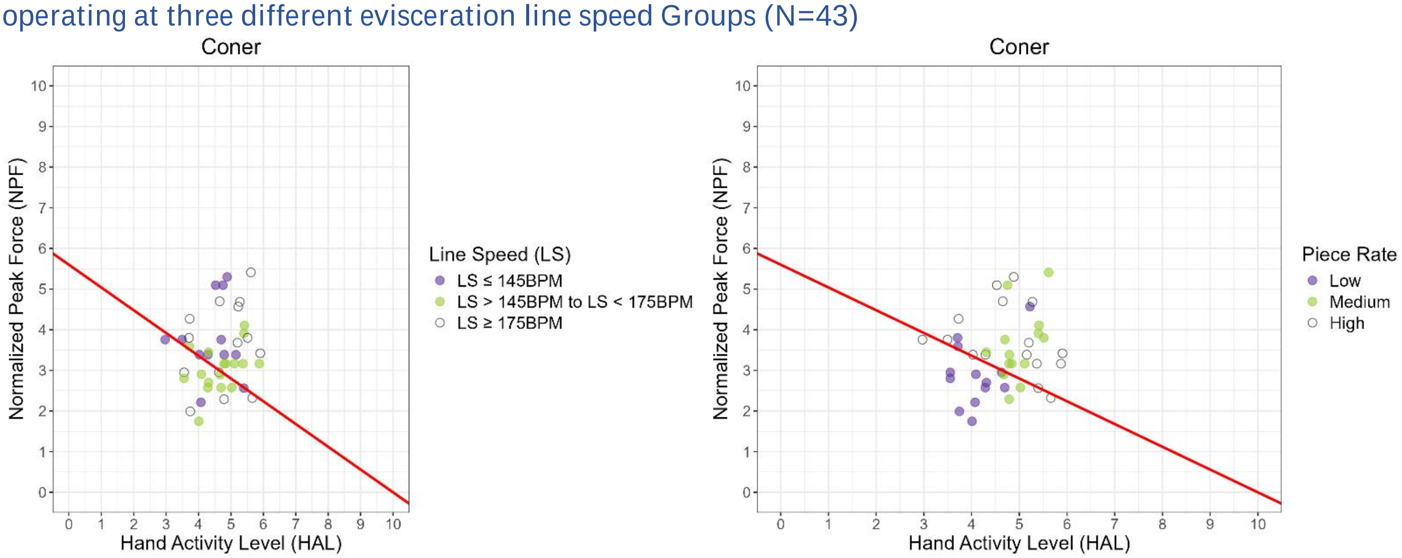


Figure A.5.3.1.d. Scatter plot of Normalized Peak Force and Hand Activity Level for Breast Processing workers in establishments operating at three different evisceration line speed Groups (N=29)

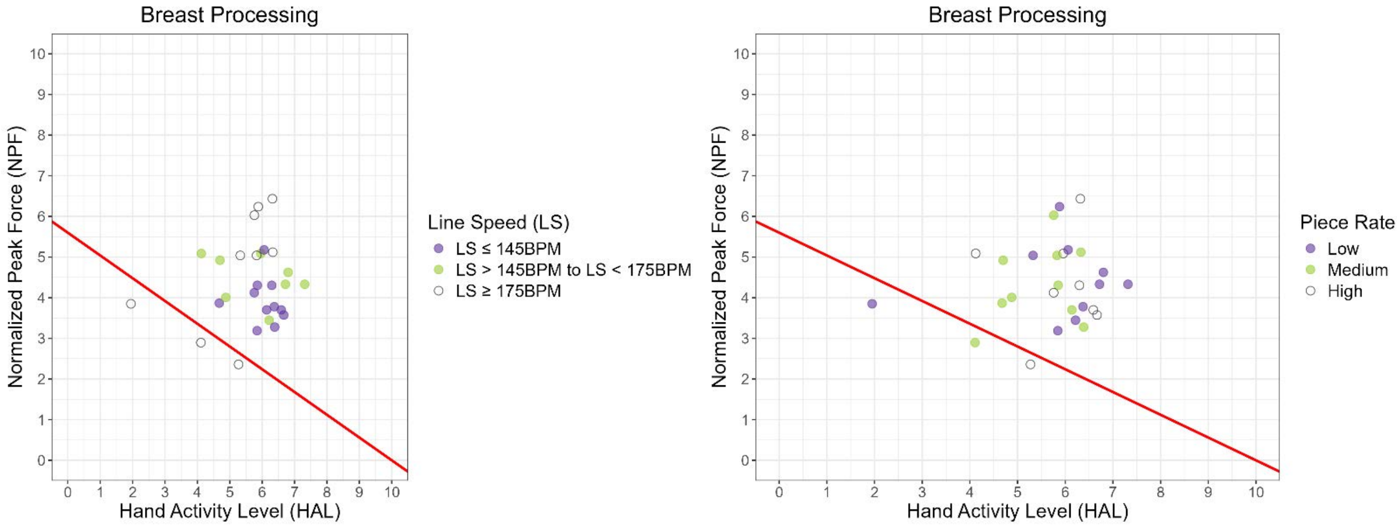


Figure A.5.3.1.e. Scatter plot of Normalized Peak Force and Hand Activity Level for Shoulder/Wing processing workers in establishments operating at three different evisceration line speed Groups (N=73)

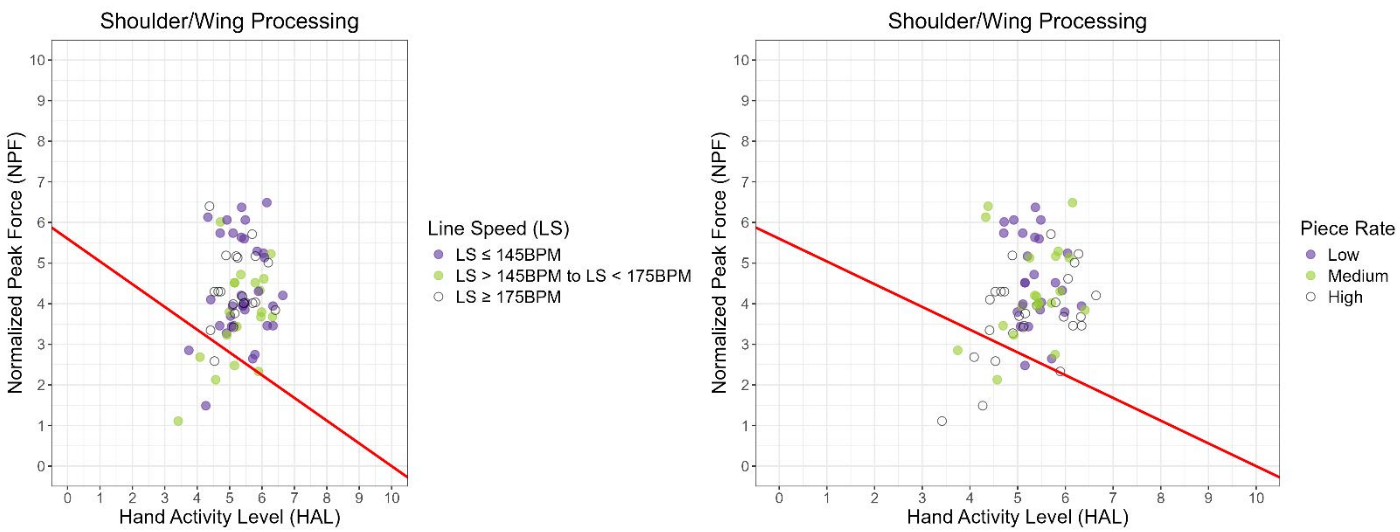


Figure A.5.3.1.f. Scatter plot of Normalized Peak Force and Hand Activity Level for Tender Processing workers in establishments operating at three different evisceration line speed Groups (N=49)

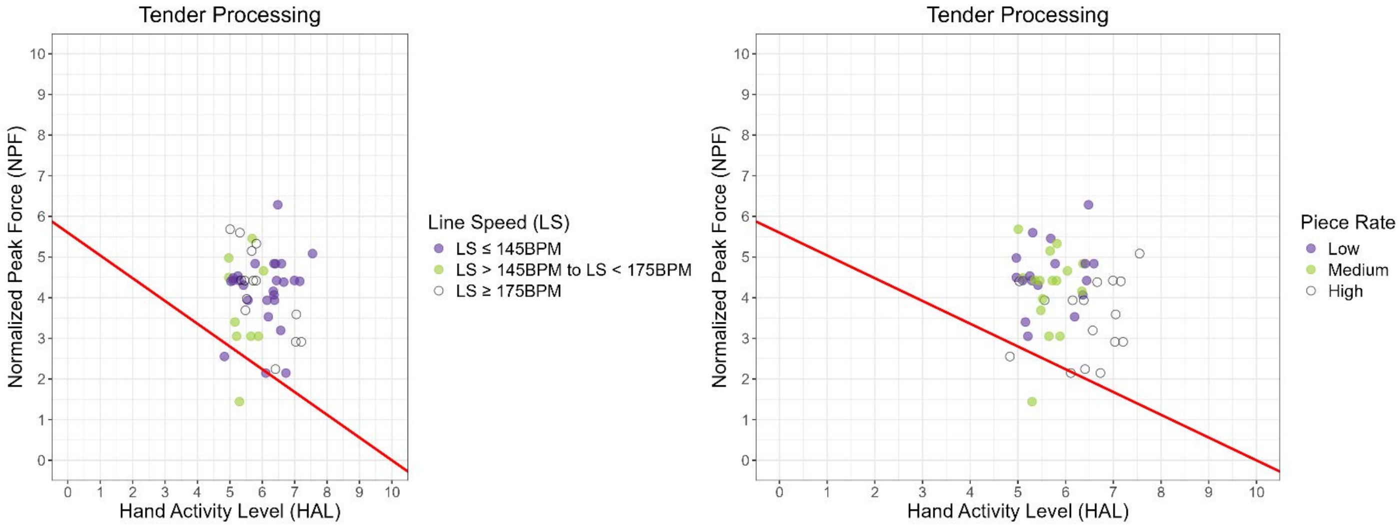


Figure A.5.3.1.g. Scatter plot of Normalized Peak Force and Hand Activity Level for Trim/Rework workers in establishments operating at three different evisceration line speed Groups (N=59)

