Digital Human Modeling of Obese & Aging Workers in Automotive Manufacturing

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Digital human modeling has become an important tool in several industries, particularly in manufacturing. However, when these models are used, their use is often limited to "50th percentile" male and female models. The dimension is typically not explicitly named, but is inferred to be stature. The U.S. population is growing in size and age, which increases the range of abilities and limitations of the workforce. The objective of this study was to improve the understanding of how to better create and utilize digital human models that reflects a worker population that is diverse in stature, weight, and age. Previous research has yet to adequately incorporate this range of human population diversity into human digital modeling used in industrial modeling applications. Through use of CATIA Delmia (Dassault Systémes), a popular digital human modeling software tool, this research investigates how modeling software can be utilized in a number of ways to depict variations in worker size and age, for planning manual assembly and other work tasks. Validation of the models was assessed through filming, questionnaires, and interviews of workers in an automobile assembly plant. This research was able to show the limitations of current applications of human modeling with respect to the age, weight, and stature of a diverse worker population and provides suggestions for how to improve modeling.

INTRODUCTION

Assembly line work in automotive manufacturing can require both extreme postures and repetitive movements. As a result, the risk of musculoskeletal injury has been a continuing issue in the workforce. Along with this problem, personal factors may increase the risk of musculoskeletal injury; trends in obesity and aging are growing concerns for several industries. In order to better understand musculoskeletal injury risk issues in the automotive industry, digital human modeling is often used as a tool to anticipate or predict worker postures while performing various tasks. Previous studies have examined ergonomics-related issues in automotive work as well as trends in obesity and aging in the workforce. However, many studies utilize digital human modeling for predicting processes for an "average" sized worker rather than examining workers of various sizes and ages. The purpose of this study is to investigate one approach for digitally modeling obese and aging workers in order to predict how a work process could affect some assembly line workers.

The percentage of adults (and children) who are classified as obese has been steadily increasing over time in the United States. As of 2012, the percentage of US adults over the age of 20 who were obese was 35%, while the percentage of adults who were overweight or obese was 69% (Ogden et al., 2014).

The segment of the workforce that is categorized as "older" continues to grow in the U.S. and in other industrialized countries. With advancements in healthcare and public health standards, Americans are able to live much longer than ever before. In 2006, 36 million people in the U.S. were over the age of 65 (Arnone, 2006).

With an increasing number of older workers, it is essential to understand the consequences that result from having older workers in jobs prone to extensive movement. While older workers are known to have less frequent injuries, they are also known to have more serious injuries (Silverstein, 2008). Physical capabilities, including vision, hearing, balance, strength, joint mobility, dexterity, reaction time, and endurance decline with age, but rates of decline in these capabilities vary from person to person (Kowalski-Trakofler et al., 2005). Aerobic capacity can decrease by 30% by age 65 compared to age 25 and muscle strength can be reduced by 25% (Kowalski-Trakofler et al., 2005). These aging issues generally appear in workers ranging from 40 to 60 years of age, along with repetitive motion-related injuries, which are prominent during this age span (Kowalski-Trakofler et al., 2005). Many physical changes, particularly those associated with balance, strength, and endurance, can make automotive assembly work challenging, as many jobs require frequent repetitive movement, often while holding a powered tool in one hand. Workers must also reach or move in and out of vehicles, which requires the ability to maintain balance, often with just one hand to aid their balance. The statistics and research conducted on the aging population show the prominence of aging in society today along with the need to address the diversity that aging contributes to workforce capabilities.

Human Modeling

The use of digital human modeling (DHM) has been growing with the advancements in computer technology (Zhang & Chaffin, 2006). It is used to evaluate products, processes, and manufacturing tasks before actual implementation (Rim et al., 2008). Modeling during the design phase provides an understanding of how a technology or process will impact users or workers. Problems detected and corrected during the design phase allow a reduction in cost and time and improvements in quality and safety (Naumann et al., 2007).

Many studies have already shown how ergonomics simulations have been used to assess manufacturing assembly tasks prior to implementation (Lamkull et al., 2009). Some studies have taken this further by evaluating how closely these ergonomics simulations depict real outcomes in a plant setting. Fritzche's research looked at 20 car assembly tasks, comparing observations of male subjects with a height of 50th percentile German male models based on the company's standard model of DIN 33402 (Fritzche, 2010). Lamkull et al. (2009) were interested in comparing DHM simulations with actual processes performed in automobile assembly plants, in order to determine the predictive accuracy and value of DHM simulations in practice. While work by Lamkull et al. (2009) and Fritzche (2010) included a few models of various sizes, McKinnon and Van Velzer (2011) expanded on size variations by including models that were morbidly obese (McKinnon & Van Velzer, 2011). The study modeled force as a percentage of MVC, using the University of Michigan Static Strength Prediction model (3DSSPP), to perform certain seated assembly tasks, using a 50th percentile male mannequin in terms of height and weight versus a morbidly obese male mannequin. Thus, the growth of human modeling makes it an important resource to continue to explore.

