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ASSESSMENT OF THE PHYSICAL DEMANDS OF WASTE COLLECTION TASKS

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ABSTRACT

This study features an analysis of the influences and effects of different postures performed within tasks of waste collection. Four men, ages 30, 46, 60 and 65, and two women, ages 38 and 48, took part in this study. The assessment makes use of a 3D Static Strength Prediction Program (3DSSPP™) to analyze the lifting and dumping postures observed in the experiment and evaluate strength requirements and the lower back impact of the different tasks. Additional analysis tools Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) were used to assess the risks associated with the tasks, and assessing the usability of this tool-setup to evaluate this kind of tasks with respect to the results expected. 3DSSPP results showed that only 86% of the population would be able to lift 9kg in this posture and 96% of the population would be capable of performing dumping. The results obtained using RULA and REBA indicated that the lifting and dumping postures are in need of change as soon as possible. Overall, this paper evaluates the postural risks of waste collection tasks mainly considering lifting and dumping tasks and assesses the physiological impacts on waste collection task performance.

Keywords: Ergonomics assessment, waste collection, posture analysis, ergonomics analyses toolsets

1. Introduction

Municipal Solid Waste (MSW), commonly known as "trash" or "garbage", is a waste type consisting of wastes such as durable goods, nondurable goods, containers and packaging, and other wastes but excludes industrial, hazardous, and construction wastes (Center for Sustainable Systems, University of Michigan.,2011). MSW collection is the initial process of solid waste management including generation, collection, transfer, treatment, and final disposal (Apaydin and Gonullu, 2007). Solid waste is collected manually in many developing countries and waste collection from home is also a job which involves repeated heavy physical activity including lifting, carrying, pulling and pushing (Yang *et al.*, 2001). Waste collection in US is at varying levels of automation including manual, semi-automatic and automatic. The focus of this study was on the type of manual waste collection tasks performed in residential communities in Orlando, Florida.

Current global MSW generation levels are around 1.3 billion tonnes per year, or 1.2 kg per city-dweller per day, nearly half of which comes from OECD countries. This will likely increase to 2.2 billion tonnes by 2025, or 1.4kg per person (Hoornweg and Bhada-Tata, 2012). In 2011, total annual MSW generation in the U.S. was about 250 million tons per year and increased by 65% since 1980 (Center for Sustainable Systems, University of Michigan, 2011). At the 2009 per capita rate of 4.34 lbs/person/day the average American generates their own weight (180 lbs) in MSW every 41 days (Center for Disease Control, 2009). The total amount of solid waste in the EU is expected to increase by about 45% between 1995 and 2020 (Hischier *et al.*, 2005; Abeliotis *et al.*, 2009). For instance, MSW generation rates (in lbs/person/day) are 2.8 in Sweden, 3.5 in Germany, and 3.4 in the UK (Organization for Economic Co-operation and Development, 2010).

Severe, functionally limiting back pain is exceptionally common: 70–85% of all people will experience back pain at some point in their lives (Andersson, 1999). Low-back disorders are more expensive for employers than any other type of injury (Marras, 2000; Oakley and Smith, 2000). Workers involved in solid waste industry are constantly subjected to specific occupational risks and the injury rate is higher than other industrial occupations (Un-Habitat, 2010). According to 1996 Bureau of Labor Statistics data, U.S. garbage collectors suffered a fatality rate of 46 per 100,000 workers, a rate one order of magnitude higher than that of the general workforce (Drudi, 1999; Englehardt *et al.*, 2003). Thus, solid waste collection can be considered as the highest risk for injuries and illnesses among the occupations due to ergonomics risk factors. Specifically, lifting and dumping tasks can be thought to compound the risks from posture when it is also performed.

Occupational injuries, defined as sudden, unanticipated, and unwanted events during work leading to harm or damage to at least one part of the body, are a severe problem among waste collectors (Poulsen *et al.*, 1995). Several authors highlighted the occupational health problems and injuries occurred among solid waste collectors. For instance, Jayakrishnan *et al.*, (2013) assessed the occupational health problems of municipal solid waste management workers in India. They resulted that occupation related morbidities like falls, accidents, and injuries were high. Similarly, Choi *et al.*, (2011) aimed to identify the characteristics of occupational accidents by work type among municipal sanitation workers. They stressed the types of occupational accident were as follows: slips and trips, falls, musculoskeletal disorders, traffic accident, collision, amputation, cut & puncture, crush injuries, strenuous movement and drop/fly, and musculoskeletal disorders showed the highest incidence in large waste collection. Abou-ElWafa *et al.*, (2012) assessed the percentage of musculoskeletal complaints and their possible risk factors among Egyptian MSW collectors. They concluded that low back was the most frequently affected body region among MSW collectors.