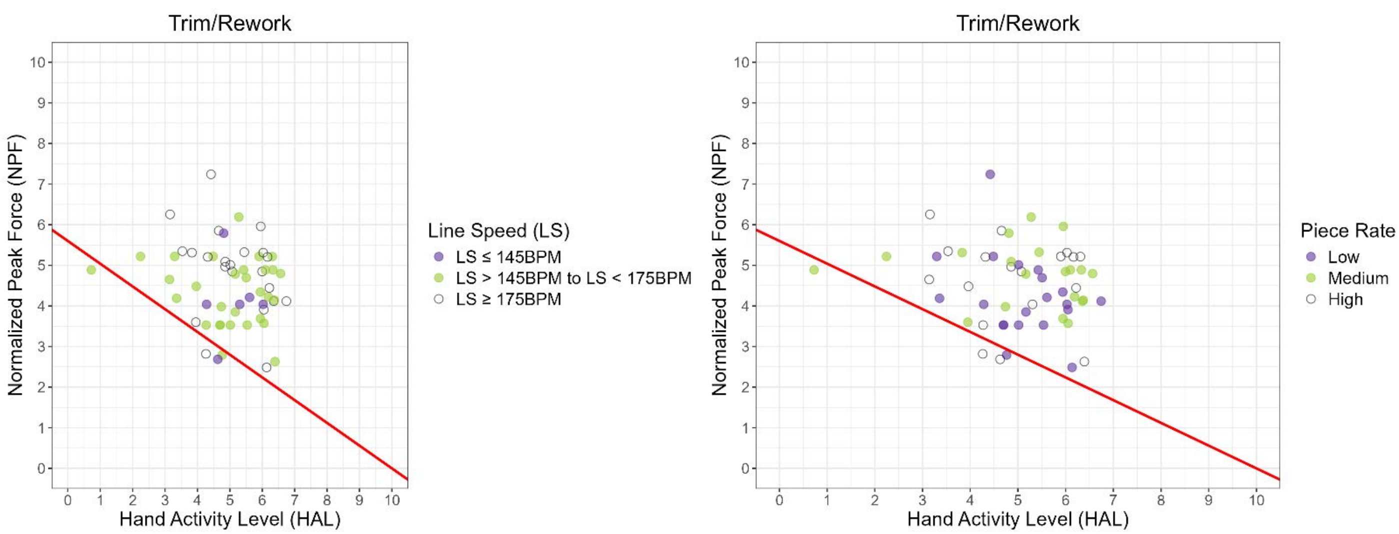


Figure A.5.3.1.h. Scatter plot of Normalized Peak Force and Hand Activity Level for Thigh Debone workers in establishments operating at three different evisceration line speed Groups (N=28)

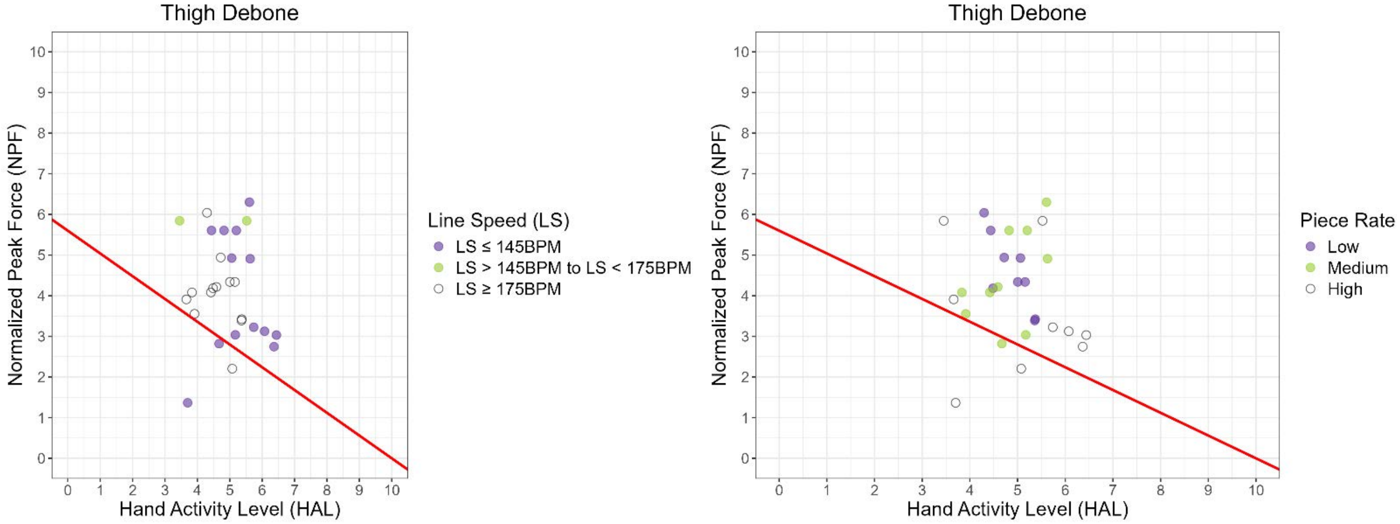


Figure A.5.3.1.i. Scatter plot of Normalized Peak Force and Hand Activity Level for Packers in establishments operating at three different evisceration line speed Groups (N=41)

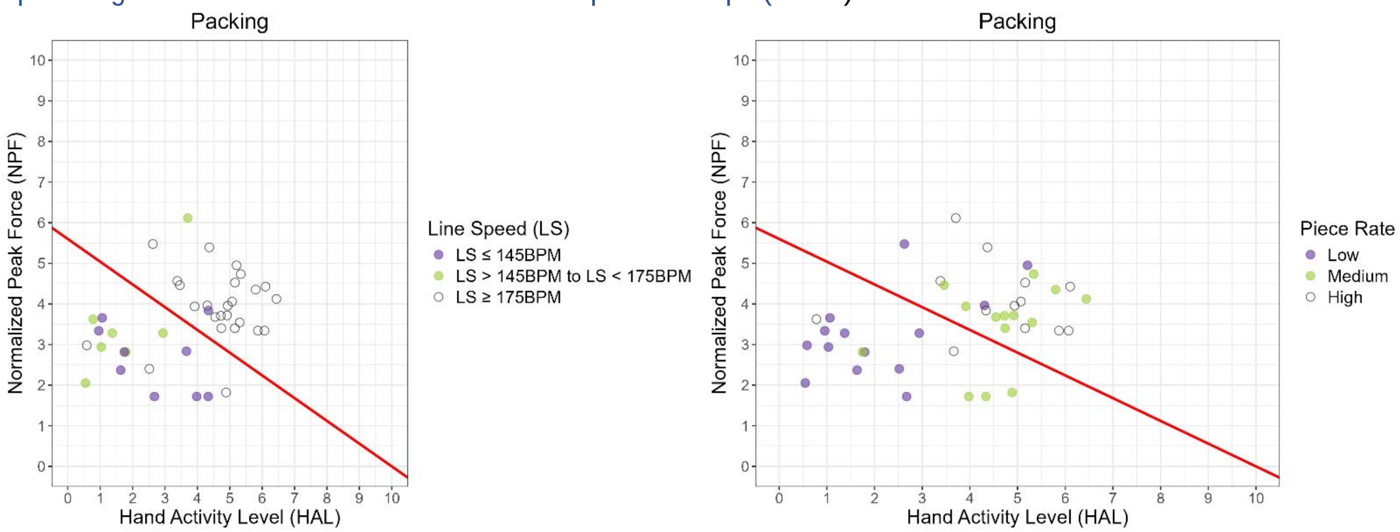


Figure A.5.3.1.j. Scatter plot of Normalized Peak Force and Hand Activity Level for Stackers in establishments operating at three different evisceration line speed Groups (N=6)

