Assessment of Physical Risk Factors using the Posture, Activity, Tools, and Handling (PATH) Method in Construction Glass and Glazing Work

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Abstract

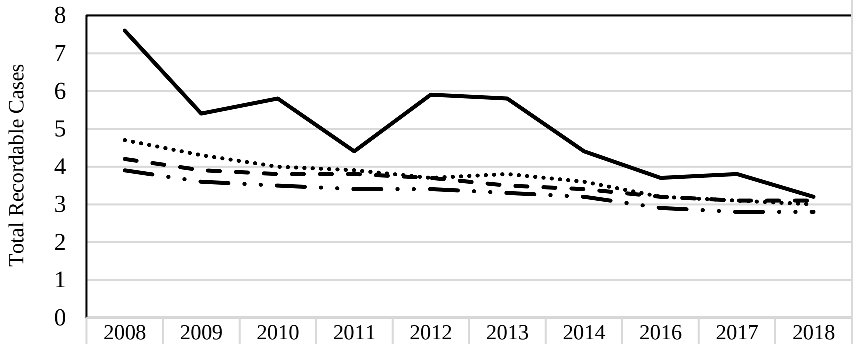
This study analysed construction glass and glazing (CGG) work tasks to determine those ergonomics risk factors that pose the greatest risk for back discomfort, pain, and injury using the PATH Method. A total of 19,300 observations were made on 30 field workers during the curtainwall, storefront, and panelling operations. Manual Material Handling (MMH) was a major activity for all tasks except finishing jobs. Carry/hold materials ranked at the top among MMH activities. CGG workers often had weights in their hands. CGG workers spent 27.2% of their time in non-neutral trunk postures, 21% of the time they had one/two elbow(s) at/above shoulder height, and 92.2 % of the time they were standing/walking. The percentage of time that CGG workers were observed in different MMH activities, holding a weight, observing in nonneutral postures differed significantly between job tasks. The results of this study provided a baseline database for future evaluations of ergonomics interventions.

Keywords: *Construction, Ergonomic Analysis, PATH method, Body Postures, Manual Material Handling*

I. Introduction

This construction industry is a heavy manual and labour-intensive industry. Construction workers are frequently exposed to awkward postures and motions such as lifting, bending, and twisting for long periods of time. Construction workers suffer from a high incidence rate of Work-Related Musculoskeletal Disorders (WRMSDs), especially low back disorders [1, 5, 9, 10, 27, 42]. The risk of back injuries varies among construction subsectors, and Construction Glass and Glazing (CGG) contractors reported the highest rate of back injuries (97.8 per 10,000 FTEs) in 2010 [9]. According to the Bureau of Labor Statistics (BLS), CGG contractors reported higher than average rates of nonfatal injury and illness [37]. Figure 1 is a summary of glass and glazing contractors' recordable cases per 100 full-time equivalent (FTE) workers, which was higher than construction, private industry, and national average in last ten years, data for the year 2015 was not available in the BLS data sheets [7]. These numbers may be underestimated due to the difficulty in establishing the work-relatedness of musculoskeletal disorders as well as injury underreporting.

In 2018, 53500 glaziers were employed, and it is projected to grow 11 percent from 2018 to 2028, much faster than the average for all occupations [6]. The labour force in the United States is also aging. The average age of construction workers jumped from 36.0 to 42.5 years old from 1985 to 2015 [10]. Back injuries are costly [20], particularly those injuries requiring longer recovery time. In addition, back injuries frequently reoccur and become chronic, and the costs increase with reoccurrence and severity [10, 30].



	2008	2009	2010	2011	2012	2013	2014	2016	2017	2018
Glass and Glazing Contractors	7.6	5.4	5.8	4.4	5.9	5.8	4.4	3.7	3.8	3.2
Construction	4.7	4.3	4	3.9	3.7	3.8	3.6	3.2	3.1	3
Private Industry	3.9	3.6	3.5	3.4	3.4	3.3	3.2	2.9	2.8	2.8
National Average	4.2	3.9	3.8	3.8	3.7	3.5	3.4	3.2	3.1	3.1

Figure 1. Total recordable cases of nonfatal occupational injuries and illnesses per 100 full-time workers for CGG workers, construction, private industry, and national average [7]

While the physical risk factors to many types of construction work have been characterized in the field [1, 3, 5, 8, 13, 15, 17, 41, 44], there is little, if any, quantitative information about risk factors in CGG work. The aim of this study was to analyse the glass and glazing work tasks to determine those ergonomics risk factors that pose the greatest risk for back discomfort, pain, and injury using the PATH (Posture, Activity, Tools and Handling) method [4].

II. METHODOLOGY

2.1. METHOD

The PATH method is an observational method that was developed by Buchholz et al. in 1996, based on the OVAKO Working Posture Analysing System (OWAS), an early observation tool that was used in the work risk assessment of highway construction workers. In comparison to OWAS, PATH not only evaluates the working postures, but also includes descriptions of workers' activity, use of tools, load handling, and types of grasp in the evaluation [5, 15, 42]. The method can be used in industries having large proportions of nonrepetitive or irregular work, such as construction, agriculture, and mining. For PATH, a task is defined as the largest group of activities that are normally performed together by a single worker to accomplish a common goal. In this study, a quantitative exposure analysis of CGG work was provided using PATH method to provide task-based estimates for construction glass and glaze specialties of the frequency workers spent in the various trunk, leg, and arm postures, as well as time spent doing MMH activities.

The PATH method is well suited for the characterization of ergonomics risks to the lower extremity, back, neck and shoulders. For each observation, posture, activity, and handling, PATH data are coded on a data collection sheet, which is customized for each combination of trade and operation [4].

