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Case Study of an Ergonomic Assessment for Aircraft Hull Assembly

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Abstract: This was a case study performed as part of an effort to analyze potential physiological risks to workers operating on one stage of the aircraft hull assembly process. Video footage of two workers engaging in part of this task was utilized. An ergonomic assessment was conducted in line with a proprietary ergonomic assessment tool to establish the potential level of risk associated with the postures required to complete the task. Major findings from this assessment showed that shoulders, neck, upper arms, wrists, grip, and the back were at the highest risk for injury. Additionally, the lower hips, lower arm, and lower extremities were at moderate risk for pain and injury. In addition to the risk posed by the postures, the workplace layout simultaneously allowed the workers to perform the task while also resulting in unstable positions that presented a risk of fall. Based upon these findings several possible solutions were considered which may reduce the risk of incidence or injury.

Keywords: Ergonomic Evaluation, Case Study, Aviation Assembly

1. Introduction

The facility under observation was an industrial aircraft assembly building where the hulls of aircrafts are constructed. The primary tool was a large semi-circular basin in which skins are placed and trimmed to size. This step in the process of aircraft assembly takes a full standard 8-hour workday with one or two employees depending on the size of the hull that is being prepared. The objective of the study was to analyze available video footage to understand potential risks that may result from assembling the hull and provide recommendations for risk reduction.

Musculoskeletal disorders (MSD's) consist of numerous types of chronic ailments involving inflammation or degeneration of joints, tendons, and ligaments (Buckle & Devereux, 2002). These disorders can impact a person's mobility, ability to live comfortably and may result in necessary time off from work to recover (Harcombe, McBride, Derrett & Gray, 2009). Many MSD's are related to engaging in repetitive or straining tasks within a work-place setting (Barbe & Barr, 2006). Work-related MSD's are incredibly common and in addition to causing pain and injury which necessitates time off, they may also open companies to litigation or worker's compensation (Collins, Janse Van Rensburg, & Particious, 2011).

Previous research has indicated that a variety of musculoskeletal disorders may arise among aircraft assembly workers specifically (Menegon & Fischer, 2012). By taking steps to reduce incidences of postures in the workplace which could be contributory to these musculoskeletal disorders, the incidence of worker's compensation and hours lost may be similarly reduced (Carrivick, Lee, Yau & Stevenson, 2005). An analysis of the present worksite and task was undertaken to determine if there were significant risks of MSD's developing as a result of the work conducted.

In order to accomplish the task, workers bent down into the semicircular tool and reached to place in pins, screws and slats of wood to secure the skin in place. Workers also had to balance themselves on the edge of the tool, bracing their legs against the adjacent safety railing, so as to reach further into the tool. This posture lead to static pressure on their thighs, hips and lower torso. It also demonstrated a risk for falling into the tool should they lose balance. Additional sub-tasks were noted as being required to perform the task, such as bending under the tool to retrieve wooden slats that must be placed along the length of the tool, as well as reaching into small boxes to retrieve pins via a pinch grip posture.

2. Method

Observation and walkthrough were conducted prior to the beginning of the exploration of the work process by a member of an ergonomics consulting organization. A video recording and still photos were collected at the walkthrough. This video and the photos were then used for the analysis of the hull assembly process in conjunction with a proprietary ergonomic assessment tool. Supplemental interviews with a managing employee were also gathered to obtain more information about the workplace environment. Following the analysis and interviews, preferred recommendations were developed to address high-risk areas for the employees working on the hull assembly process.

2.1 Injury Data

A formal injury report was not provided however, unofficial records indicate one person received a right shoulder injury, and others have indicated discomfort in both shoulders, lower back, and hips.

2.2 Workstation Dimensions

The primary tool for the hull assembly ranges between 6 and 8 feet wide and is crescent-shaped with the bottom of the crescent setting around 3 feet high (about waist height). The upper edges of the hull tool are about 4 feet from the lowest to the highest points. The upper edges are reached via a parallel catwalk that runs the length of the tool. Employees must traverse the catwalk to reach the interior sections of the hull and must bend down into the tool to secure struts, pins, and screws. The catwalk is about 2 feet wide with a 3 to 3 ½ feet high safety railing. This workstation may vary in size depending on the size of the hull being assembled. The larger hulls require two employees to assemble, while the smaller hulls can be assembled by a single individual in a typical 8-hour working shift.

2.3 Employee Anthropometry

The average age of the workers was 45 years old, with ages ranging from mid-twenties to mid-fifties. The worker population at the facility primarily consisted of females, either Asian or Caucasian, and several male Caucasians.