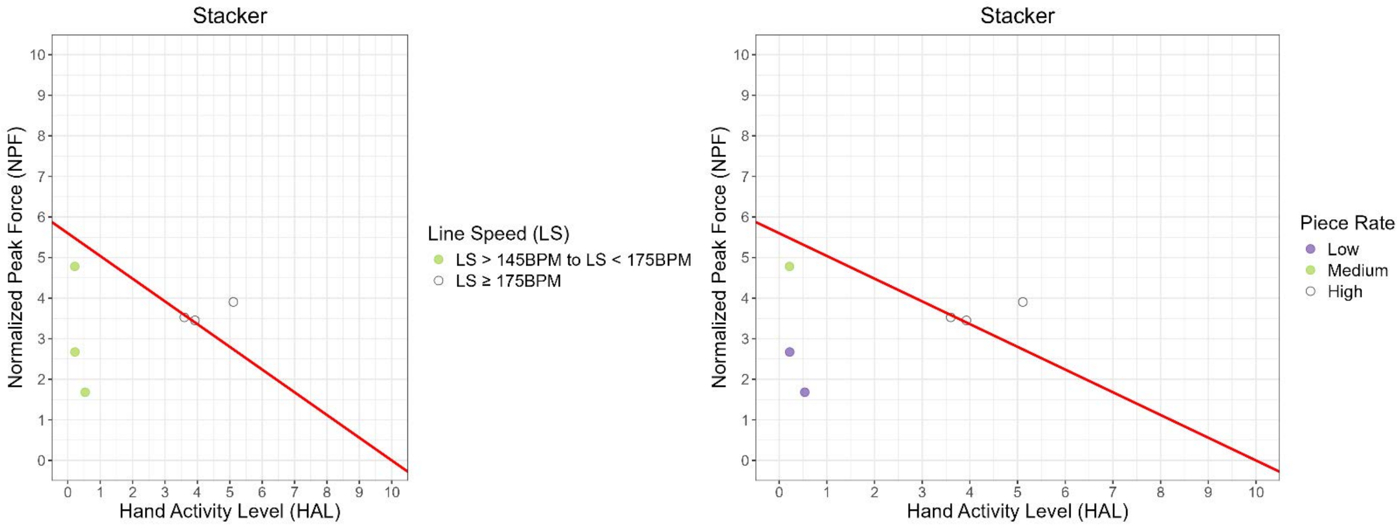
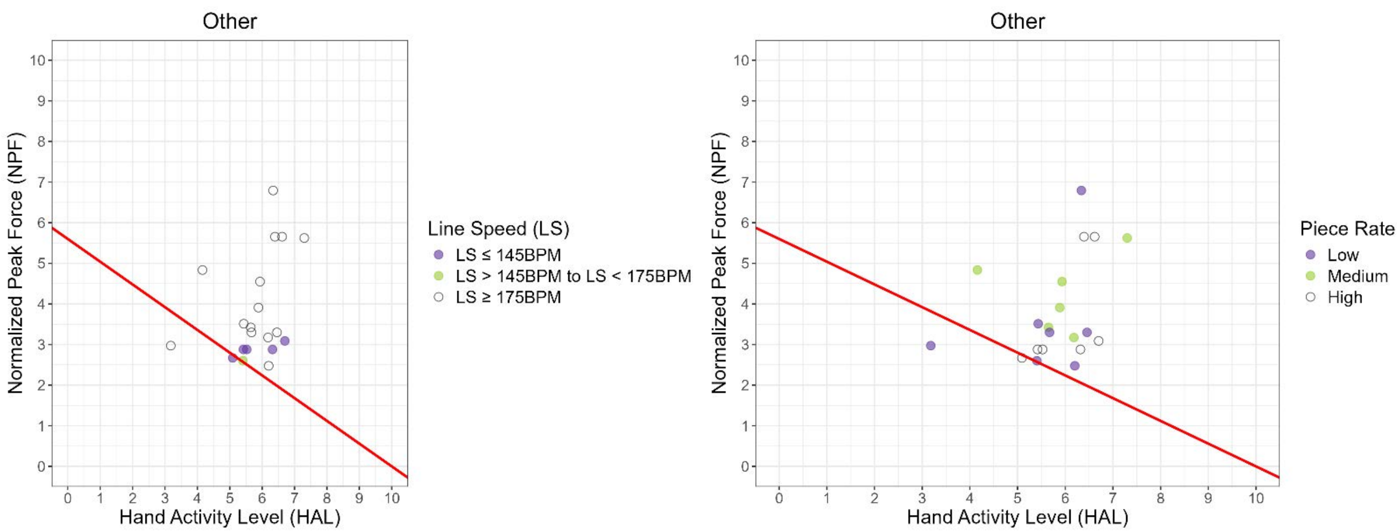


Figure A.5.3.1.k. Scatter plot of Normalized Peak Force and Hand Activity Level for all other workers in establishments operating at three different evisceration line speed Groups (N=20)



A.5.4. Comparison of MSD Risk by evisceration line speed Category and Job

Table A.5.4.1. The Association between line speed and the ACGIH Peak Force Index Threshold Limit Value (PFI-TLV Score), by job (N=454)

Job	N	PFI-TLV Score Mean Estimate (SE)[1]	PFI-TLV Score Difference (95% CI)[2]	p-value
Live Hang	56			
≤145 BPM	22	1.2 (0.2)	Referent	
>145 to <175 BPM	14	1.3 (0.2)	0.1 (-0.2 to 0.5)	0.9
175 BPM	20	1.2 (0.6)	-0.002 (-0.3 to 0.3)	0.9
Chiller Rehang	54			
≤145 BPM	20	1.6 (0.2)	Referent	
>145 to <175 BPM	15	1.2 (0.2)	-0.4 (-0.8 to -0.1)	0.3
175 BPM	19	1.2 (0.2)	-0.4 (-0.7 to -0.05)	0.3
Coning	46			
≤145 BPM	18	1.2 (0.2)	Referent	
>145 to <175 BPM	14	1.0 (0.2)	-0.3 (-0.6 to 0.1)	0.9
175 BPM	14	1.2 (0.2)	-0.1 (-0.5 to 0.3)	0.9
Breast Processing	32			
≤145 BPM	13	1.6 (0.2)	Referent	
>145 to <175 BPM	10	1.6 (0.2)	0.03 (-0.4 to 0.5)	0.9
175 BPM	9	1.4 (0.2)	-0.2 (-0.7 to 0.2)	0.9
Shoulder/Wing Processing	81			
≤145 BPM	39	1.6 (0.2)	Referent	
>145 to <175 BPM	20	1.7 (0.2)	-0.3 (-0.6 to -0.01)	0.5
175 BPM	22	1.7 (0.2)	-0.1 (-0.4 to 0.2)	0.9
Tender Processing	52			
≤145 BPM	24	1.6 (0.2)	Referent	
>145 to <175 BPM	12	1.3 (0.2)	-0.3 (-0.7 to 0.1)	0.9
175 BPM	16	1.7 (0.2)	0.1 (-0.3 to 0.4)	0.9
Trim/Rework	62			
≤145 BPM	19	1.4 (0.3)	Referent	
>145 to <175 BPM	20	1.3 (0.2)	0.3 (-0.5 to 0.4)	0.9
175 BPM	23	1.5 (0.2)	-0.2 (-0.3 to 0.6)	0.9
Thigh Debone	28			
≤145 BPM	10	1.2 (0.2)	Referent	
>145 to <175 BPM	5	1.6 (0.4)	0.3 (-0.4 to 1.0)	0.9
175 BPM	13	1.0 (0.4)	-0.2 (-0.6 to 0.2)	0.9
Packing	43			
≤145 BPM	12	0.3 (0.3)	Referent	
>145 to <175 BPM	5	0.5 (0.2)	0.1 (-0.4 to 0.6)	0.9
175 BPM	26	1.0 (0.2)	0.6 (-0.2 to 1.0)	0.03

1 Mean and standard errors using single imputation for missing NPF values adjusted for age, sex, and primary language
2 Mean difference adjusted for age, sex, and primary language

Table A.5.4.2. The association between the piece rate and the ACGIH Peak Force Index Threshold Limit Value (PFI-TLV Score), stratified by job (N=454)

Job	All, N	PFI-TLV Score Estimate (SE)[1]	PFI-TLV Score Difference (95% CI)[2]	p-value
Live Hang	56			
Low	19	0.9 (0.2)	Referent	
Medium	18	1.3 (0.2)	0.3 (-0.1 to 0.7)	0.6
High	19	1.8 (0.2)	0.2 (0.4 to 1.3)	0.01
Chiller Rehang	54			
Low	18	1.0 (0.2)	Referent	
Medium	18	1.5 (0.2)	0.3 (0.1 to 0.9)	0.2
High	18	2.0 (0.2)	0.7 (0.5 to 1.3)	<0.001
Coning	44			
Low	15	0.9 (0.3)	Referent	
Medium	14	1.3 (0.2)	0.4 (0.0 to 0.8)	0.6
High	15	1.4 (0.2)	0.4 (0.0 t0 0.9)	0.6
Breast Processing	32			
Low	10	1.8 (0.3)	Referent	
Medium	11	1.3 (0.3)	-0.5 (-1.0 to 0.1)	0.6
High	11	2.6 (0.3)	-0.2 (-0.8 to 0.4)	0.9
Shoulder/Wing Processing	81			
Low	27	1.6 (0.2)	Referent	
Medium	27	1.5 (0.2)	-0.1 (-0.5 to 0.2)	0.9
High	27	1.2 (0.3)	-0.4 (-0.8 to 0.0)	0.3
Tender Processing	52			
Low	17	1.8 (0.3)	Referent	
Medium	18	1.5 (0.3)	-0.2 (-0.7 to 0.2)	0.9
High	17	1.6 (0.3)	-0.1 (-0.8 to 0.6)	0.9
Trim/Rework	62			
Low	20	1.4 (0.3)	Referent	
Medium	21	1.6 (0.3)	0.2 (-0.2 to 0.6)	0.9
High	21	1.4 (0.3)	0.0 (-0.4 to 0.4)	0.9
Thigh Debone	28			
Low	9	1.3 (0.3)	Referent	
Medium	10	1.2 (0.3)	0.0 (-0.6 to 0.5)	>.99
High	9	1.1 (0.3)	-0.2 (-0.8 to 0.4)	0.9
Packing	43			
Low	14	0.4 (0.2)	Referent	
Medium	15	0.9 (0.3)	0.5 (0.0 to 0.9)	0.3
High	14	1.1 (0.3)	0.6 (0.2 to 1.1)	0.1

1 Mean and standard errors using single imputation for missing NPF values adjusted for age, sex, and primary language
2 Mean difference adjusted for age, sex, and primary language

Appendix 6: Association between evisceration line speed, Piece rate and Risk of MSDs: Sensitivity Analysis using Directly Measured data

Figure A.6.1. Distribution of PFI-TLV scores across workers in establishments operating at all evisceration line speeds (N= 275)