With the development and application of PATH, it has become practical to quantify the percent of time that construction workers are exposed to awkward postures, various tasks and activities, and manual handling [5, 15, 16, 21, 25, 33, 34, 36, 39, 47].

PATH has also been used in other industrial sectors that involve non-repetitive job activities including retail [31], agriculture [12], fishing [24], and healthcare industries [25, 26, 35]. The PATH method has been shown to be both reproducible, given adequate observer training [35] and valid, when compared to results from studies using a bio instrumentation approach [32, 39]. Further, in a review of observational exposure assessment methods, Takala et al. [40] rated PATH as a "thoroughly developed" method with a "systematic and well-designed sampling approach" [40 cited in 21]. The PATH method is more than just postures assessment. It links the posture data to the worker activity. This cannot be done simply with instrumentation. It also ties in tool and handling information that would permit biomechanical modelling.

2.2. DATA COLLECTION

2.2.1. Data collection preparation

Observer PATH training sessions were held from 11/12/2017 to 11/15/2017 at the University of Massachusetts Lowell before starting the observation under the supervision of Dr. Buchholz and his team. It was expected that new observers would have at least 80% agreement with an experienced observer by the end of the training. Definition of operations, tasks, and activities were discussed. The stages, operations, tasks, and a list of typical activities performed within each task of glass and glazing work were determined and described according to supervisors/managers and workers interviews. The PATH data collection sheets were customized to collect data during each operation. The PATH data collection sheet was designed to collect the following information: observation info, product/operation, task, working condition, trunk posture, arm posture, leg posture, weight in hands, materials/assemblies/tools in hands, Manual Material Handling (MMH), team MMH, MMH activities, frame installation activities, glass/panel installation activities, wood/foam installation activities, loading/unloading activities, finishing jobs, tool specific activities, hand tools/materials, powered equipment, hand 1 posture, and hand 2 posture.

2.2.2. Ethical considerations

The Before starting the study, a research proposal was submitted to the University of Nebraska Institutional Review Board (IRB) that examined study details before the research began. Five construction glass and glazing companies including City Glass Company (Omaha; 70-75 employees), Bil- Den Glass (Omaha; ± 56 employees), Keystone Glass Company (Omaha, 51 employees), Glass Edge, Inc. (Lincoln; ±45 employees), and Lincoln Glass Inc. (29 employees) agreed to participate in this study. Permission to enter a construction site was obtained before research team members collected data on CGG workers performing construction tasks. CGG companies provided employee candidates from all skill levels of their team of construction field glaziers for PATH method observations. All participants showed their willingness to participate by signing the informed consent form after receiving information about the study aim, objectives, and data collection process. At the end of observation period, each participant received a gift card valued around $25 in appreciation of his participation.

2.2.3. Data collection process

All participating companies indicated that their construction projects were almost exclusively large commercial-industrial projects. Specific construction projects for data gathering were discussed with the companies at the beginning of the research project to determine how to get the best representative sample in the time and resources allowed. For any given data collection session, typically a crew of glass and glazing workers (the number of workers was different for each operation in each company) were selected, observed, and followed. The workers' selection is based on how easy it is to (i) observe what they are doing; (ii) properly assess their postures; and (iii) follow their movements as they move from point to point in the performance of their tasks [14]. According to BLS employment-population data, Nebraska had 400 glazing workers in May 2016. A sample size of n = 30 was selected and then the margin of error for this sample size was calculated based on a total glazing worker population of approximately 400 [6]. It was found that the margin of error for this sample size and the population was 9% with a confidence interval of 95% [46].

Three major operations including curtainwall, storefront, and panelling were observed over a period of approximately 3 months (one observer), for a total of 54 observation days (January, 13 days; February,19 days; and March, 22 days), of which 41 days were productive and entered to the Qualtrics software in total, spread over the five companies. That resulted in 19,300 observations for all three operations. According to Paquet, Punnett, Woskie, and Buchholz [34], for each task of an operation, observation periods of at least 6-10 days with sampling periods of 3-4 hours per day is needed (95% CI) to obtain reliable estimates for all variables.

PATH observations were collected at regular intervals (60 seconds) to describe the percent of observed time each worker was exposed to risk factors such as non-neutral postures and heavy loads. Data were collected by taking digital images using a Google Glass (Explorer Edition, Model No. XE-C) and taking notes in the field. An application called Simple Interval Timer (SIT) was installed on the observer's iPhone (iPhone 7 Plus, Model Number NN612LL/A) which was synchronized with an Apple Watch (Sport 38mm, Version 4.3.2 (15U70), Model Number MLCJ2LL/A) so that the watch notified the research analyst to take photographs at the end of every 60 second interval. On each observation day, at the end of each 60 second, a picture was taken, and note related to that picture was recorded; notes were specified with a time, date, location, operation, and tasks. All images and their related notes were examined one by one and PATH data collection survey was filled in for a picture(s) in Qualtrics software. A total number of 19300 PATH surveys were filled in. The data that support the findings of this study are available from the corresponding author, upon reasonable request.

III. RESULTS

3.1. DATA ANALYSIS

Thirty male construction field glaziers were observed over a period of approximately 3 months in 2018. All construction field glaziers were right-handed. The average temperature at which these observations took place was 32 °F (7°F, 53 °F) [43]. The storefront product was observed in two different construction sites in Lincoln over a period of 16 days. Two curtainwall projects and one panelling project were observed in three different sites in Omaha over a period of 25 days. All the projects were commercial for all participating companies. Data collected from the PATH method were statistically analysed using the Qualtrics Software (Qualtrics XM; Qualtrics, 2018), SPSS Statistics (Version 24; SPSS, 2018), and Microsoft Excel (Version 16; Office, 2016). Data were imported to the software to analyse for specific body postures and activities. The frequencies of exposures to ergonomics factors such as non-neutral postures, work height, and loads handled were determined by analysing imported data from the data collection surveys (coding sheets). Percentage of work time spent in various postures, activities, manual material handling activities, and different work heights was determined.

