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An Examination of the Musculoskeletal Impact of Residential Solar Panel Installation

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Abstract: The solar energy industry has experienced substantial growth since the beginning of the 21st century. According to the Solar Energy Industries Association, industry growth is greater than 60% over the last decade. Residential solar has seen a steady increase in installations, providing jobs for over 260,000 Americans. While safety analyses of this field have focused mostly on falls and electrical hazards, little work has been done outlining the musculoskeletal risks for those involved with solar panel installation. One challenge of this field is that the workers are on inclined surfaces and analysis methods may be challenging. This study examined the ergonomic risks that residential solar installers were exposed to over the course of a shift. The Michigan 3DSSP was used to predict static strength requirements for a given number of tasks. Photographs were taken in the field of solar panel installation and eleven postures were chosen as representative of those experienced by installers during the course of an installation. Each posture was analyzed and broken down into 4 categories (as classified by the researcher): strength capability of 90-100% was good, 75-89% acceptable, 50-74% high risk, and 0-49% unacceptable. Of the eleven postures, the four with the greatest risk were: kneeling against roof, kneeling against panel mount, and two postures related to placing panels. It was suggested that the tasks could be improved by trying to have workers better distribute their weight and have them try to avoid tasks that include pivoting and turning with their legs planted on the roof. Additional research needs to be done on how to better handle the panels while on an inclined surface in order to reduce musculoskeletal risk.

Keywords: solar panel installation, ergonomic assessment

1. Introduction

The solar energy industry has experienced substantial growth since the turn of the century. According to the Solar Energy Industries Association, industry growth is greater than 60% over the last decade (SEIA, 2017). Residential solar has seen a steady increase in installations, providing jobs for over 260,000 Americans (SEIA, 2017).

As industries emerge and evolve, it's important that safety professionals keep up with the industries as they change. There are many tools available to the safety professional to properly evaluate the suitability of a job for the worker to perform safely. It's with these tools that workers are protected from both acute and repetitive motion injuries. The need for these evaluations continues to emerge as new jobs arise for workers to perform. One instance of an emerging new industry in need of an evaluation of worker safety is the residential solar installation industry.

A body of literature outlining the musculoskeletal risk has yet to be performed for solar installation due to the rapid growth of the solar industry. This study examined the risks to solar panel installers by using the 3DSSPP, a program developed by the University of Michigan for the assessment of the physical strain on the human body. This research provides only one approach to ergonomic risk reduction, more work is needed to fully understand the risks of solar panel installation that is done on a slanted, roof surface.

2. Background

This analysis used 3DSSPP, a program developed by the University of Michigan for the assessment of the physical strain on the human body. The program operates by modeling the postures of a task, considering body angles, lifting weight, and posture. The program then gives quantitative data for the amount strength capability for each part of the body (lower back, neck, knees, etc.).

Computer analysis is simplest method for analyzing physical strain. The alternative to computer modeling is a much more invasive analysis process, which collects data by using sensors connected to a worker to measure muscle strain and exertion. This is a more precise method for recording data, but is cumbersome and expensive. Computer modeling provides the researcher with a less invasive, less expensive way to analyze health and safety hazards (Arjmand, N., Dreischarf, M., Rohlmann, A., Schmidt, H., and Shiraz-Adl, A., 2015). The trade-off in accuracy results in a 20% error from real life to computer modeling (Arjmand, N., Dreischarf, M., Rohlmann, A., Schmidt, H., and Shiraz-Adl, A., 2015) . As noted by Feyen et al. in a study on computer modelling efficacy in ergonomic studies, the analysis software allows for studies to completed faster, and for ergonomic inputs to be more easily inserted into the analysis (Camp, J.E., Johnson, P. W., Russell, S. J., and Winnemuller, L., 2007).

One of the most unique factors of this study is the effect of the roof incline on spinal loading. Studies have been on spinal loading for roofing, finding that the increased angle does have an effect on spinal compression (Beaudette, S. M., Brown, S.H., and Graham, B., 2014). Studies on traditional roofing, however, don't have considerations for the lifting of large, heavy solar panels on the steep incline of a roof. Instability, coupled with lifting pressure, should add significantly more strain on the body.

This study is only a focus on the physical strain and strength capability aspect of this job. While there is little to no reliable statistical information for solar installer injuries, there is data available for roofing, which poses a similar hazard in falls. According to Bureau of Labor and Statistics, roofing contractors have an injury rate of 5.4 injuries per 100 workers, which is nearly double the average rate of 2.8 in 2016 (United States Department of Labor, 2017a). As well as injury, worker deaths are higher in the roofing industry. Roofing deaths accounted for 1.8% of all worker deaths in the United States in 2015 (the most current data year available), with 79% of those deaths being a result of falls (United States Department of Labor, 2017b).