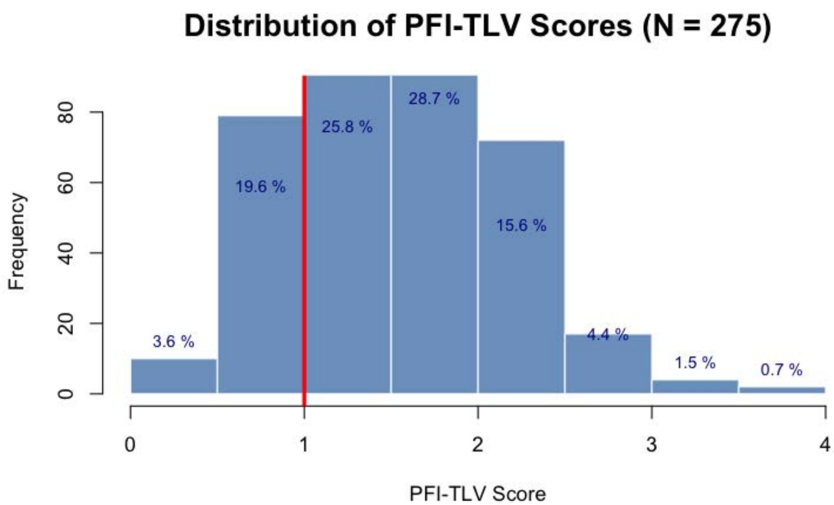


Table A.6.1. Prevalence of PFI-TLV score >1.0 by job for workers in establishments operating at all evisceration line speeds (N=275)

	N	PFI-TLV score>1, N (%)	PFI-TLV score Mean (SD)
Live Hang	33	21 (63.6%)	1.4 (0.6)
Chiller Rehang	30	24 (80.0%)	1.6 (0.6)
Coning	25	14 (56.0%)	1.2 (0.5)
Breast Processing	18	15 (83.3%)	1.9 (0.7)
Shoulder/Wing Processing	45	39 (86.7%)	1.6 (0.6)
Tender Processing	25	22 (88.0%)	1.9 (0.7)
Trim Rework	34	31 (91.2%)	1.7 (0.5)
Thigh Debone	18	15 (83.3%)	1.4 (0.5)
Packing	28	17 (60.7%)	1.1 (0.5)
Stacker	6	2 (33.3%)	0.9 (0.4)
Other	13	11 (84.6%)	1.7 (0.9)

Table A.6.2. Association between evisceration line speed, piece rate, and PFI-TLV Score adjusted for sex, age, job, work tenure, and primary language (fixed effects) and establishment (random effect)

	All, N	PFI-TLV score Mean (SE)	Difference (SE)	Adjusted p-value
Line Speed (N=244)				
≤145 BPM	79	1.4 (0.2)	referent	
>145 to <175 BPM	68	1.2 (0.2)	-0.2 (0.1)	0.3
175 BPM[2]	97	1.4 (0.2)	-0.001 (0.1)	0.9
Piece Rate[1] (N=243)				
Low	82	1.3 (0.2)	referent	
Medium	80	1.4 (0.2)	0.2 (0.1)	0.08
High[3]	81	1.5 (0.2)	0.2 (0.1)	0.01

1 Each worker's piece rate was assigned to a low, medium, or high category based on a tertile split by job
2 p=0.98 for test of trend of PFI-TLV score across the three line speed categories
3 p=0.01 for test of trend of PFI-TLV score across the three piece rate categories

Table A.6.3. The association between the line speed and the ACGIH Peak Force Index Threshold Limit Value (PFI-TLV score), stratified by job (N=244)

Job	All, N	PFI-TLV score Mean (SD)	PFI-TLV score Est. Mean	PFI-TLV score Difference[1] (95% CI)	p-value
Live Hang	32				
≤145 BPM	11	1.2 (0.3)	1.2 (0.6 to 1.7)	Referent	
>145 to <175 BPM	9	1.4 (0.3)	1.3 (0.8 to 1.9)	0.2 (-0.3 to 0.7)	0.9
175 BPM	12	1.3 (0.3)	1.2 (0.7 to 1.7)	0.0 (-0.5 to 0.5)	>.99
Chiller Rehang	29				
≤145 BPM	11	1.7 (0.2)	1.6 (1.1 to 2.0)	Referent	
>145 to <175 BPM	8	1.4 (0.3)	1.2 (0.6 to 1.7)	-0.4 (-1.0 to 0.1)	0.9
175 BPM	10	1.5 (0.3)	1.3 (0.7 to 1.8)	-0.3 (-0.8 to 0.2)	0.9
Coning	24				
≤145 BPM	4	1.2 (0.3)	1.2 (0.6 to 1.9)	Referent	
>145 to <175 BPM	11	1.0 (0.3)	0.9 (0.3 to 1.4)	-0.3 (-1.0 to 0.4)	0.9
175 BPM	9	1.3 (0.3)	1.2 (0.7 to 1.8)	-0.0 (-0.7 to 0.7)	>.99
Breast Processing	17				
≤145 BPM	8	1.9 (0.3)	1.4 (0.9 to 2.0)	Referent	
>145 to <175 BPM	4	2.0 (0.4)	1.4 (0.7 to 2.2)	-0.0 (-0.7 to 0.7)	>.99
175 BPM	5	2.0 (0.4)	1.2 (0.5 to 1.9)	-0.2 (-0.9 to 0.5)	>.99
Shoulder/Wing Processing	43				
≤145 BPM	18	1.7 (0.3)	1.4 (0.9 to 1.9)	Referent	
>145 to <175 BPM	12	1.5 (0.3)	1.1 (0.5 to 1.6)	-0.3 (-0.7 to 0.2)	0.9
175 BPM	13	1.7 (0.3)	1.3 (0.8 to 2.0)	0.1 (-0.3 to 0.6)	>.99
Tender Processing	22				
≤145 BPM	10	1.9 (0.3)	1.4 (0.9 to 2.0)	Referent	
>145 to <175 BPM	4	1.5 (0.4)	1.3 (0.5 to 2.0)	-0.2 (-0.9 to 0.5)	>.99
175 BPM	8	1.8 (0.4)	1.4 (0.7 to 2.2)	-0.0 (-0.6 to 0.6)	>.99
Trim/Rework	33				
≤145 BPM	4	1.5 (0.4)	1.2 (0.4 to 2.0)	Referent	
>145 to <175 BPM	15	1.7(0.3)	1.3 (0.7 to 1.8)	0.1 (-0.7 to 0.9)	>.99
175 BPM	14	1.8 (0.3)	1.3 (0.8 to 1.9)	0.2 (-0.6 to 0.9)	0.9
Thigh Debone	18				
≤145 BPM	8	1.6 (0.3)	1.2 (0.6 to 1.8)	Referent	
>145 to <175 BPM	1	2.0 (0.6)	1.1 (-0.1 to 2.4)	-0.0 (-1.3 to 1.2)	>.99
175 BPM	9	1.3 (0.6)	0.9 (-0.4 to 2.1)	-0.3 (-0.9 to 0.3)	0.9
Packing	26				
≤145 BPM	5	0.3 (0.4)	0.2 (-0.5 to 1.0)	Referent	
>145 to <175 BPM	4	0.8 (0.4)	0.4 (-0.3 to 1.2)	0.2 (-0.7 to 1.0)	>.99
175 BPM	17	1.4 (0.4)	0.9 (0.1 to 1.6)	0.6 (-0.0 to 1.3)	0.7

1 Mean difference adjusted for age, sex, and primary language

Table A.6.4. The association between the piece rate and the ACGIH Peak Force Index Threshold Limit Value (PFI-TLV score), stratified by job (N=243)

Job	All, N	PFI-TLV score Mean (SD)	PFI-TLV score Est. Mean[1]	PFI-TLV score Difference (95% CI)	p-value
Live Hang	32				
Low	10	1.1 (0.3)	1.0 (0.5 to 1.6)	Referent	
Medium	11	1.2 (0.3)	1.2 (0.7 to 1.8)	0.2 (0.0 to 0.3)	0.8
High	11	1.8 (0.3)	1.3 (0.7 to 1.8)	0.2 (0.0 to 0.4)	0.5
Chiller Rehang	29				
Low	10	1.2 (0.2)	1.5 (1.1 to 2.0)	Referent	
Medium	9	1.6 (0.4)	1.8 (1.0 to 2.5)	0.3 (-0.6 to 1.1)	0.9
High	10	1.8 (0.4)	2.3 (1.5 to 3.0)	0.7 (0.2 to 1.3)	0.2
Coning	23				
Low	9	0.8 (0.4)	1.3 (0.5 to 2.1)	Referent	
Medium	7	1.3 (0.6)	0.8 (-0.3 to 1.9)	-0.5 (-1.3 to 0.3)	0.9
High	7	1.3 (0.6)	0.7 (0.0 to 1.8)	-0.5 (-1.5 t0 0.4)	0.9
Breast Processing	17				
Low	7	2.0 (0.3)	1.4 (0.8 to 1.9)	Referent	
Medium	5	1.8 (0.5)	1.3 (0.4 to 2.2)	-0.1 (-1.0 to 0.8)	0.9
High	5	2.0 (0.5)	1.0 (0.1 to 1.9)	-0.4 (-1.1 to 0.3)	0.9
Shoulder/Wing Processing	43				
Low	14	1.8 (0.3)	1.3 (0.8 to 1.9)	Referent	
Medium	14	1.6 (0.5)	1.1 (0.1 to 2.2)	-0.2 (-1.1 to 0.6)	0.9
High	15	1.5 (0.5)	1.3 (0.3 to 2.4)	0.0 (-0.9 to 1.0)	0.9
Tender Processing	22				
Low	8	1.9 (0.3)	1.4 (0.9 to 1.9)	Referent	
Medium	8	1.7 (0.7)	1.2 (0.0 to 2.7)	-0.2 (-1.5 to 1.1)	>.99
High	6	1.9 (0.7)	1.4 (0.0 to 2.9)	0.0 (-0.9 to 1.0)	0.9
Trim/Rework	33				
Low	9	1.6 (0.4)	1.1 (0.3 to 1.9)	Referent	
Medium	13	1.9 (0.7)	0.3 (0.0 to 1.8)	-0.8 (-2.0 to 0.4)	0.9
High	11	1.6 (0.7)	0.0 (0.0 to 1.5)	-1.1 (-2.9 to 0.7)	0.9
Thigh Debone	18				
Low	6	1.6 (0.3)	1.1 (0.5 to 1.7)	Referent	
Medium	5	1.6 (0.5)	0.8 (0.0 to 1.8)	-0.2 (-0.9 to 0.5)	0.9
High	7	1.3 (0.5)	1.1 (0.1 to 2.1)	0.0 (-0.9 to 0.9)	>.99
Packing	26				
Low	9	0.8 (0.4)	0.3 (0.0 to 1.0)	Referent	
Medium	8	1.1 (0.6)	0.2 (0.0 to 1.3)	-0.1 (-0.9 to 0.8)	>.99
High	9	1.4 (0.6)	0.2 (0.0 to 1.4)	-0.1 (-0.7 to 0.6)	0.9

1 Mean difference adjusted for age, sex, and primary language

Appendix 7: Modeling the Relationship between Line speed and Staffing

7.1. Modeling of Biomechanical Exposure and Risk Assessment Scores as a function of Alternate Line speeds and Staffing levels

It is well known that worker exposure to biomechanical risk factors varies by both line speed and staffing levels. Each of these operational factors contributes to worker *piece rate*, i.e., the number of items handled by a worker per unit time. Within any particular job, the risk for MSDs varies by piece rate. This means that companies have at least two approaches to mitigating hazardous exposures, specifically, slowing the line or adding additional workers to jobs where such hazardous exposures are occurring. The anticipated effects of line speed and staffing levels can be estimated using actual measures of biomechanical exposure collected during Phase-2 plant visits in combination with investigator-designated line speeds and investigator-designated staffing levels. The result, when presented in tabular form can provide companies with detailed information on the risk mitigation they can achieve with specific line speed and staffing level changers.