3.2. STUDY RESULTS

3.2.1. Job tasks

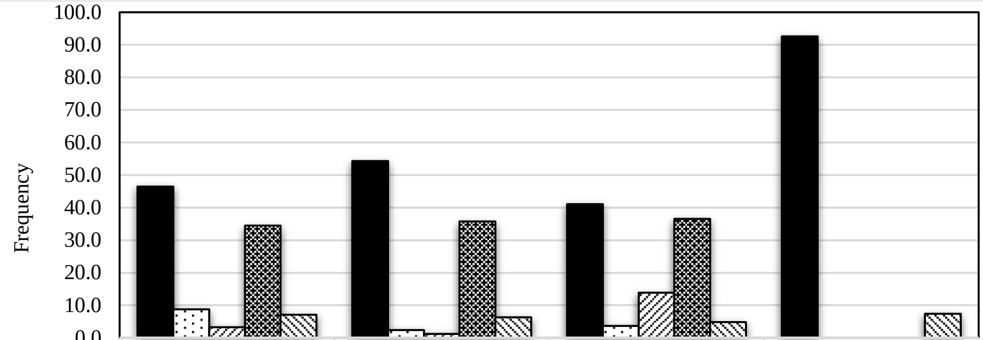
Observations took place over 41 days, and a total of 19,300 observations were made on 30 field workers performing CGG job tasks during the curtainwall, storefront, and panelling operations. Storefront operation had the highest number of observations (44.0%). According to site observations in this study, CGG workers spent a higher amount of their time installing glass/panel or temporary materials into frames (41.9%) compared to frame installation (25.9%), finishing jobs (20.7%), and loading/unloading (11.5%) (Table 1).

Table 1. Total number of observations spread over five construction sites

Product/ Operation	Number of Observation (%)	Frame Installation Observation	Glass/Panel Installation Observation	Finishing Jobs Observation	Loading/ Unloading Observation
Curtainwall	7699 (39.9%)	2002	2803	2753	141
Storefront	8498 (44.0%)	2989	2297	1239	1973
Panelling	3103 (16.1%)	0	2992	0	111
Total (%)	19300 (100%)	4991 (25.9%)	8092 (41.9%)	3992 (20.7%)	2225 (11.5%)

3.2.2. Work condition

The CGG workers spend large proportions of time working on the ground (53.9%) followed by working on a boom lift (31.5%) for all CGG tasks combined. Work conditions differed significantly between job tasks (chi-square on 9 degrees of freedom (df), p 0.0). Figure 2 shows estimates of the proportion of time that CGG workers were observed in various work conditions during CGG job tasks. CGG workers were observed most frequently working on the ground during loading/unloading tasks (92.6%) and least frequently during glass/panel installation tasks (41.0%).



	Frame Installation	Glass/Panel Installation	Finishing Jobs	Loading/Unloading
Working on the ground	46.5	54.3	41.0	92.6
Working on a ladder	8.8	2.4	3.7	0.0
Working on a scissor lift	3.3	1.2	13.9	0.0
Working on a boomlift	34.4	35.8	36.6	0.0
Not Observed/Not Sure	7.1	6.4	4.9	7.4

Figure 2. Estimate of the proportion of time that CGG workers (given as a percentage) were observed in various work conditions during CGG job tasks

3.2.3. Job task activities

For both frame installation and glass/panel installation tasks, the highest percentage of observations were given to MMH, hold, and screwing/unscrewing activities.