Purpose & Objectives

The current study had the following five aims:

1. Identify jobs that were challenging for older or obese workers
2. Define characteristics (i.e. limitations of older or obese individuals) and then create digital human models that represent older and heavier workers. Following this, model auto assembly jobs in the regular DMH approach with the older and heavier worker mannequins.
3. Observe a variety of workers performing these jobs and compare observations with the model predictions for traditional/standard, older, and obese workers.
4. Revise models as needed to increase the accuracy of the model relative to the observations.
5. Provide guidance for automobile manufacturers and other users of DHM to create models that better represent the overall population.

This study could greatly benefit industries utilizing digital human modeling by demonstrating 1) how consideration of worker size and age can be used to create models that are more representative of the workforce, and 2) a practical approach for making adjustments to a current approach to DHM utilized in the automotive industry.

MATERIALS & METHODS

Subjects

Twenty-five automotive assembly line workers from the same company and shift participated in the study. Seven subjects were under 34 years of age, 5 were between 35-44, and 13 were between 45-55. There were 14 male subjects, with an average height 5'10" and an average weight of 192 pounds. The group of 11 female subjects had an average height of 5'3" and an average weight of 150 pounds. Across all 25 subjects, height ranged from 5'1" to 6'3" and weight ranged from 105 to 236 pounds. Based on BMI, 9 subjects were categorized as overweight and another 7 as obese. The study was approved by the university's Institutional Review Board (IRB), and subjects provided informed consent prior to starting their participation in the study.

Materials

A video camera was used to film each of the five selected tasks. Demographic and injury history data were gathered through a questionnaire and in a short interview. In addition, subjects were asked to rate their level of physical comfort/discomfort they experienced while performing the task. For the interview portion, questions pertained to how subjects felt while performing the task in terms of reach and comfort. They were also asked about difficult aspects of the tasks and what could be done to make the task easier.

Following the completion of data collection for each task, the data were entered and then analyzed in Excel. The averages for height, weight, age, overall discomfort, and anticipated discomfort after two hours of performing the task were calculated. In addition, previous injuries and areas of discomfort were noted. For the interview data, each response was inserted into Excel along with a summary of the most common response(s).

Methods

The first part of the study involved modeling workers in various tasks through use of CATIA Delmia V5 (Dassault Systémes). The tasks were selected based on activities that are likely to be strenuous for the obese or older segments of the worker population. For the obese models, tasks were chosen that included far reach, overhead work, movement in and out of the car, as well as frequent hand movement. Aging was simulated in the models through limiting neck, shoulder, back, or knee posture. These areas were selected based on past research and discussions with safety representatives at the assembly facility. The models were then created in CATIA Delmia prior to observing the line worker, similar to the process described by Lamkull et al. (2009), and similar to the workflow in the host company wherein designers typically create an initial digital model of an assembly task while a new vehicle is being designed; this is done based on a general description of the task. For face validity, this method was followed in this study, though the added step was creating digital models with specialized mannequins as well as the standard mannequins. In this study, the term "model" represents the end result of the mannequin positioned to perform the task within or near the vehicle, as required by the task. The dimensions of the traditional mannequin were 50th percentile in height, weight, waist circumference, and the lengths of body segments; one 'average' male and one 'average' female model were created. Thus, this served as a baseline for making comparisons between the traditional ('average') model and each of the special population models.

After creating the average mannequins, the obese or aging mannequin was made for the same task.

Modeling of an average worker

To create the "average" model, a vehicle body was first inserted into CATIA Delmia, followed by a mannequin. A feature embedded in the program is the evaluation of the posture of the mannequin. Body parts are displayed in red, yellow, or white to indicate body parts that are under extreme stress, some stress, or are acceptable, respectively; posture thresholds were based on proprietary guidelines of the Delmia licensee. The program's default mannequin is an average 50th percentile male, based on height, weight, circumference of the waist, and body segment lengths. The mannequin was then adjusted within the program to the desired position for the task of interest.

Modeling an obese worker

The mannequin of the obese worker was started through the same process as the average worker. The vehicle body was first inputted along with an average sized mannequin. The obese mannequin was made through adjusting weight, chest breadth, waist breadth, hip breadth, chest depth, waist depth, and buttock depth to 95th percentile values. For tasks in which a larger stomach could interfere with the process, an additional semi-ball was attached to the stomach portion.

Modeling an aging worker

In order to model the effects of aging, limited movement of various body parts was utilized. Since moving different regions of the body is a common problem with aging (Kowalski-Trakolfer et al., 2005), this was a mechanism used to represent those problems. Each task in the study targeted a different element of aging, aligning with previous research discussing limitations in the neck, back, shoulder, and knees.