3. Method

The first phase of the study was to establish the tasks and postures used by installers for residential solar installations. Installations were observed, and one installation photographed, with notes taken on the tasks completed and the frequency with which they are done. The installation took place on a two-story home with a 55-degree tiled roof. Ten panels were required for this installation. The photographs identified the key postures involved in the installation and the task to which they correspond. The objective of the observation of the solar panel installation was to document the installation process, identify key and repeated postures and positions of the workers, and to photograph postures identified for observation.

Key postures were then identified by assessing the frequency of use for the posture and how vital those postures are to the key aspects of the installation process. The key postures were then input to the 3DSSPP software for analysis. The software allows for photos to be uploaded and for manual manipulation of a sample body, both tools are utilized in this study.

3.1 Description of the Installation Process

The installation process (without taking into account installation planning and the transporting of materials) starts with the installation of panel mounting rails on the roof. The mounting rails in this instance were 11 feet long, weighing roughly 15 pounds. Three mounting rails were brought to the roof. Two different methods were observed to accomplish this: the first by one worker on the ground raising the rails up to a worker on the roof, the second by a worker carrying the rail up the ladder. The rails were connected to the roof using a variety of power tools to drill into the roof of the home and fasten the rails to the roof.

Once the rails are mounted to the roof, the solar panels are brought to the roof by a worker carrying a panel in one hand as he traveled up a ladder. The worker then uses two hands to lift the panel overhead, and hands the panel off to a worker on already on the roof. Once on the roof, the panels are connected to the mounting rails. Each panel is connected to the rail by 4 clips, which are bolted in at each corner of the panel. This process was repeated for 10 panels, with 2 rows of 5 panels. As each panel is connected, it is affixed to a power grid connected to the mounting rail by a snap-in mechanism that is pre-wired to each panel. Once all panels have been connected, the solar grid is connected to the power grid by running wire from the panel rails to the power line running into the home.

Key Posture Identification

Over 300 photos and videos were taken during the installation, with 11 postures chosen for analysis. The initial batch of photos and videos covered a wide variety of postures and positions, so it was important to be diligent when identifying which photos most accurately depicted the key postures involved in the vital steps of the installation process. This was done to ensure that the analysis was as generalized to the residential solar industry as possible, and eliminate some of the extra movements and postures taken by the workers in this particular crew. Variance between crew-to-crew and job-to-job is to be expected, but the key aspects of the installation will be more universal.

The process for narrowing down the photographs into 11 postures was done by identifying which postures were necessary for installation. This included postures involved in the carrying of panels to the roof, the connection of mounting rails to the roof, and the placing and attaching of the solar panels to the rails.

4. Results

Each posture was analyzed using the 3DSSPP software from the University of Michigan's Ergonomics Department. This program was chosen for ease-of-use, cost effectiveness, and reporting capability. 3DSSPP gives the user the ability to model a posture using a combination of numerical inputs for body angle, as well the ability to drag-and-click on the X, Y, and Z axis of the model to identically replicate a given posture (United States Department of Labor, 2017b).

Each posture was modelled in 3DSSPP to identify strength capability for each body segment. Due to the unique nature of the installation process' inclined surface work, forces were applied where necessary to ensure that the model was "in balance". The center of gravity, without the application of outside forces, would be unacceptable as modeled due to the angle of the lower body joints. The roof in this installation was a 55-degree incline.

Once the posture was effectively modeled to mimic the posture and position of the worker, a report was generated for the strength capability for each body segment in each posture. Each posture was analyzed and broken down into 4 categories: strength capability of 90-100% was good, 75-89% acceptable, 50-74% high risk, and 0-49% unacceptable. This rating scale was created for the study. Any postures containing an unacceptable score for any body segment were considered to be "high risk". "Moderate risk" postures contained multiple "high risk" scores. "Low risk" postures received only "good" and "acceptable" scores.

The data indicates that solar installations pose a risk to worker safety in a variety of postures. As an example, the following posture was shown to be "high risk":

Minimum Wrist Percentile	61.67
Minimum Elbow Percentile	99.35
Minimum Shoulder Percentile	62.39
Minimum Torso Percentile	87.84
Minimum Hip Percentile	83.03
Minimum Knee Percentile	81.17
Minimum Ankle Percentile	59
AVERAGE	**76.4%**

Figure 1 Kneeling Panel Mount and 3DSSP % Strength Capability Table

Figure 1 shows an image of the task and a representative example of how the calculations were done. The worker doesn't have any particular body segment in the "red/unacceptable" zone, but has multiple body segments in the "orange/high risk" zones, resulting in a low average strength capability. This posture puts the workers' upper and lower body at risk, the wrist and shoulder at the top, and the (right) ankle at the bottom.

The data being analyzed from 3DSSPP is the Percent Strength Capability for each body segment. Table 1 shows a breakdown of each body segment, for each posture.