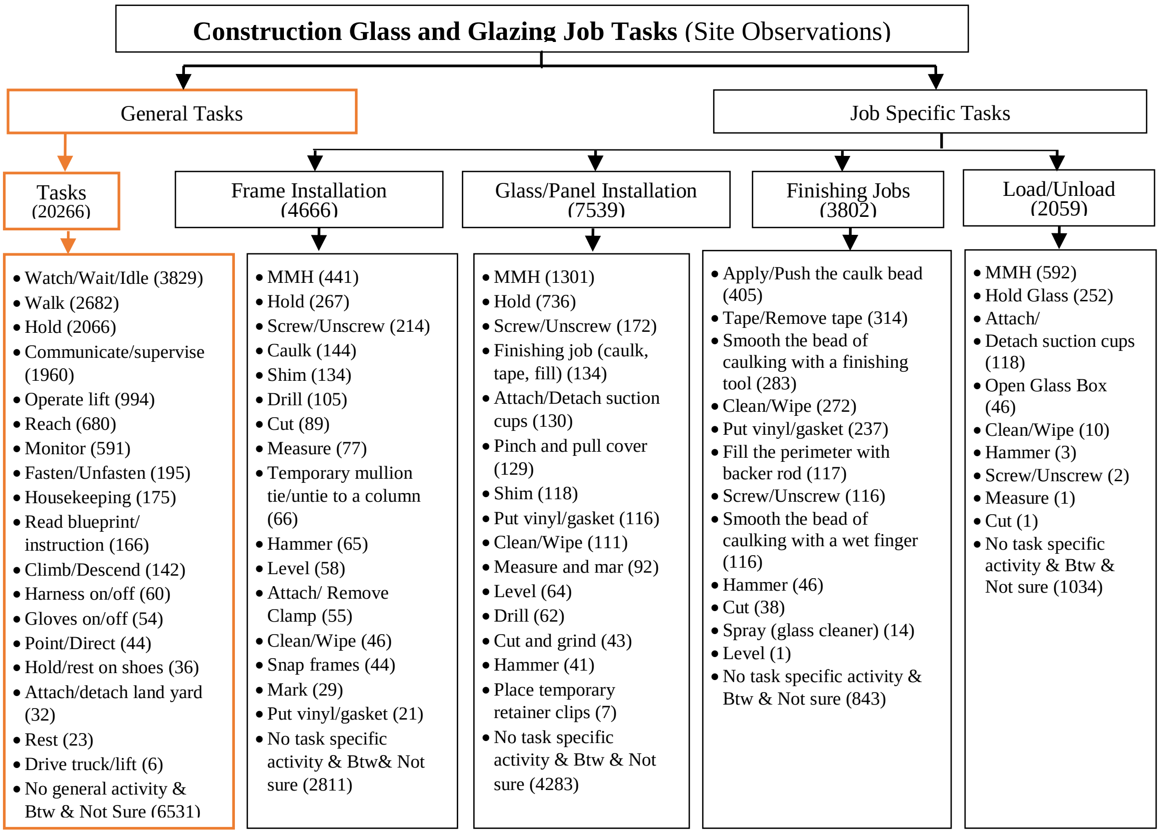


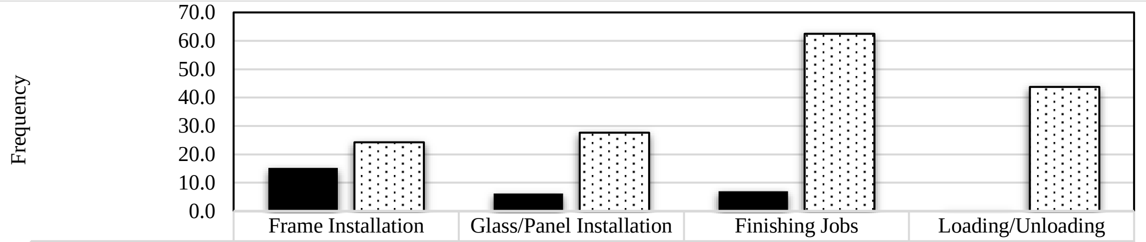
Figure 3. Distribution of observations among construction glass and glazing job tasks

The results indicated that applying/pushing the caulk bead, taping/removing tape, and smoothing the bead of caulk with a finishing tool were the activities with the highest number of observations for the finishing jobs. In loading/unloading tasks, the field glazier spent a large proportion of their time in MMH, holding the glass, and attaching/detaching suction cups (Figure 3).

3.2.4. Tool specific activities

3.2.4.1. Hand tool activities

Regarding the tool specific activities, 41.6 % of time glaziers had tools/powered equipment in their hands, and most of the time they were operating them (62.6%). The percentage of time CGG workers that were observed using hand tools or powered equipment differed significantly between job tasks (chi-square on 3 df, p 0.0) (Figure 4). Hand tools were used more frequently during finishing jobs (62.5%) and loading/unloading (43.7%) tasks compared to glass/panel installation (27.7%) and frame installation (24.3%) tasks (Figure 4). Suction cups were the most frequent hand tool used during the loading and unloading and glass/panel installation tasks.

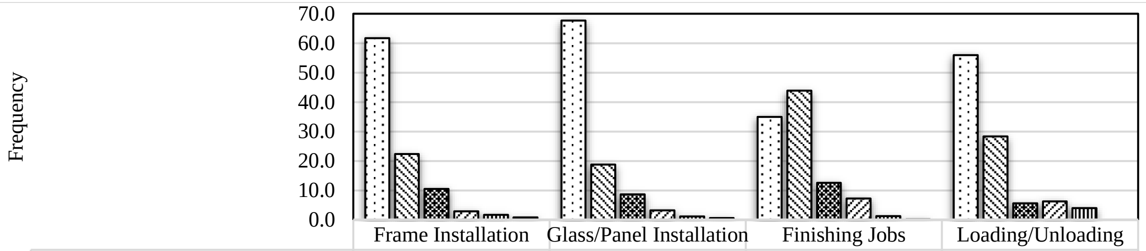


	Frame Installation	Glass/Panel Installation	Finishing Jobs	Loading/Unloading
■ Powered Equipment	15.2	6.2	7.0	0.3
□ Hand Tools	24.3	27.7	62.5	43.7

Figure 4. Estimate of the proportion of time that CGG workers (given as a percentage) were observed using hand tools and powered equipment during CGG job tasks

3.2.4.2. Powered equipment activities

Powered equipment was used less compared to hand tools; they were mostly used during frame installation tasks (15.2%) followed by finishing jobs (7.0%). The impact drill was the most common powered equipment used. Operating tools/equipment was the most frequent tool specific activity for the four observed tasks, and finishing work was the task that workers spent most of their time operating tools/equipment (43.8%) (Figure 5). The percentage of the time that CGG workers were observed in different tool-specific activities differed significantly between CGG job tasks (chi-square on 12 df, p 0.0).