Some researchers compared occupational health problems with other occupational groups. Verbeek, (1991) found that the incidence rate of disability for work among waste collectors in the capital of the Netherlands was about four times higher than the rate among office workers of the same waste collecting company. A similar study was conducted by Yang *et al.*, (2001) for waste collectors in Taiwan. The risks for musculoskeletal complaints of the low back and elbow/wrist among waste collectors were more than two times higher than those of their colleagues that worked in the office.

Ivens *et al.,* (1998) analyzed and described risk circumstances associated with injuries among waste collectors. They resulted that better education of the waste collectors might lower the injury rate and so might a reduction in the working speed. Recently, Kim *et al.*, (2013) investigated the relationship between job stress and work-related musculoskeletal symptoms (WRMS) in street sanitation workers. They concluded that job stress could be a possible reason of WRMS among street sanitation workers.

Engkvist *et al.*, (2011) identified frequent situations of injuries occurred in Swedish recycling centers. They concluded that the reported accidents mostly had occurred during manual handling of waste. Similarly, Frings-Dresen *et al.*, (1995) identified the handling of heavy waste bags and dustbins as the most risky task for musculoskeletal disorders among waste collectors. An *et al.*, (1999) analyzed Florida Workers Compensation data and provided some insights into work-related injuries among MSW workers in Florida, US. They resulted that occupational illness rates are considered to be high in MSW workers. Englehardt *et al.*, (2003) assessed the actual numbers of musculoskeletal and dermal injuries requiring clinical care of

MSW workers in Florida and predicted a musculoskeletal and dermal injury rate of 80 injuries per 100 workers. Robazzi *et al.*, (1997) aimed to determine occupational accidents occurred among garbage collectors. They concluded that the major cause of the accidents was improper garbage wrapping and the body parts most often injured were the legs, followed by the arms; the early days of the week seemed to favor a higher frequency of occupational accidents than other days; the first four hours of work seem to have favored a higher occurrence of occupational accidents.

Since many lifting and carrying tasks have been replaced by pushing and pulling tasks in order to reduce load on the workers, Schibye *et al.*, (2001) compared the mechanical load on the low back and shoulders during pushing and pulling a two-wheeled container with the load during lifting and carrying with the same amount of waste. They observed that the torques at the low back and the shoulders are low during pushing and pulling. In a study on the size of the solid waste industry in the US, 53% of the solid waste facilities were owned by the private sector (Beck, 2001). Bunn *et al.*, (2011) compared injuries among solid waste collectors in the private versus public sectors. They concluded that solid waste collectors in the private sector are more likely to have injuries that resulted in a workers' compensation first report of injury or claim with awarded benefits when compared with those in the public sector.

Although injuries and health within many categories of waste collectors have been well studied, there is a dearth of information and assessments of waste collectors' physical demands. Therefore, the objectives of this study were to i) evaluate the postural risks of waste collection tasks mainly considering lifting and dumping tasks, and ii) assess the physiological impacts on waste collection task performance.

2. Materials and Methodology

2.1. Participants

The study groups comprised 4 healthy male and 2 healthy female participants. The population was aged between 30 and 65 years and none of the participants were waste collectors. The picking of wastes in this study was practiced in the Ergonomics Laboratory at the University of Central Florida, Orlando, USA. The average values and standard deviations of age, height and weight of the subjects were 47.83 $\pm$ 11.97 years, 169.83 $\pm$ 8.80 cm, and 68.41 $\pm$ 12.72 kg, respectively. The participants were informed about the study and they each indicated their willingness to participate by signing a Consent to Participate form. This study was approved by the Institutional Review Board for Research with Human Subjects at University of Central Florida. At the time of the study, none of the participants reported musculoskeletal problems. Two researchers were trained to take the measurements in this study by practicing on themselves. They started data collection only after their measurements were considered accurate and consistent.

2.2. Apparatus and assessment tools

Equipment utilized in this study included a trashcan, a goniometer, a Timex Ironman heart rate monitor, Borg scale of perceived exertion, 3D Static Strength Predictor Program (3DSSPP), and Jack simulation software. The goniometer was used to measure the various joint angles needed to complete a rapid upper limb assessment (RULA) and rapid entire body assessment (REBA). The heart rate monitor was used during the simulated waste collection task to record the participants' heart rates in one minute intervals. The Borg scale was used to assess the rating of perceived exertion (RPE).