Low Risk	90-100% strength capability
Moderate Risk	70-89% strength capability
High Risk	50-69% strength capability
Unacceptable Risk	0-49% strength capability

Table 1 Body Segment Strength Capability Percentages for Analyzed Postures

	knee drill	kneel again roof	Sideway kneel against roof	bent at lower back lift	wide stance lean over drill	across panel lean drill	kneel panel mount	place panel - pos. A	place panel - pos. B	carry panel up ladder	panel over on ladder
Minimum Wrist Percentile	98.67	96.36	97.08	99.63	86.74	98.58	61.67	81.5	75.94	73.29	88.75
Minimum Elbow Percentile	100	99.86	99.82	100	91.29	100	99.35	98.89	99.77	98.69	98.8
Minimum Shoulder Percentile	99.81	96.43	98.82	99.89	99.56	81.5	62.39	87.75	98.5	84.94	62.51
Minimum Torso Percentile	99.27	98.45	92.36	97.09	99.66	87.2	87.84	77.89	96.91	98.79	94.84
Minimum Hip Percentile	96.76	80.89	52.76	91.58	96.24	98.35	83.03	72.51	29.11	97.41	83.1
Minimum Knee Percentile	74.23	49.94	95.13	92.18	98.69	99.64	81.17	77.95	68.2	90.15	72.17
Minimum Ankle Percentile	97.9	89.03	85.56	94.22	87.97	95.41	59	27.28	64.66	73.48	98.08
AVG	**95.2%**	**87.3%**	**88.8%**	**96.4%**	**94.3%**	**94.4%**	**76.4%**	**74.8%**	**76.2%**	**88.1%**	**85.5%**

**Percentages indicate strength capability for 50th percentile male*

The data shows that across all postures, the lower body segments (ankles, knees, hips) routinely have a low strength capability. This is likely due to the angled positions of these joints as a result of standing on the inclined roof. The postures that allow the worker to distribute some body weight to the upper body had more strength capability in lower joints.

Another area of increased risk (although lower than the hips, knees, and ankles) in multiple postures is shoulders, elbows, and wrists. The postures with the lifting of solar panels showed a decrease in strength capability for the worker's

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wrists, elbows, and shoulders as they are lifted above and away from the body. The weight of the panels (~50lbs) combined with the large dimensions (2' x 4') required the workers to carry panels in awkward positions that put strain on these joints.

5. Conclusions and Recommendations

The aim of this study was to conduct fundamental research to determine the musculoskeletal risks facing workers in the rapidly growing field of residential solar energy. The lack of injury and health hazard information for this industry informed the design; the study was done to learn the basic functions and postures of the job and the effect that those postures have on strength capability for the worker. The results from this study will help solar installers evaluate the way that they perform the tasks of their jobs. Whether it is adding tools, changing postures, or limiting exposures, interventions need to be implemented to reduce the workers' risk of injury. The analysis highlights a risk in a number of body segments in multiple postures, especially in the lower body segments.

It should be noted that this study only analyzed the ergonomic risks of these workers. Other factors, primarily falling, were not considered in this analysis but are a significant concern for the workers in every posture on the roof. Fall protection should be used by the workers in all aspects of work on a surface over 6 feet off the ground. More basic and applied research for worker safety needs to be conducted in the rapidly-growing solar panel installation industry. Employees in this field are more likely to experience musculoskeletal injury in all body segments, especially the lower body segments of hips, knees, and ankles if working in the postures identified as high risk.

The data indicates that workers would be advised to utilize their hands more when standing on a roof, distributing their weight across their body more evenly. This is a cost-effective way to accomplish the same task without adding additional equipment or staff. By utilizing the positions that are less physically demanding, the worker can greatly reduce their risk for injury. Workers should avoid tasks that have them pivoting and turning with their legs planted on the roof. These postures put a significant amount of pressure on joints that are already at unnatural angles due to the incline of the roof.

More attention needs to be paid the handling of the solar panels. The panels, due to their weight and dimensions, consistently put the workers in moderate to high risk postures. It would be prudent to look into a pulley or lift that would allow the panels to be brought to the roof and placed with as little human handling as possible.

6. Limitations and Future Research

It would have been beneficial to observe more solar installations to compare styles and techniques. This would have allowed for a larger pool of postures for analysis and help to more narrowly identify which postures are truly essential in the installation process. Unfortunately, few installers were willing to allow me to observe and photograph their installations. The relatively small amount of solar installation being done in the Athens, OH was also a factor in the volume of installations I was able to observe.

Another limitation to consider is that it's possible that 3DSSPP isn't the most effective software for this type of analysis. A wider range of software is available to achieve a similar goal, but this software was the most practical tool to be used for this study. As software advances and emerges, it's certainly possible that more accurate data can be achieved using different software. This is especially true in the application of incline to the worker's hazard risk, as the effect of inclined work has yet to be fully understood and integrated into any analysis program.

This study was small in scale. A larger study should be done observing more installations and analyzing additional postures, as well as the postures analyzed in this study. A similar study done with different software will also help to clarify our understanding of the risks posed to solar installers. The 3DSSPP software, while useful, is only one in a field of many different ergonomic assessment tools available. Different software may also allow for a greater look at motion instead of static postures. The treatment of incline between programs is also a consideration, as there is yet to be a consensus regarding the effect of incline on lifting and health hazards.

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