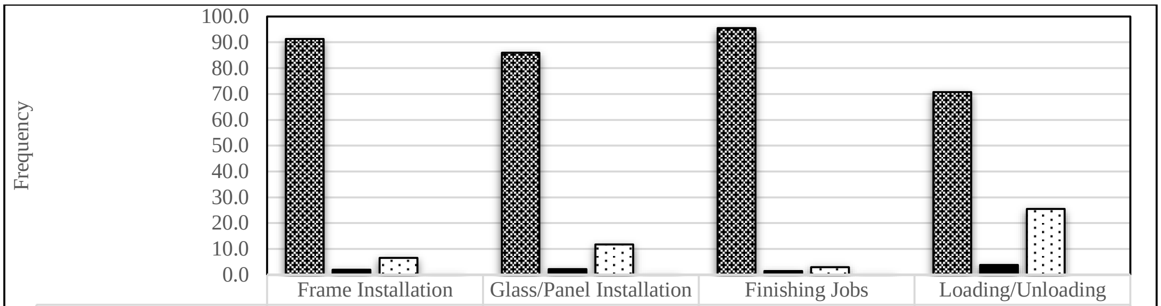
	Frame Installation	Glass/Panel Installation	Finishing Jobs	Loading/Unloading
NoTools/Equipment in Hands	61.7	67.6	35.0	56.0
Operate Tool/Equipment	22.3	18.8	43.8	28.3
Hold Tool/Equipment not Operate	10.5	8.7	12.6	5.6
Adjust Tool/Equipment	2.9	3.2	7.2	6.2
Carry Tool/Equipment	1.7	1.2	1.3	3.9
■ Not Observed/Not Sure	0.8	0.6	0.2	0.0

Figure 5. Estimate of the proportion of time that CGG workers (given as a percentage) were observed in different tool-specific activities during CGG job tasks

3.2.5. Manual material handling (MMH)

3.2.5.1. MMH during CGG tasks

MMH with two hands was more common (10.1%) than time spent working with one hand (2.2%) for all tasks combined. Loading/unloading tasks obtained the highest percentage of MMH for both 2-hand and 1-hand categories (25.5 %, and 3.8 % respectively). The percentage of time that CGG workers were observed in MMH using one hand or two hands during CGG job tasks differed significantly between job tasks (chi-square on 6 df, p 0.0) (Figure 6).

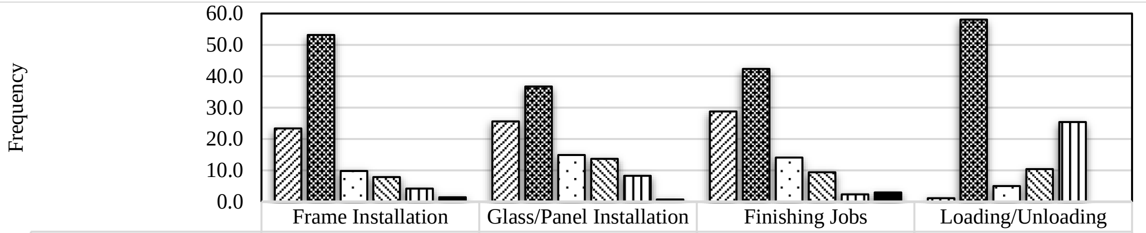


	Frame Installation	Glass/Panel Installation	Finishing Jobs	Loading/Unloading
No MMH	91.3	86.0	95.5	70.8
1 Hand	2.0	2.2	1.4	3.8
2 Hands	6.6	11.7	2.9	25.5
Not Observed/Not Sure	0.1	0.1	0.1	0.0

Figure 6. Estimate of the proportion of time that CGG workers (given as a percentage) were observed in MMH during CGG job tasks

3.2.5.2. MMH activities

Carrying/holding materials ranked at the top (45.9%) among all MMH activities followed by moving/placing activities (18.9%), for all tasks combined. The percentage of time that CGG workers were observed in different MMH activities during CGG job tasks differed significantly between job tasks (chi-square on 12 df, p 0.0). The most frequent MMH activities were moving/placing during finishing jobs (25.7%), carrying/holding (58.0%) and lowering (25.4%) during loading/unloading, pushing/pulling/dragging (14.9%) and lifting (13.7%) during glass/panel installation (Figure 7).

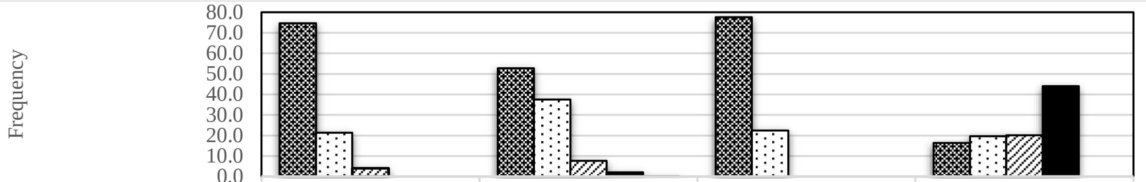


	Frame Installation	Glass/Panel Installation	Finishing Jobs	Loading/Unloading
Move/Place	23.4	25.7	28.8	1.2
Carry/Hold	53.2	36.7	42.4	58.0
Push/Pull/Drag	9.9	14.9	14.1	5.0
Lift	7.9	13.7	9.4	10.5
Lower	4.2	8.3	2.4	25.4
Not Observed/Not Sure	1.5	0.8	2.9	0.0

Figure 7. Estimate of the proportion of time that CGG workers (given as a percentage) were observed in different MMH activities during CGG job tasks

3.2.5.3. Team numbers during MMH

Field glaziers participated in both team manual material handling (50.9%), and individual handling (48.4%) and a team of two individuals was the preferable team option, accounting for 55.8% of team MMH observations. The percentage of time that CGG workers were observed in different team number categories for MMH during CGG job tasks differed significantly between job tasks (chi-square on 9 df, p 0.0). A team of two individuals was observed most frequently during glass/panel installation tasks (37.5 %), and groups of three and four were preferred for during the loading/unloading tasks (20.1%, 44.0% respectively) (Figure 8).