2.4 Video Analysis

The video analysis revealed certain postures required as part of the assembly process, that were cause for safety concerns. In order to affix plates into the tool, workers had to slip them on over a previously lowered “skin.” After which they needed to bend under the tool to remove a variety of wooden slats that were stored underneath it. They were then required to sequentially lay the slats down onto the plates bracing them in place. In order to do this, they bent themselves over a raised metal barrier and reach inside the tool. In some cases, workers had to raise both legs and balance against a back railing to keep from falling into the tool. In addition to laying the slats, workers also affixed the plates into place via a series of pins and screw-tools. It should be noted that the video analysis consisted of a single clip of two workers over a period of three minutes twenty-two seconds and did not demonstrate all parts of the procedure required of the employees.

2.5 Ergonomics Assessment Tool

An Ergonomic assessment tool was used to evaluate loads, the types of posture deviations, and frequencies of posture deviations to ordinally rank problems for prioritizing solutions. Postures and frequency data were collected using thorough video analysis with a two-person integrity method whereby one person served primarily as the video analyst, and a second person served as quality assurance.

3. Results

A proprietary ergonomic assessment tool was utilized in conjunction with the video analysis. The assessment tool contained a series of postures representing angles of deviation for various body parts, along with a coding mechanism to extrapolate the number of motions performed within a selected time span into a severity rating. These severity ratings are categorized as “low” meaning no action needs to be taken, “moderate” meaning action should be taken to reduce the incidence of these postures, and “severe” meaning action should be taken to reduce these postures immediately.

The neck area was rated as a severe risk. The task required extension of the neck while working in the tool, as well as flexions in excess of 20 degrees. Regular flexions of the neck to this degree may increase instances of neck pain and MSD's (Ariëns, Bongers, Douwes, Miedema, Hoogendoorn, van der Wal, van Mechelen, 2001). Regular twisting of the neck was also observed as workers surveyed the length of the tool.

Both the left and right shoulders were indicated as moderate warnings based on the unofficial report of injuries during the initial interviews and severe warnings based on the ergonomic assessment tool. A potential source for this pain may have stemmed from the repeated action seen in the sample video analysis wherein workers bending over the tool had to push themselves up. The push-up technique used to extricate themselves from the tool is similar to previous work environments where pushing and pulling is involved and may result in pain, strain, and injury (Hoozemans, van der Beek, Frings-Dresen, van der Woude & van Dijk, 2002).

Wrist postures were ranked as severe using the ergonomic assessment tool. The video sample demonstrated employees engaging in flexion of the wrist when screwing in bolts as well as extension of the wrist when slotting boards into place. Ulnar deviation was also observed in one of the employees as they were trimming the skin off the tool with a pair of scissors. It is believed that such deviations may be contributory to wrist related injuries such as Carpal Tunnel Syndrome (CTS) (Armstrong & Chaffin, 1979).

Postures relating to the lower arms were only rated as a moderate risk. This was captured by the ergonomic assessment tool due to the frequent use of manual hand tools beyond the limits of a neutral posture range. In particular, the use of the manual screwdrivers seems to be the major cause of this posture as workers must re-adjust their hand placement on the tool with each rotation.

Pinch grips also occurred regularly as employees needed to reach into a horizontal tray of small items required to affix the skin in the tool. Similarly, they needed to repeatedly pinch and push-in pins into the metal plates to securely affix them. This is problematic as repetitive pinch grips can also lead to chronic strain issues such as CTS (Chatterjee, 1987).

The lower extremities were considered moderate risk according to the checklist due to a deviation from the neutral standing posture in the range between 0 to 30 degrees, and 30 to sixty degrees. In part, this deviation stemmed from the act of getting onto and off of the edge of the tool, as well as maintaining balance by bracing their feet against the adjacent safety railing.

Issues with the back were unusual as they were given a moderate risk for one worker and a severe rating for another. This was due to the differences in the frequency of tasks performed by both workers in the sample. The first worker did not bend over as frequently or as deeply, though they did show an anterior back deviation in the range of 20 degrees to 60 degrees. However, the second workers back, bent at an angle greater than 60 degrees, thus warranting a severe rating. A full list of the results of the checklist may be seen in Table 1. This table includes the warning severity ratings derived using the ergonomic assessment tool, along with proposed recommendations that should allow for a reduction in risk to the workers. Additionally, the estimated rate of return for each of these recommendations based on the estimated cost of potential MSD injury was calculated.

Along with the issues presented in the ergonomic assessment, there is also the risk of falling that comes from balancing over the tool. Whenever balancing is necessary within a workplace setting, there is also a risk of falling. A fall, in turn, can result in contusions or other trauma (Umer, Li, Lu, Szeto & Wong, 2018). As there are strong health and monetary costs for fall-related injuries, potential solutions must be proposed for falls in addition to the other ergonomic recommendations.