Developing the aging model began in a way that was similar to creating the other models for this study. A vehicle body was inserted into the model along with a 50th percentile mannequin. A 50th percentile female mannequin was selected as the starting point for modeling an older female worker. The mannequin was then positioned based on the task of interest. However, it had to be created considering the limitation assigned to the person/mannequin. Thus, to compensate for the mannequin's limited neck movement, other body parts had to be adjusted, such as leaning back further or through alternative positioning of another body part.

Observation of workers

After creating the models, it was important to understand what the modeling may have missed. To accomplish this, workers of various sizes and ages were observed and filmed while working on the production line doing the tasks that had been modeled. This was done for the five tasks examined, each of which was filmed for approximately 5 cycles to get a sense of how the workers performed the task. Observations were made of how the task was accomplished by each observed worker. This was used to further ensure the modeling of the workers reflected how they would perform the task. Differences in task performance method between average, obese, and older workers were documented through video recordings. To assist with this component, a questionnaire and interview were administered, focusing on body parts that experienced the most strain and elements of the task that workers saw as challenging.

Interviewing trainers

The trainers were asked how the various processes would be difficult for a certain type of worker, based on their extensive experience training many different employees. Since each trainer specializes in a particular aspect of the vehicle assembly process, a different trainer was consulted for each task.

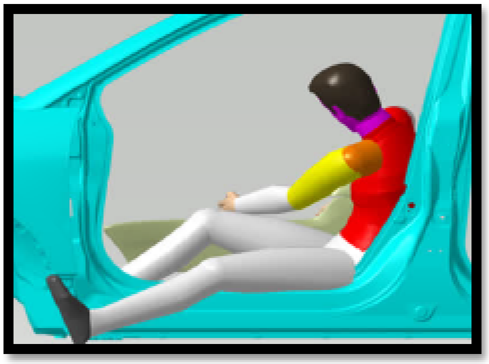
Comparison of modeling and observations

Following the development of the original models and the onsite data collection (observations, questionnaires, and interviews), the last part of the method involved comparing how the modeling and observations related or differed. If certain aspects of the task were missed in the modeling, the observations aided in making corrections to the model to ensure the model accurately depicted how overweight/obese or older workers would complete the task. If any differences existed, the model was revisited to show how the observed worker(s) actually accomplished the task. Then the two models of the same task were analyzed to identify differences between the standard worker/mannequin and the mannequin representing either overweight or older workers. Analysis was conducted by comparing the number of at risk body segments in both models. Body angles of the two models were compared to quantitatively show differences.

RESULTS & DISCUSSION

Results

For each of the five assembly tasks the following was completed: task models created with standard and specialized mannequins, worker data obtained during line-side observations of workers and interviews, corrections to task models informed by observations and interviews, and systematic comparisons of predicted work posture differences between the standard and specialized mannequins. Completion of these steps and analyses provided new insight into the jobs and potential benefits of additional DHM in task design. For example, Figure 1b depicts how accessing the center console with the left hand could be more challenging for an obese worker compared with an "average" worker (Fig. 1a).



(a)

(b)

Figure 1: Center console installation comparing (a) a 50th percentile worker with (b) an obese worker.

Through observing the job, a number of changes were made to the model, as two different working postures were observed.

Table 1 provides the comparison of the at risk body parts that were identified through modeling the standard female model and a movement-limited aging model. These are consistent with information from the interviews of workers who perform this job. The body parts in which they experienced discomfort included mid- and low-back regions, and the right shoulder.

Color	50th Percentile Revised Female	Aging Revised Female
Red	Head	Head
	Spine	
	Both shoulders	Both shoulders
		Both legs (knee to ankle)
Yellow	Left upper arm (elbow to shoulder)	
Total	4 Red; 1 Yellow	5 Red

Table 1. Comparison of predicted "at risk" zones using standard and aging models, for the center console job.

Discussion

This research extends past work by highlighting the limited attention to special populations in the design and modeling of vehicle manufacturing assembly processes. The research demonstrates the wider range of potentially awkward and stressful work postures that workers may be forced to adopt in order to compensate for personal conditions (weight, body part pain, etc.) and work design conditions. This discussion will highlight the key findings from the study as they relate to past research. It also includes recommendations for future research and limitations of the study.

Obesity. Excess body fat can be distributed in various patterns and locations on the human body (pear and apple shapes, abdominal obesity, etc.). For the current study, the decision was made to focus on a male who carries excess fat in the anterior torso region (abdominal obesity) in order to explore the effects of obesity and demonstrate the role digital modeling could play in planning processes and assessing effects of combinations of process and worker characteristic related to a greater variety of body shapes. The results of the study relating to obesity came from both the observational and interview portions of the analysis.