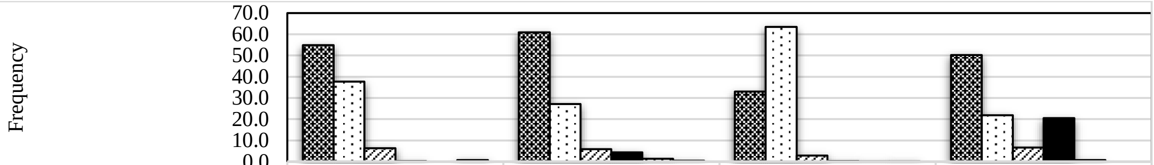


	Frame Installation	Glas/Panel Installation	Finishing Jobs	Loading/Unloading
Individual Handling	74.7	52.8	77.6	16.4
Team of Two	21.3	37.5	22.4	19.6
Team of Three	4.0	7.7	0.0	20.1
Team of Four	0.0	2.0	0.0	44.0
Not Observed/Not Sure	0.0	0.1	0.0	0.0

Figure 8. Estimate of the proportion of time that CGG workers (given as a percentage) were observed in different team numbers during MMH

3.2.5.4. Weight in hands

CGG workers were holding and handling objects that had weight 47.3% of the time, whether handling materials/tools, holding tools, or operating tools. The percentage of time that CGG workers were observed handling different load categories during CGG job tasks differed significantly between job tasks (chi-square on 12 df, p 0.0). A load category of less than 10 lbs. was observed most frequently for all tasks, and finishing jobs ranked at the top for this category (63.4 %). Loading/unloading tasks obtained the highest percentage of time spent handling weights in the 10-50 lbs. and 50-100 lbs. categories (6.6%, 20.6% respectively). Loads in the 50-100 lbs. category were rare for the other three tasks. Extra heavy loads (greater than 100 lbs.) were handled infrequently (<2%) during CGG tasks, with glass/panel installation tasks being highest percentage in this category (1.5 %) (Figure 9).



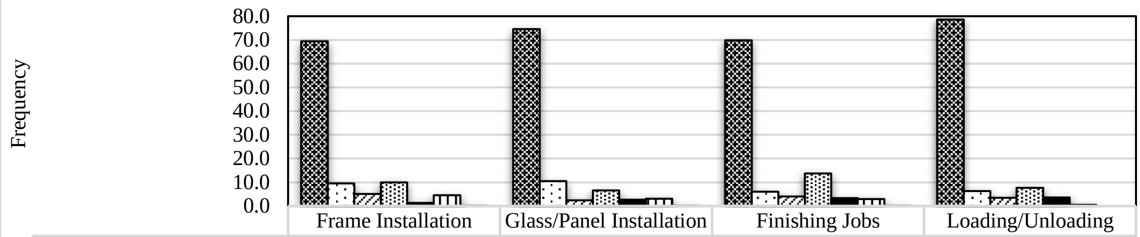
	Frame Installation	Glass/Panel Installation	Finishing Jobs	Loading/Unloading
No weight in hands	54.9	60.9	33.1	50.2
Weight < 10 lbs	37.8	27.1	63.4	21.9
10 lbs. ≤ Weight < 50 lbs.	6.3	5.9	2.9	6.6
50 lbs.≤ Weight<100 lbs.	0.3	4.4	0.3	20.6
Weight ≥ 100 lbs.	0.0	1.4	0.1	0.7
Not Observed/Not Sure	0.7	0.5	0.2	0.0

Figure 9. Estimate of the proportion of time that CGG workers (given as a percentage) were observed handling loads during CGG job tasks

3.2.6. Posture analysis

3.2.6.1. Trunk postures

Non-neutral trunk postures were observed frequently for all tasks combined (27.2%) including mild flexion (8.8%), severe flexion (3.7%), lateral bend or twist natural (9.1%), lateral bend and twist flexed (2.5%), and bend backwards (3.1%). Trunk postures differed significantly between job tasks (chi-square on 15 df, p 0.0). Neutral trunk posture was observed most frequently during the loading/unloading (78.6 %) and the glass/panel installation (74.6%). Mild flexion was observed most frequently during the glass/panel installation task (10.4%). Severe flexion was observed most frequently during the frame installation task (5.1%). CGG workers experienced lateral bend or twist postures most frequently during the finishing job tasks (13.7%). Field glaziers also experienced lateral bend or twist flexed and bend backward postures most frequently during loading/unloading (3.5%) and frame installation (4.6%) tasks respectively (Figure 10).

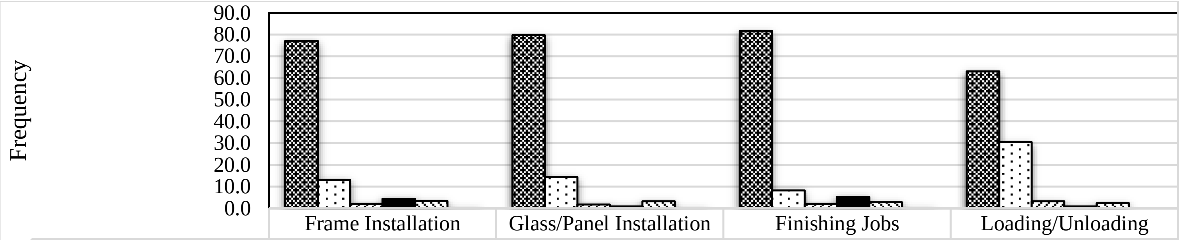


	Frame Installation	Glass/Panel Installation	Finishing Jobs	Loading/Unloading
Neutral (Flex < 20)	69.5	74.6	69.9	78.6
Mild (20 ≤ Flex ≤45)	9.5	10.4	6.0	6.4
Severe (Flex ≥ 45)	5.1	2.5	4.1	3.5
Lateral bend/Twist neutral	9.9	6.6	13.7	7.6
Lateral bend/Twist flexed	1.3	2.6	3.3	3.5
Bend Backward	4.6	3.1	3.0	0.4
Not Observed/Not Sure	0.1	0.1	0.1	0.0