Table 1. Area's with Assessed Risks and Proposed Accommodations

Area at risk	Warning Rating for Worker 1	Warning Rating for Worker 2	Recommended accommodation	Cost of implementation per person	Estimated Cost of potential MSD injury	Estimated Rate of Return
Neck	Severe risk	Severe risk	Training	$4,000	$33,545	43.5 Days
Upper Arms	Severe risk	Severe risk	Exoskeleton	$10,000	$33,545	109 Days
Lower Arms	Moderate risk	Moderate risk	Inline drill	$200	$29,918	2.5 Days
Wrists	Severe risk	Severe risk	Inline drill	$200	$29,918	2.5 Days
Grip	Severe risk	Severe risk	Vertical tool tray	$80	$29,918	1 Day
Back	Moderate risk	Severe risk	Harness system	$10,000	$38,424	95 Days
Lower Extremities	Moderate risk	Moderate risk	Fatigue mats	$1,200	$31,227	14 Days
Total				**$25,680**	**$226,495**	**41.4 days**

4. Discussion

By comparing the severity rating of certain postures along with the direct costs to the company in similar industries where similar injuries have occurred, it was possible to predict the approximate cost that one incidence of such an injury would incur. All data about the cost of injuries was sourced from the National Council on Compensation Insurance's (NCCI) Workers Compensation Statistical Plan database from claims filed from 2016-2017 (Workers' Compensation Costs., 2019).

4.1 Neck

Previous research has shown that neck injuries were unfortunately common occurrences in this work environment. A separate ergonomic assessment of 552 employees in the aircraft assembly industry shows that 23 (4.2%) took leave related to reported neck injuries (Menegon & Fischer, 2012). The average direct costs of a neck strain injury were $33,545 per incident (Workers' Compensation Costs., 2019). A potential solution to this is to provide training to inform workers about the dangers of excessive neck flexions and movements. Unfortunately, without a drastic redesign of the task itself, it is difficult to remove the necessity of neck extensions.

4.2 Upper Arms

The sever warning for the upper arms via the ergonomic assessment tool primarily stemmed from two areas. The first was extrication from the tool itself, as the workers engaged in a repetitive modified pushup to extricate themselves from the tool. The second was working with their arms extended away from their body with a deviation in excess of ninety degrees. These could be considered strain injuries which may contain a direct cost of approximately $33,545 per incident (Workers' Compensation Costs., 2019). In order to mitigate these risks, passive exoskeletal support mechanisms could potentially be utilized to reduce the strain on the workers (Huysamen, Bosch, de Looze, Stadler, Graf & O'Sullivan, 2018). The exoskeleton was selected as a solution as it promised long-lasting changes that did not necessarily require reinforcement via training and did not dramatically change the nature of the existing task.

4.3 Lower arms, wrists and pinch grip

Twisting the bolts into the tool by hand resulted in numerous cases where the wrists deviated from the neutral position. This was enough to result in a severe rating by the ergonomic assessment tool. In a separate ergonomic assessment of 552 workers, twenty-six of the sample (4.7%) employees had wrist related injuries and were on leave as a result of the wrist injury. (Menegon & Fischer, 2012). If these wrist related injuries are related to CTS, which was one of the most common forms of work-related injuries (Van Rijn, Huisstede, Koes & Burdorf, 2009), then it would incur an average direct cost of $29,918 per incident (Workers' Compensation Costs., 2019).

While it has a lower severity rating, similar concerns exist for the lower arms as well. These deviations usually were in conjunction with the non-neutral upper arms postures and the workers sought to place the pins or screw them in. While this only yielded a moderate severity rating it can cause also result in CTS or other related injuries and increase the likelihood of chronic injuries occurring.

Furthermore, the frequent pinch grips used to extract the pins from the tray and to push them into the skin of the tool are also problematic for the workers. According to the ergonomic assessment tool, this was given a severe warning rating. Similar to the lower arms and wrist deviations mentioned earlier, the excessive pinching posture may also contribute to the prevalence of CTS.

In order to fix these issues, it is suggested that rather than utilizing manual hand tools to tighten the screws once they have been placed, than an inline drill should be used instead. The cost of commercial hand drills suitable for this kind of work is in the $100-$300 range and their adoption should be considered strongly so as to preclude the direct cost of a single case of CTS as described above.

Likewise, pinch grips could potentially be reduced by switching the tool tray that the workers extract the various screws from a horizontal to a vertical one. Thus preventing the pinch-grip posture when extracting tools. As commercial vertical tool trays can be less than $100 this change is highly recommended given its potential to reduce the incidence of CTS in workers.