7.2. Modeling Approach

The anticipated impacts of line speed and staffing levels on biomechanical exposure and risk of MSDs for specific jobs were modeled. Three data sets were applied to three different models. The average job-specific line speed, staffing levels, and piece rate for all sites, slower sites (<155BPM) and faster sites (>155BPM) were applied to three models and compared in three models that: 1) changed line speed; 2) changed staffing levels and 3) changed both line speed and staffing levels, were modeled and compared to threshold limits. The incremental change in line speed (Scenario 1) or staffing levels (Scenario 2) were lowered until both the ACGIH TLV-HA and the ULLF Ratio were below the acceptable thresholds of 1.0 or less. For Scenario 3, line speed and staffing levels were adjust to optimize piece rate while reducing previously mentioned risk scores to 1.0 or less.

Scenario 1: The ratio of estimated to actual line speed resulted in a scalar change that was used to reduce piece rate proportionately, keeping staffing levels constant. The scalar change in piece rate was used to proportionately change appropriate exposure values, as indicated below.

Scenario 2: The ratio of estimated to actual staffing resulted in a scalar change that was used to reduce piece rate proportionately, keeping line speed constant. The scalar change in piece rate was used to proportionately change exposure values, as indicated below.

Scenario 3: The ratio of estimated to actual staffing *and* the ratio of estimated to actual line speed each resulted in scalar changes that were used to reduce piece rate proportionately. The scalar change in piece rate was used to proportionately change exposure values, as indicated below. For demonstration purposes, access to a template worksheet has been provided.

The modeled piece rate per worker is based on (i) investigator assigned line speed with the actual observed staffing level (Scenario 1), (ii) investigator assigned staffing levels with the actual line speed (Scenario 2) or (iii) investigator assigned line speed and staffing levels (Scenario 3). For each scenario, the modeled piece rate is used to estimate exposure measures and risk scores, as described below.

Job Name	Line Speed	Worker Pace (aka Piece Rate)	Staffing
Live Hang Chiller Rehang	Number of shackles on one line that pass by a fixed point, per minute	Number of birds hung on shackles by one worker, per minute	Number of staff hanging side by side, along the same the shackle line
Cone Line (Coner) Shoulder Cut Wing Round Breast Pull Breast Trim Tender Cut Tender Pull	Number of cones on one line that pass by a fixed point, per minute	Number of birds processed (i.e., placed, cut, pulled, trimmed) by one worker, per minute	Number of staff performing the same job, working along the same the cone line
Thigh Debone White Trim Dark Trim White Rework	N/A (product is delivered to worker via conveyer, or a bin fed from a conveyer)	Number of pieces (e.g., thighs, breasts) processed (i.e., trimmed, deboned) by one worker, per minute	Number of staff performing the same job (i.e., sharing the same flow of conveyed product)

7.3. Estimated Exposure Measures

Temporal Metrics

- Duration (D) of each exertion is held constant $D_{estimated} = D_{observed}$
- Repetition rate (F) is calculated based on actual repetition rate * proportional Δ in piece rate
    - $F_{estimated} = F_{actual}$ * proportional Δ in piece rate
- Duty Cycle (DC) is recalculated as estimated repetition rate * actual exertion duration * (100/60)
    - $DC_{estimated} = F_{estimated} * D_{estimated} * 100/60$
- Hand Activity Level (HAL) is recalculated using the estimated repetition rate and duty cycle
    - $HAL_{estimated} = 6.56 \ln (DC_{estimated} * 100) [F_{estimated} 1.31 \; 1 + 3.18 F_{estimated} 1.31]$
    - DC in units of 1-100 and F measured in Hz

Muscle Activity Metrics

- Median Muscle Activity (MM50) was recalculated based on the estimated duty cycle by subtracting the proportional change in duty cycle from the actual median muscle activity
    - $MM50_{estimated} = MM50_{observed} - [(DC_{observed} - DC_{estimated}) * MM50_{observed}/100]$
- Peak Muscle Activity (PM50) was recalculated based on the estimated duty cycle by subtracting the proportional change in duty cycle from the actual peak muscle activity
    - $MM90_{estimated} = MM90_{observed} - [(DC_{observed} - DC_{estimated}) * MM90_{observed}/100]$

Wrist Posture Metrics

- Estimated APDF 50 wrist flexion posture ($PF50_{est}$) was recalculated based on the estimated duty cycle by subtracting the proportional change in duty cycle from the actual APDF 50 wrist flexion posture
  - ($PF50_{est}$) = $PF50_{act} - [(DC_{act} – DC_{est}) * PF50_{act}/100]$
- Estimated APDF50 wrist extension posture ($PE50_{est}$) was recalculated based on the estimated duty cycle by subtracting the proportional change in duty cycle from the actual APDF 50 wrist extension posture ($PE50_{est}$) = $PE50_{act} - [(DC_{act} – DC_{est}) * PE50_{act}/100]$
- Estimated median wrist posture was then determined to be the weighted average of the estimated APDF50s for wrist flexion ($PF50_{est}$) and wrist extension ($PE50_{est}$), where weights applied correspond to the actual percent time spent in wrist flexion (DC_{flx}) and wrist extension (DC_{ext}) over one-hundred
  - $P50_{est} = (PE50_{est} * DC_{ext}/100) + (PF50 * DC_{flx}/100)$
- Estimated median sagittal wrist speed was recalculated based on the estimated duty cycle by subtracting the proportional change in duty cycle from the actual median sagittal wrist speed
  - $S50_{est} = S50_{act} - [(DC_{act} – DC_{est}) * S50_{act}/100]$

7.4. Estimated Risk Assessment Scores

Estimated risk assessment scores from the RSI, ACGIH PFI-TLV score for Hand Activity, the ULLF %MVC, and the ULLF Ratio were recalculated using estimated exposure values.

Table 7.4.1. Comparison of Line Speed, Staffing, and Piece Rate by Job Category

Job	N	Line Speed [min-1]	Staff per Line	Piece Rate [min-1]
Live Hang	109	163.38	6.8	26.79
Chiller Rehang	117	105.16	3.7	29.58
Cone-Automatic	17	49.23	1.94	25.64
Cone-Manual	29	37.10	1.00	40.15
Shoulder Cut	96	37.47	3.83	17.97
Wing Rounder	66	37.19	1.94	37.79
Breast Trim	52	37.66	3.25	17.21
Breast Pull	23	37.05	2.25	18.20
Tender Trim	54	37.72	2.04	17.98
Tender Pull	38	36.97	1.32	35.09
Trim Rework	104	14.08	2.87	16.72
Thigh Debone	71	40.74	3.05	20.53
Packing	64	34.34	2.53	27.21
Stacking	63	N/A	1.17	51.19

7.5. Modeled exposure measurements and risk assessment scores based on line speed and staffing changes for select jobs

The changes in piece rate, exposure, and risk scores were similar between slower line speed sites and faster line speed site. Thus, only the results for the average of all sites are presented below.

Table 7.5.1. Example of modeled change in Exposure Measurements and Risk Scores with Staffing and Line Speed Changes for Live Hang in All Establishments

	Mean[1] Observed Line Speed and Staffing Level	Example 1 with Alternate Line Speed and Observed Staffing Level	Example 2 with Alternate Staffing Level and Observed Line Speed	Example 3 with Alternate Line Speed and Alternate Staffing Level
Inputs				
Line Speed (birds/min)	163.4	100.0	163.4	148.0
Staff (# of persons)	6.8	6.8	12.0	10.0
Outputs				
Task Line Speed (Alternate/Observed)	--	0.6	1.0	0.9
Staffing Level (Alternate/Observed)	--	1.0	1.8	1.5
Piece Rate	24.0	14.7	13.6	14.8
Exposure Measurements				
Exertion Duration(s)	1.6	1.6	1.6	1.6
Repetition Rate (reps/min)	29.2	17.9	16.6	18.0
Duty Cycle (%)	78.1	47.8	44.3	48.1
Hand Activity Level (HAL)	5.0	3.2	2.9	3.2
Median Muscle Activity (%MVC)	24.4	17.0	16.1	17.1
Peak[1] Muscle Activity (%MVC)	39.4	25.7	24.7	25.7
Median Sagittal Wrist Angle (°)	-14.0	-9.8	-9.3	-9.8
Median Sagittal Wrist Speed (°/s)	71.2	49.6	47.1	49.8
Peak[1] Sagittal Wrist Speed (°/s)	245.7	159.8	153.8	160.3
Risk Assessment Scores				
Revised Strain Index (RSI)	34.7	13.9	12.5	14.1
ACGIH PFI-TLV score [2]	1.4	0.7	0.6	0.7
ACGIH ULLF[3] (%MVC)	10.1	17.2	18.3	17.1
ULLF Ratio[4]	2.4	1.0	0.9	1.0