Figure 10. Estimate of the proportion of time that CGG workers (given as a percentage) were observed in different trunk postures during CGG job tasks

3.2.6.2. Leg postures

Overall, CGG workers were standing/walking 92.2% of the time. Leg postures differed significantly between job tasks (chi-square on 12 df, p 0.0). The most frequent leg posture experienced by CGG workers was flex < 35 (stand) for all CGG tasks; finishing job tasks ranked the top (81.6%) in this category followed by glass/panel installation (79.7%), frame installation (77.1%), and loading/unloading (63.0%) tasks. Walk/run postures were observed most frequently during loading/unloading tasks (30.5%), and least frequently during finishing job tasks (8.3%). Squat and kneel postures also were experienced most frequently during loading/unloading (3.2%) and finishing jobs (5.3%) respectively. CGG workers experienced other rare postures, including one leg in the air/one foot not supported, lunge (1 knee >35), sitting on a raised seat, sitting on the ground, crawling, lying on the chest, lying on either side, leaning forward, and leaning to either side (Figure 11).

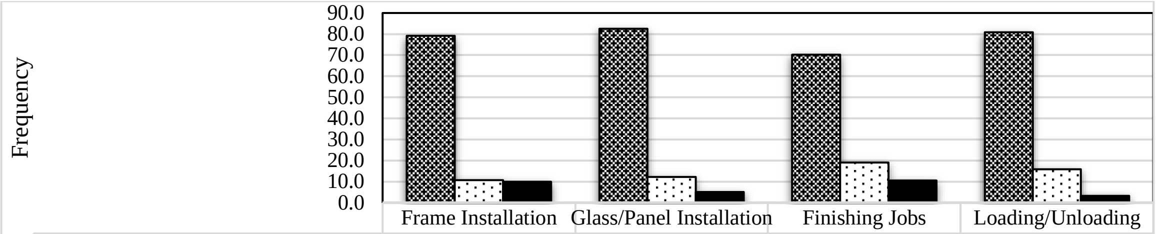


	Frame Installation	Glass/Panel Installation	Finishing Jobs	Loading/Unloading
Stand (Flex < 35)	77.1	79.7	81.6	63.0
Walk / Run	13.1	14.4	8.3	30.5
Squat (Shallow+Deep)	2.0	1.8	1.8	3.2
Kneel (Vertical+Sitting)	4.4	0.8	5.3	0.9
Other	3.3	3.3	2.8	2.4
Not Observed/Not Sure	0.1	0.1	0.1	0.0

Figure 11. Estimate of the proportion of time that CGG workers (given as a percentage) were observed in different leg postures during CGG job tasks

3.2.6.3. Arm postures

Site observation results showed CGG workers had one/two elbow (s) at/above shoulder height 21% of their time. Arm postures differed significantly between job tasks (chi-square on 6 df., p 0.0). Arm postures at or above shoulder height (one elbow at/above shoulder height) were observed most frequently during finishing job tasks (19.1%) and least frequently during frame installation tasks (10.7%). Two elbows at/above shoulder height were observed most frequently during finishing job tasks (10.6%) and least frequently during loading/unloading tasks (3.3%) (Figure 12).

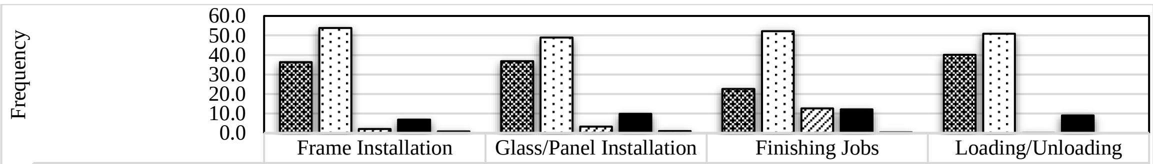


	Frame Installation	Glass/Panel Installation	Finishing Jobs	Loading/Unloading
Elbows below shoulder height	79.3	82.6	70.2	80.9
One elbow at/above shoulder height	10.7	12.3	19.1	15.9
Two elbows at/above shoulder height	10.0	5.1	10.6	3.3

Figure 12. Estimate of the proportion of time that CGG workers (given as a percentage**)** were observed in different arm postures during CGG job tasks

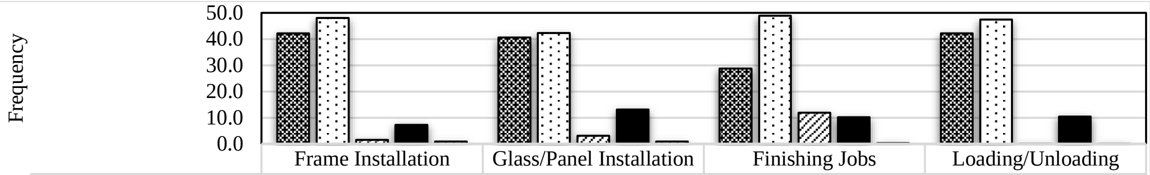
3.2.6.3. Hand postures

CGG workers spent a large proportion of their time experiencing non-neutral hand postures. The majority of their time was spent grasping and pressing with the right hand (65.2%) or the left hand (60.6%). Hand postures differed significantly between job tasks (chi-square on 9 df, p 0.0). The power grasp posture (right-hand) was the most the frequently observed posture for all CGG tasks including frame installation (53.8%), finishing jobs (52.2%), loading/unloading (50.8%), and glass/panel installation (48.9%) tasks. CGG workers also experienced precision grasp and finger press postures most frequently during finishing jobs (12.7%, 12.2% respectively) (Figure 13). The power grasp posture was the most frequently observed in all CGG tasks for the left hand. The proportion of the time that CGG workers experienced grasp posture in different CGG tasks were as follows: finishing jobs (48.9%), frame installation (48.0%), loading/unloading (47.4%), and glass/panel installation (42.3%) tasks. Precision grasp was observed most frequently during the finishing job tasks (11.9%), and finger press posture was experienced most frequently during the glass/panel installation (13.1%) tasks (Figure 14).