The current research is consistent with past research while also making a contribution by examining the use of modeling of larger sized workers, in this case with weight focused on the stomach (abdominal obesity). Future work should investigate modeling excess weight in other regions of the body apart from the abdomen.

Aging. The aging portion of this research was initially created to show how some older workers may not be able to position their bodies in the same way as younger workers. However, it is important to note that this could pertain to any worker with limited range of motion in one or more joints, which could occur for any reason (aging, current or prior injury, etc.). Thus, the results of this analysis show another use for digital human modeling. It could be used to plan where to place a previously injured worker who has temporary or permanent work restrictions.

Digital Human Modeling. Furthering work in and with digital human modeling was an objective of this inquiry. The research involved creating initial models, filming and interviewing workers to validate these models, and finally re-adjusting the models based on the video findings and interviews. The results of the observational assessment showed significant differences in almost all the processes when comparing the initial and final outcomes. Variations were observed with only four to six subjects for each process; not all the subjects performed the tasks in the same way. This greatly differed from Fritzche's work (2010), in which a good correlation was found between model predications and observations. Lamkull et al. (2009) also observed similarities between simulations and real outcomes on the plant floor. Thus, findings in this study differed from prior published research. This could be due to less knowledge of the car assembly process by the author of this study verses the knowledge of the modelers in previous literature, which is a limitation of this study. However, the key contribution of the current study was demonstrating the feasibility and benefits of incorporating mannequins in work process modeling that reflect a broader distribution of the workforce found in manufacturing facilities throughout the U.S. and other industrialized countries. This is a practice that companies should consider adopting, and process software modeling manufactures should consider supporting.

Past work in digital human modeling has been limited in terms of modeling special populations. McKinnon & Van Velzer demonstrated some key points to understand about obesity using an existing tool to model a few work tasks (McKinnon & Van Velzer, 2011). However, the study was limited by the software's ability to make adjustments to the model to be representative of the diversity of body shapes in the obese worker population. The current study showed how CATIA could be utilized as a tool to add a stomach component to represent one variation of obesity (abdominal obesity) and vary the stomach's depth and width. In addition, the aging population appears not to have been researched in terms of digital modeling of older workers. This was advanced in the current study by showing how modeling can contribute to visualizing limitations of the aging workforce. Not only is it useful for an aging workforce, but can also be used as a tool to examine how any individual with a physical limitation might perform a task.

Limitations & Recommendations

Expansion of Subject Population. A significant limitation of the current research is the limited observation of obese workers of various body shapes and inability to observe aging workers with process specific joint range of motion (ROM) limitations. While some workers were larger or older, the sample size was not large enough to draw conclusions nor were the workers limited in terms of the targeted aspects (e.g., larger stomachs or limited neck movement). Future work should utilize a larger sample size of subjects that is more diverse in body shape with regards to obesity and more specific in terms of joint range of motion limitations in older or any age workers.

Improvements to Modeling. The current modeling process of CATIA has several attributes. However, it is limited in some key features. The ability to create obese workers could greatly expand in terms of being able to distribute weight to various parts of the body. Future work should also consider integrating strength or fatigue analysis in process modeling applications, as shown by the integration of posture results in CATIA Delmia with the use of the 3DSSPP™ or through using advanced versions of CATIA Delmia.

Improved Design & Modeling Process. One of the aims of the current study is to provide suggestions for improving the efficiency as well as the effectiveness of the design and modeling process used in the transportation vehicle manufacturing industry. One approach to make this more efficient would be to reduce the number of design revision cycles. A way to address this issue would be to have designers trained in key aspects of ergonomics, such that a higher-level interaction between ergonomists and designers can evolve.

A bigger change to note with this process would involve hiring safety or ergonomics specialists to work in the design phase of the assembly planning process. This would allow more work to be done concerning safety and ergonomics earlier on in the modeling process as well as reduce the number of changes and revisions, for a more efficient design process.

Validation. Laboratory studies could be conducted wherein body postures and exerted forces could be quantified in order to supplement observation and modeling efforts and validate results.

CONCLUSION

With the growing trend in the obese and aging portions of the population in the U.S., it becomes a significant priority to expand research that analyzes how this trend could impact design and modeling in a variety of manufacturing settings. Modeling special populations, or rather various sectors of the working population, has not been widely done in research thus far. As a result, in practice modeling still heavily focuses on the "average" male or female rather than incorporating the diversity in the U.S. population in terms of size and age of workers.

This study expanded past research by investigating working postures and discomfort in average, obese, and aging workers. An important contribution of the study was the creation of models of these workers to show how CATIA can be used to model not only average sized workers (50^{th} percentile in height), but obese and aging workers as well. Information from the study could be applied to make improvements in the overall design and modeling process vehicle manufacturers currently employ.

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