1 Peak value is defined as the 90th% value of the distribution
2 PFI-TLV score: Peak Force Index Threshold Limit Value
3 ULLF: Upper Limb Localized Fatigue
4 ULLF Ratio: %MVC divided by the Median Muscle Activity

Table 7.5.2. Example of modeled change in exposure measurements and risk scores with staffing and line speed changes for Chiller Rehang in all establishments

	Mean[1] Observed Line Speed and Staffing Level	Example with Alternate Line Speed and Observed Staffing Level	Example with Alternate Staffing Level and Observed Line Speed	Example with Alternate Line Speed and Alternate Staffing Level
Inputs				
Line Speed (birds/min)	163.4	100.0	163.4	147.0
Staff (# of persons)	6.8	6.8	12.0	10.0
Outputs				
Line Speed (Alternate/Observed)	--	0.6	1.0	0.9
Staffing Level (Alternate/Observed)	--	1.0	1.8	1.5
Piece Rate	24.0	14.7	13.6	14.7
Exposure Measurements				
Exertion Duration(s)	1.6	1.6	1.6	1.6
Repetition Rate (reps/min)	29.2	17.9	16.6	17.9
Duty Cycle (%)	78.1	47.8	44.3	47.8
Hand Activity Level (HAL)	5.0	3.2	2.9	3.2
Median Muscle Activity (%MVC)	24.4	17.0	16.1	17.0
Peak[1] Muscle Activity (%MVC)	39.4	27.5	26.1	27.5
Median Sagittal Wrist Angle (°)	-14.0	-9.8	-9.3	-9.8
Median Sagittal Wrist Speed (°/s)	71.2	49.6	47.1	49.6
Peak[1] Sagittal Wrist Speed (°/s)	245.7	171.3	162.5	171.2
Risk Assessment Scores				
Revised Strain Index (RSI)	34.7	14.8	13.1	14.8
ACGIH PFI-TLV score[2]	1.4	0.7	0.7	0.7
ACGIH ULLF[3] (%MVC)	10.1	17.2	18.3	17.2
ULLF Ratio[4]	2.4	1.0	0.9	1.0

1 Peak value is defined as the 90th% value of the distribution
2 PFI-TLV score: Peak Force Index Threshold Limit Value
3 ULLF: Upper Limb Localized Fatigue
4 ULLF Ratio: %MVC divided by the Median Muscle Activity

Figure 7.5.1. The relationship between job-specific line speed, staffing, and risk of MSDs (PFI-TLV score) for Live Hang and Chiller Rehang

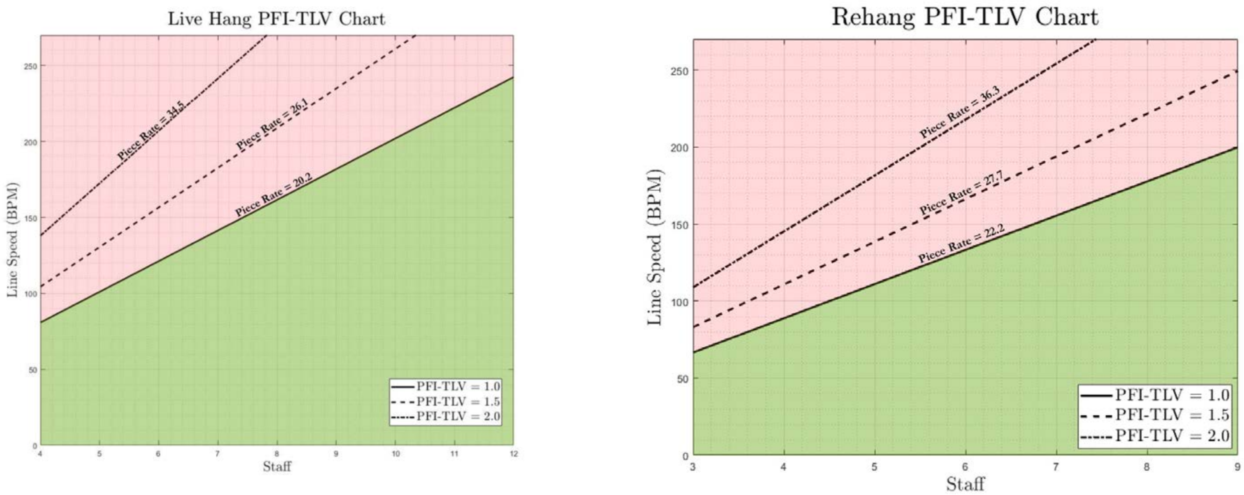


Figure 7.5.2. The relationship between job-specific line speed, staffing, and risk of MSDs (PFI-TLV score) for Coning on Manual Line and Coning on Automatic Line

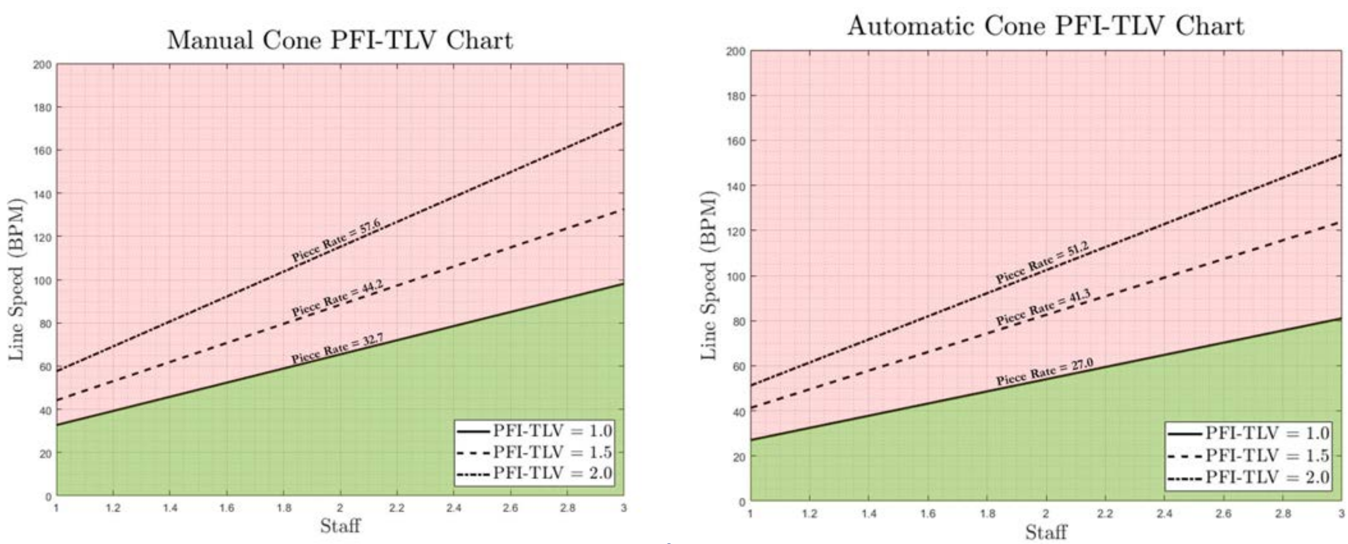


Figure 7.5.3. The relationship between job-specific line speed, staffing, and risk of MSDs (PFI-TLV score) for Shoulder Cut and Wing Round

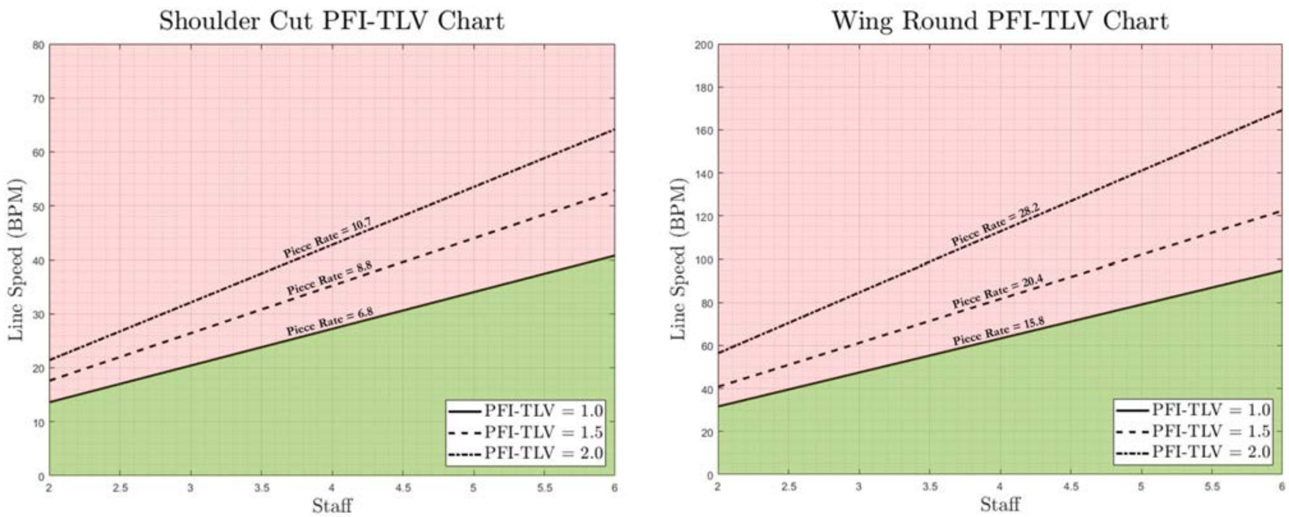


Figure 7.5.4. The relationship between job-specific line speed, staffing, and risk of MSDs (PFI-TLV score) for Breast Trim and Breast Pull