	Frame Installation	Glass/Panel Installation	Finishing Jobs	Loading/Unloading
Empty Right-Hand	36.3	36.8	22.6	40.1
Power Grasp	53.8	48.9	52.2	50.8
Precision Grasp	2.1	3.4	12.7	0.1
Fingers Press	6.9	9.9	12.2	9.1
Not Observed/Not Sure	0.9	1.0	0.3	0.0

Figure 13. Estimate of the proportion of time that CGG workers (given as a percentage) were observed in different right-hand postures during CGG job tasks



	Frame Installation	Glass/Panel Installation	Finishing Jobs	Loading/Unloading
Empty Left-Hand	42.2	40.7	28.7	42.1
Power Grasp	48.0	42.3	48.9	47.4
Precision Grasp	1.6	3.1	11.9	0.1
Fingers Press	7.3	13.1	10.2	10.4
Not Observed/Not Sure	1.0	0.9	0.3	0.1

Figure 14. Estimate of the proportion of time that CGG workers (given as a percentage) were observed in different left-hand postures during CGG job tasks

IV. Conclusions and Discussion

The PATH observational method was used to quantify the percent of the time that CGG workers were exposed to awkward postures, various tasks and activities, and manual handling. Three body postures were recorded: trunk, leg, and arm. Observation is a systematic recording of postures in a workplace (i.e., region, frequency, severity, duration) [11]. Observational tools cause minimal disturbance to worker task performance, allowing for assessments of tasks in real settings, and need minimal instrumentation for field investigations [42]. According to Xu, Chang, Faber, Kingma, and Dennerlein [45], although posture observation is not as accurate or as precise as using laboratory equipment, such as cinematographic systems or electromagnetic field-based motion tracking systems, it still has been widely adopted by ergonomists to assess mechanical exposure [22].This is widely adopted because posture observation has a low cost, does not require specialized equipment, does not involve strong interference with the normal operations of those being surveyed, and can be done in the field [2, 19, 23]. Using the PATH method, the posture data were linked to the CGG workers' activities, and this cannot be done easily with instrumentational methods.

Overall, the ergonomics hazards identified for CGG job tasks were awkward postures (the large percentage of time workers spent in non-neutral trunk, leg, and arm postures), force (MMH activities), cold weather, whole body vibration (working in boom lifts), hand-arm vibration (operating powered equipment such as drills, saws, powered caulking guns), and contact stress (operating manual caulking gun, and tooling knife). The frequency of ergonomics exposures differed significantly among CGG job tasks observed in this study, which could be the result of differences in task requirements. During the loading/unloading and glass/panel installation tasks, CGG workers were involved more in heavy MMH compared to the frame installation and finishing jobs. Finishing jobs and frame installation tasks required more hand tools/equipment usage.

Although CGG workers were observed 53.9% of their time working on the ground, they also spent 31.5% of their time working in boom lifts which could be a source of ergonomics risk factors such as noise and vibration. Vibration as a physical ergonomics risk factor may increase a worker's risk of back injury. Aerial lift vibration reduction and increased stability would be an intervention to reduce risk associated with this ergonomics risk factor.

MMH was the most frequent activity for frame installation, glass/panel installation and loading/unloading activities. MMH with two hands was more common than MMH with one hand for all tasks. One-hand MMH was observed most frequently during loading /unloading tasks using a suction cup which put more pressure on one side and may cause damage to a worker's back and shoulder. Carrying/holding materials ranked at the top (45.9%) among all MMH activities followed by moving/placing activities (18.9%), for all tasks combined. MMH may be reduced by using mechanical equipment such as carts, boom trucks, powered lifts, and robots (carts, robots, etc.) as much as possible to reduce the frequency of MMH. CGG workers preferred to do MMH in a smaller team due to the difficulty of team cooperation; one individual mistake could result in whole team members' injury/incident. Although most of the time loads handled during MMH activities were light (less than 10 lbs.), in some cases weight exceeded maximum recommended weight limits (50 lbs.) which may increase a worker's risk of back injury. CGG workers were most frequently exposed to heavy loads greater than 50 lbs. during loading /unloading tasks and extra heavy loads (greater than 100 lbs.) during glass/panel installation tasks. Safer designs for construction products and materials (lighter and smaller glass), safe lifting technique training, job rotation and teamwork training are possible options to reduce heavy lifting, though other construction methods should be investigated. Several authors have stressed manual handling as a main cause of back injuries in construction industry [3, 5, 8, 13, 15, 28, 29, 38].

In addition to MMH, frequent awkward trunk, leg, and arm postures recorded during CGG work may increase workers' risk of back and shoulder injuries. Most of the time CGG workers were grasping and pressing with the right hand (65.2%) or the left hand (60.6%) which may result in upper body WRMSDs because of vibration and contact stress. Better pre-fabrication assembly design that require significantly less overhead drilling, screwing, holding posture and force application could be considered as an ergonomics intervention to reduce the risk of back injury.

PATH data collection was performed during the cold season in Nebraska (January, February, and March); other ergonomics exposures may arise during hot weather that may affect the incident rates of injuries/illnesses among CGG workers.

The results of this study provided a baseline database for future evaluations of ergonomics interventions to eliminate or reduce the risk of WRMSDs in CGG work. The results of this study constructed fundamental knowledge on WRMSDs risks in CGG tasks and such knowledge will be critical in designing effective ergonomics interventions to reduce physical stress and back injury potential.

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