4.4 Lower extremities

While the ergonomic assessment tool did show a moderate risk to the lower extremities as part of the workers lowering themselves into the tool, there was another issue that needed to be addressed as well. This is that when they lowered themselves into the tool, they place their hips, abdomen and upper legs against the edge of the tool, thus incurring a static load. This static load can result in incidences of pain, strain, and injury just as repetitive motions could (Roman-Liu, 2014). Likewise, similar costs could occur as a result of this, approximating $31,227 per incident (Workers' Compensation Costs., 2019). While normally static load has been noted to occur in a standing environment, in this particular prone position over an unyielding hard surface, it can also emerge. However, a similar solution to a standing static load is possible as well. By providing a softer surface to displace the static load through the adoption of specialized fatigue mats, fitted around the metallic flat segments of the tool.

4.5 Back

The risks of lower back injury were especially focused on given their prevalence in other workplace settings (Andersson, 1999). Lower back injuries have been noted to be one of the most commonly reported MSD's (Marras, 2000). Workers in this setting were noted as attempting to reduce incidences of bending, which can contribute to lower back injuries (Adams & Dolan, 1996) through the use of a creative balancing act. By bracing themselves against the edge of the tool and raising their legs to contact the back railing, they were able to bend for only the periods of time when they are either entering or leaving the tool. However, this also resulted in a balancing act in which the workers were partially suspended over the tool and at risk of losing balance and falling in. Additionally, during this balancing act, the lower back may have been flexioned to help maintain clearance over the edge of the tool. While the feet may have been braced against the railing to maintain balance and reduce load on the lower back, it was also possible that the worker may lose traction and slip.

There were also instances where the simple bending posture greater than sixty degrees was unavoidable, such as when the workers were screwing in plates that were closer to the edge of the tool rather than the center. While the balancing act could not occur during this stage, the workers needed to bend further to accomplish the task. This also could not alleviate the strain on the lower back through bracing the feet against the railing. Such postures may lead to strain and inflammation of the lower back which can have a direct cost to the company of up to $31,227 and $38,424 respectively, according to NCCI reports (Workers' Compensation Costs., 2019.).

Potential solutions for this ranged from exoskeletons meant to help workers extricate themselves from the tool to a more complicated rigging and harness system. These options were necessarily expensive given the design of the current task, approximating $10,000 for engineering, construction materials, and assembly, on top of harnesses for two workers. However, given the sheer prevalence of work-related lower back injuries (Marras, 2000) as well as their associated costs, all reasonable efforts should be afforded to reduce their incidence. The added benefit of such a harness system is that it may also help reduce the fall risk of the workers as well.

4.6 Fall

The risk of falling into the tool needed to be addressed specifically as it did not necessarily risk chronic pain due to an MSD. It did, however, present a risk for a variety of other acute damages including contusions, bone breaks and concussions (Smith, Timmons, Lombardi, Mamidi, Matz, Courtney & Perry, 2006). According to NCCI reports, contusions and concussions can have an average direct cost of $30,261 per incident (Workers' Compensation Costs., 2019). Thankfully, potential ways for reducing the incidences of falls exist in previous solutions. Developing a form of harness system meant to relieve strain on the lower back, could also be used to support workers and help prevent them from falling into the tool if used properly.

4.7 Conclusion

The present task required workers to engage in repetitive and awkward postures which may contribute to the incidence of a variety of musculoskeletal disorders (Menegon & Fischer, 2012). Furthermore, due to the structure of the work environment, the workers found it necessary to engage in regular acts of balancing which increased the risk of fall and injury. To reduce the potential incidence of injury, there were several changes that could have been made to the current operation to reduce the risk of injury to the workers. These included engineering controls, such as purchasing tools that were more ergonomically suited for the tasks performed during the hull assembly. Examples of this include; fatigue mats to line the tool to reduce static load. Passive exoskeletons to help workers as they worked in static postures for extended periods of time.

Developing harnesses to reduce fall incidents. Utilizing tools which do not necessitate pinch grips, and repetitive wrist deviations.
For instances where tools are lacking, administrative controls and training on how to survey the surroundings without excessive neck twisting or flexion are also viable options. These recommendations may be adopted in whole or in part, but adoption of all recommendations is encouraged given the estimated rate of return for full adoption of these modifications is 41.4 days.

By taking steps to prevent risk and injury, the company may accrue several benefits. Fewer injuries may also lead to fewer missed workdays and less worker turn over (Anderson & Briggs, 2008). With less worker turnover there is less expense wasted on new-hiring and training procedures. Ultimate cost savings can be reasonably maximized and productivity can be maintained at optimal levels.

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