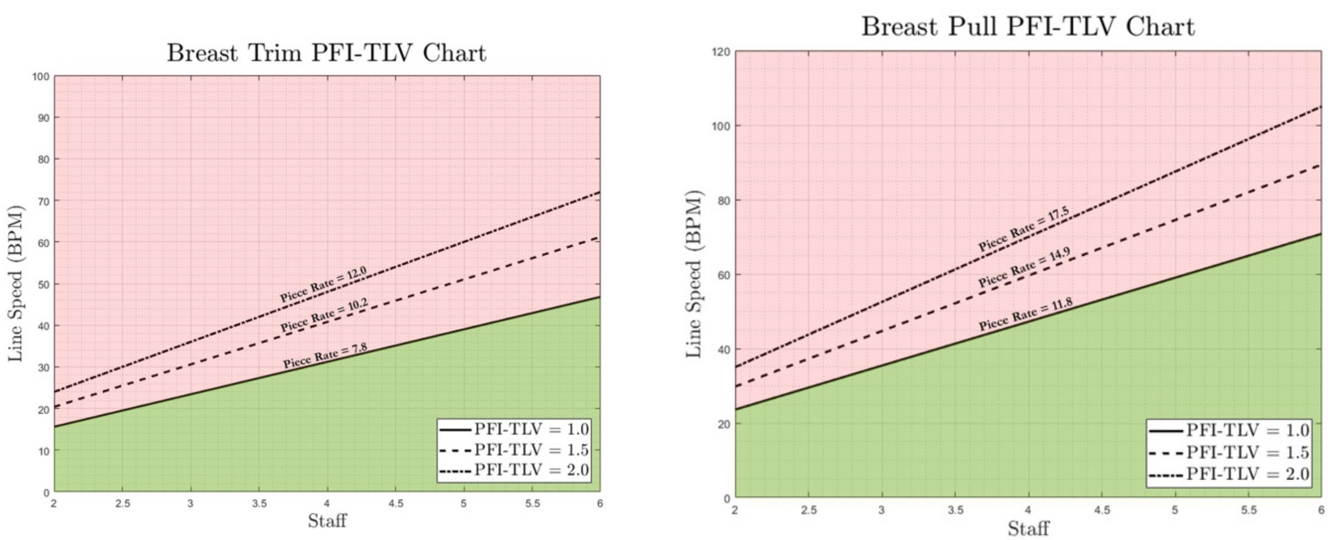


Figure 7.5.5. The relationship between job-specific line speed, staffing, and risk of MSDs (PFI-TLV score) for Tender Cut and Tender Pull

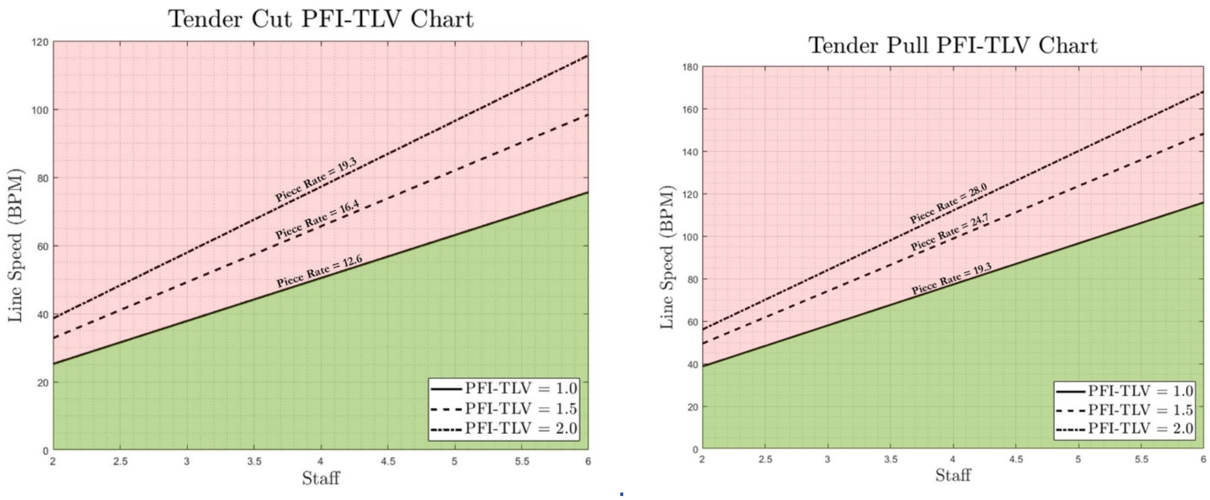


Figure 7.5.6. The relationship between job-specific line speed, staffing, and risk of MSDs (PFI-TLV score) for White Meat Rework and White Meat Trim

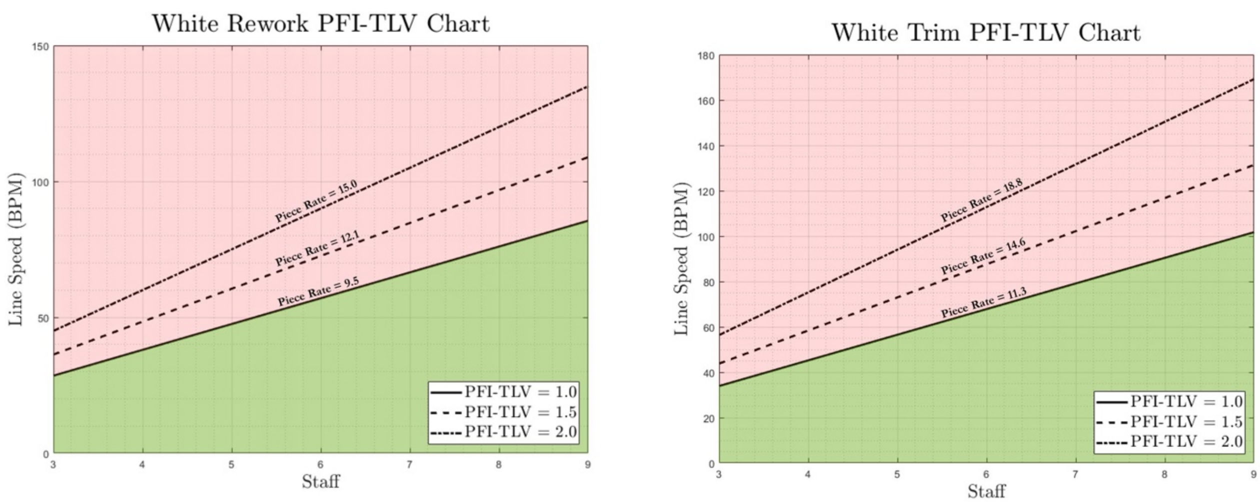
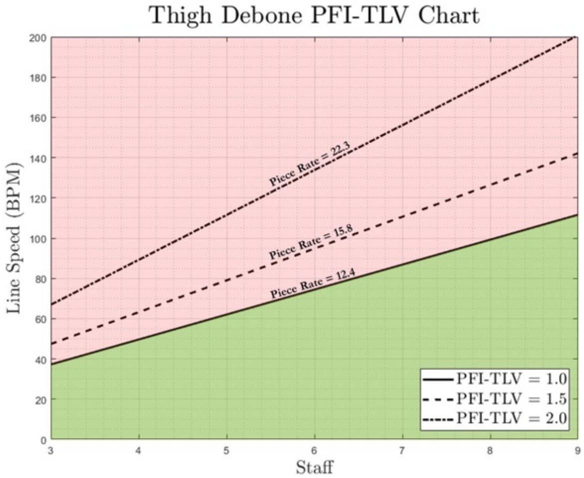


Figure 7.5.7. The relationship between job-specific line speed, staffing, and risk of MSDs (PFI-TLV score) for Thigh Debone



Appendix 8: The Relationship between Line speed, Piece rate, and Moderate to Severe Work-related pain by Job

Table 8.1. Association between line speed and the prevalence of moderate to severe work-related upper extremity pain, by job

		Moderate to Severe Work-Related Upper Extremity Pain		
	All, N	N (%)	Odds Ratio (95% CI)	p-value
Live Hang	107			
≤145 BPM	42	17 (40.5%)	1.0	
>145 to <175 BPM	25	3 (12.0%)	0.2 (0.1 to 1.0)	0.04
175 BPM	40	14 (35.0%)	0.8 (0.3 to 2.3)	0.6
Chiller Rehang	116			
≤145 BPM	42	18 (42.9%)	1.0	
>145 to <175 BPM	27	10 (37.0%)	0.6 (0.2 to 2.1)	0.5
175 BPM	47	16 (34.0%)	0.6 (0.2 to 1.7)	0.3
Coning	70			
≤145 BPM	21	7 (33.3%)	1.0	
>145 to <175 BPM	27	7 (25.9%)	1.0 (0.2 to 4.0)	>.99
175 BPM	22	11 (50.0%)	2.5 (0.6 to 10.4)	0.2
Breast Processing	72			
≤145 BPM	28	16 (57.1%)	1.0	
>145 to <175 BPM	12	6 (50.0%)	0.9 (0.2 to 4.2)	0.9
175 BPM	32	17 (53.1%)	0.6 (0.2 to 1.9)	0.4
Shoulder/Wing Processing	154			
≤145 BPM	82	41 (50.0%)	1.0	
>145 to <175 BPM	27	9 (33.3%)	0.5 (0.1 to 1.4)	0.2
175 BPM	45	18 (40.0%)	0.4 (0.2 to 1.1)	0.1
Tender Processing	88			
≤145 BPM	45	26 (57.8%)	1.0	
>145 to <175 BPM	11	6 (54.6%)	1.4 (0.3 to 6.5)	0.7
175 BPM	32	19 (59.4%)	0.9 (0.3 to 2.7)	0.8
Trim/Rework	101			
≤145 BPM	10	3 (30.0%)	1.0	
>145 to <175 BPM	54	28 (51.9%)	3.1 (0.6 to 16.1)	0.2
175 BPM	37	20 (54.1%)	4.5 (0.8 to 24.6)	0.1
Thigh Debone	70			
≤145 BPM	36	16 (44.4%)	1.0	
>145 to <175 BPM	7	3 (42.9%)	0.5 (0.1 to 3.4)	0.5
175 BPM	27	15 (55.6%)	1.3 (0.4 to 4.3)	0.7
Packing	62			
≤145 BPM	13	9 (69.2%)	1.0	
>145 to <175 BPM	12	6 (50.0%)	0.3 (0.05 to 1.9)	0.2
175 BPM	37	19 (51.4%)	0.5 (0.1 to 2.5)	0.4

1 BPM = birds per minute
2 adjusted for age, sex, job, and primary language

Table 8.2. Association between piece rate and the prevalence of moderate to severe work-related upper extremity pain stratified by job

		Moderate to Severe Work-Related Upper Extremity Pain		
	All, N	N (%)	OR (95% CI)	p-value
Live Hang	53			
Low	19	2 (10.5%)	1.0	
Medium	18	2 (11.1%)	0.9 (0.1 to 8.8)	0.9
High	16	2 (12.5%)	1.5 (0.2 to 15.6)	0.7
Chiller Rehang	50			
Low	18	7 (38.9%)	1.0	
Medium	16	6 (37.5%)	0.5 (0.1 to 2.4)	0.4
High	16	5 (31.3%)	0.4 (0.1 to 2.2)	0.3
Coning	41			
Low	13	1 (7.7%)	1.0	
Medium	14	2 (14.3%)	3.4 (0.2 to 51.6)	0.4
High	14	0 (0.0%)	0.0 (0.0 to 0.0)	>.99
Breast Processing	28			
Low	10	3 (30.0%)	1.0	
Medium	10	1 (10.0%)	0.1 (0.0 to 2.1)	0.2
High	8	1 (12.5%)	0.2 (0.0 to 2.4)	0.2
Shoulder/Wing Processing	73			
Low	24	2 (8.33%)	1.0	
Medium	22	2 (9.1%)	0.7 (0.1 to 5.9)	0.7
High	27	7 (25.9%)	2.6 (0.4 to 16.9)	0.3
Tender Processing	46			
Low	15	1 (6.7%)	1.0	
Medium	15	2 (13.3%)	2.0 (0.1 to 29.3)	0.6
High	16	2 (12.5%)	2.1 (0.1 to 30.7)	0.6
Trim/Rework	59			
Low	20	5 (25.0%)	1.0	
Medium	20	5 (25.0%)	1.0 (0.2 to 5.0)	0.9
High	19	1 (5.3%)	0.1 (0.0 to 1.1)	0.1
Thigh Debone	27			
Low	9	1 (11.1%)	1.0	
Medium	9	0 (0.0%)	0.0 (0.0 to 0.0)	>0.99
High	9	2 (22.2%)	3.4 (0.2 to 60.6)	0.4
Packing	40			
Low	13	2 (15.4%)	1.0	
Medium	14	5 (35.7%)	1.8 (0.2 to 14.1)	0.6
High	13	3 (23.1%)	1.0 (0.1 to 9.4)	0.9

Appendix 9: Peracetic Acid exposure measurement summary

Table 9.1. Descriptive summary of peracetic acid concentrations of samples collected across the 11 PAA job categories and 11 establishments

PAA Job Category	establishment	evisceration line speed category	N[1]	mean	st dev	5th%	50th%	95th %	% sample >0.40ppm
Evis: Live Hang	A	<145BPM	5	0.07	0.00	0.07	0.07	0.08	0%
Evis: Auto Rehang	I	<175 BPM	4	0.05	0.03	0.01	0.06	0.08	0%
Evis Trim	A	<145BPM	8	0.31	0.05	0.27	0.30	0.39	0%
Evis Trim	B	<145BPM	18	0.05	0.04	0.00	0.06	0.12	0%
Evis Trim	G	>145 to <175 BPM	33	0.59	0.08	0.47	0.58	0.73	100%
Evis Trim	I	<175 BPM	20	0.26	0.16	0.07	0.21	0.52	25%
Evis Trim	K	<175 BPM	25	0.22	0.03	0.19	0.22	0.26	0%
Evis Inspector	A	<145BPM	9	0.38	0.03	0.30	0.39	0.42	11%
Evis Inspector	F	>145 to <175 BPM	5	0.15	0.02	0.12	0.16	0.17	0%
Evis Inspector	G	>145 to <175 BPM	6	0.44	0.02	0.42	0.43	0.47	100%
Evis Inspector	H	<175 BPM	19	0.30	0.08	0.17	0.26	0.43	11%
Evis Inspector	I	<175 BPM	4	0.10	0.02	0.08	0.09	0.12	0%
Chiller Rehang	A	<145BPM	21	0.43	0.07	0.31	0.44	0.51	76%
Chiller Rehang	B	<145BPM	19	0.06	0.05	0.01	0.07	0.22	0%
Chiller Rehang	C	<145BPM	5	0.31	0.00	0.31	0.31	0.32	0%
Chiller Rehang	D	>145 to <175 BPM	258	0.73	0.25	0.39	0.73	1.17	93%
Chiller Rehang	E	<145BPM	14	0.02	0.01	0.00	0.03	0.04	0%
Chiller Rehang	F	>145 to <175 BPM	165	0.46	0.24	0.16	0.43	1.05	57%
Chiller Rehang	G	>145 to <175 BPM	193	0.67	0.16	0.43	0.65	0.99	100%
Chiller Rehang	H	<175 BPM	9	0.11	0.11	0.01	0.10	0.38	0%

Chiller Rehang	I	<175 BPM	38	0.30	0.05	0.22	0.30	0.37	0%
Chiller Rehang	J	<175 BPM	12	0.09	0.02	0.07	0.08	0.12	0%
Chiller Rehang	K	<175 BPM	4	0.26	0.04	0.22	0.27	0.29	0%
Debone (Dark)	A	<145BPM	24	0.50	0.20	0.32	0.41	0.99	58%
Debone (Dark)	C	<145BPM	41	0.47	0.06	0.38	0.48	0.53	85%
Debone (Dark)	E	<145BPM	159	0.08	0.06	0.00	0.08	0.17	0%
Debone (Dark)	F	>145 to <175 BPM	5	0.16	0.03	0.13	0.17	0.20	0%
Debone (Dark)	G	>145 to <175 BPM	1	0.19	.	0.19	0.19	0.19	0%
Debone (Dark)	I	<175 BPM	34	0.36	0.15	0.07	0.36	0.58	44%
Debone (Dark)	J	<175 BPM	3	0.06	0.01	0.06	0.06	0.07	0%
Debone (Dark)	K	<175 BPM	17	0.17	0.03	0.12	0.17	0.23	0%
Debone (White)	A	<145BPM	45	0.35	0.12	0.25	0.32	0.64	13%
Debone (White)	B	<145BPM	6	0.27	0.06	0.17	0.29	0.33	0%
Debone (White)	C	<145BPM	29	0.66	0.13	0.46	0.68	0.85	100%
Debone (White)	D	>145 to <175 BPM	13	0.20	0.07	0.16	0.17	0.40	0%
Debone (White)	E	<145BPM	146	0.10	0.09	0.01	0.07	0.29	0%
Debone (White)	G	>145 to <175 BPM	47	0.19	0.07	0.06	0.19	0.30	0%
Debone (White)	I	<175 BPM	31	0.17	0.08	0.05	0.15	0.29	0%
Debone (White)	K	<175 BPM	35	0.36	0.24	0.11	0.29	0.87	40%
Portioning	C	<145BPM	8	0.39	0.07	0.31	0.39	0.52	38%
Portioning	D	>145 to <175 BPM	4	0.17	0.02	0.15	0.16	0.20	0%
Grader	A	<145BPM	31	0.54	0.31	0.10	0.46	1.10	58%
Grader	B	<145BPM	28	0.21	0.06	0.14	0.19	0.35	0%
Grader	C	<145BPM	50	0.42	0.14	0.25	0.41	0.70	58%
Grader	D	>145 to <175 BPM	67	0.80	0.27	0.46	0.75	1.30	96%
Grader	E	<145BPM	87	0.36	0.20	0.09	0.40	0.67	49%

Grader	F	>145 to <175 BPM	6	0.07	0.01	0.06	0.07	0.08	0%
Grader	G	>145 to <175 BPM	24	0.22	0.05	0.16	0.22	0.31	0%
Grader	H	<175 BPM	43	0.14	0.07	0.08	0.12	0.30	0%
Grader	I	<175 BPM	7	0.02	0.03	0.00	0.02	0.06	0%
Grader	J	<175 BPM	48	0.06	0.02	0.02	0.06	0.10	0%
Grader	K	<175 BPM	34	0.28	0.17	0.06	0.25	0.59	21%
Product Wash	B	<145BPM	14	0.24	0.10	0.06	0.24	0.40	0%
Product Wash	C	<145BPM	6	0.39	0.04	0.35	0.38	0.46	33%
Bagger/Packout	A	<145BPM	38	0.44	0.25	0.06	0.37	0.96	37%
Bagger/Packout	C	<145BPM	11	0.39	0.03	0.33	0.40	0.42	45%
Bagger/Packout	E	<145BPM	25	0.14	0.04	0.10	0.13	0.19	0%
Bagger/Packout	F	>145 to <175 BPM	7	0.08	0.04	0.03	0.11	0.13	0%
Bagger/Packout	I	<175 BPM	11	0.21	0.07	0.14	0.16	0.30	0%
Bagger/Packout	J	<175 BPM	13	0.04	0.02	0.01	0.04	0.07	0%
Bagger/Packout	K	<175 BPM	73	0.25	0.12	0.08	0.22	0.46	14%

1 N is the number of 1-minute samples, as described in section 4.7.4

Figure 9.1. Mean, 25th%, 50th%, 75th%, minimum and maximum of peracetic acid concentrations (ppm) across the eleven establishments collected during personal-level sampling