Several assessment tools are especially effective in handling the relationship of various lifting motions to low back pain. 3DSSPP (Three Dimensional Static Strength Prediction Program) is one of these analysis tools developed at the University of Michigan (Chaffin *et al.*, 1999). It is applicable to worker motions in three-dimensional space. The program provides an approximate job simulation that includes posture data, force parameters and male/ female anthropometry. Originally, this tool was developed to predict population percent capabilities and low back forces resulting from manual exertions in industry. The biomechanical models used in 3DSSPP are meant to evaluate very slow or static exertions (Chaffin, 1997). The program predicts static strength requirements for tasks such as lifts, presses, pushes, and pulls. This is due to the program's assumption that the effects of acceleration and momentum are negligible. The output of the software gives the percentage of men and women who have the strength to perform the described job, spinal compression forces, and data comparisons to NIOSH guidelines.

Besides this tool, other ergonomics assessment tools such as Rapid upper limb assessment or RULA, and rapid entire body assessment, or REBA evaluation were considered as supportive tools under waste collection tasks. RULA, is a subjective survey method developed for posture analysis that focuses on not only work-related upper body but also lower body, which uses illustrations of body postures and scoring tables of observed postures to accommodate evaluation of exposure to risk factors (McAtamney and Corlett, 1993). REBA has been developed and can be used for assessment workloads with manual material handling tasks (Hignett & McAtamney, 2000). This tool has been employed in studies involving posture and lifting, and its use has been studied to determine the benefits and drawbacks of observational techniques for assessing postural load (Kee and Karwowski, 2007). One of the primary benefits of the REBA tool is that it allows for variance with respect to the neutral postures. Additionally, REBA takes the dynamics of performance into consideration during evaluation (Kjellberg *et al.*, 2000).

Jack is a human modeling tool that was developed at the Center for Human Modeling and Simulation at the University of Pennsylvania in the mid-1980s used for human modeling and simulation (Philips and Badler, 1988). It allows the users to build a virtual environment in which they can create virtual humans. They can assign a task, or tasks, for them to complete and then analyze the results. Jack is particularly useful for ergonomic evaluations and can help to improve product design and workplace tasks. For the purpose of this study, Jack was used to obtain a RULA score for comparison with the hand calculated scores.

2.3. Study steps

The experiment was broken up into three stages. The first stage was preparatory and consisted of:

- Briefing the participant as to the purpose, method and risks of the experiment
- Obtaining informed consent from the subject
- Equipping the participant with a heart rate monitor
- Recording subject age, height, weight, gender, resting heart rate, frequency of exercise and smoking habits

After the paperwork was complete, the RULA/REBA assessment portion of the experiment began. The procedure was first demonstrated by the researcher so that participants would understand what was required. The process involved:

- Lifting the empty trash can into an initial lifting position
- Using the goniometer to measure joint angles relating to the neck, trunk, legs, arms, and hands
- Taking pictures for comparison with the waste collection task
- Lifting the empty trash can into the dumping position
- Using the goniometer to measure joint angles relating to the neck, trunk, legs, arms, and hands
- Taking pictures for comparison with the waste collection task

The final step in the experiment was conducting the simulated waste collection task (Figure 1.a and 1.b). Prior to running the task, the participants were familiarized of the Borg scale of perceived exertion, the trash can was loaded to 9.5kg, approximately half the weight of the average trash can, and a table was set up to simulate the height of the garbage truck. The average weight was reduced to half in order to maintain safety in the lab setting. The task consisted of multiple steps:

- Walking from the table to the trash can location
- Pulling the can back to the table
- Lifting the trash can
- Dumping the contents onto the table
- Placing the can back on the ground
- Pulling the trash can back to the starting location
- Returning to the table

Figure 1.a. Waste Collection lifting task

Figure 1.b. Waste Collection dumping task

This process was done once a minute for 10 minutes, during which pictures were taken. After each repetition, the participant's heart rate and RPE were recorded. Heart rate was also recorded every minute after the task concluded until it returned to within 5% of resting.

3. Results

3.1. RULA/REBA assessment

Measurements for RULA and REBA were taken for four different participants, two male and two female. The results of the analyses are shown in Table 1 which depicts the individual scores for each subject. For REBA, "A" indicates the score associated with the neck, trunk and legs, "B" indicated the score associated with the arms and wrists, "C" is a composite score obtained from a table based on the "A" and "B" scores, the Activity score is based on static/dynamic lifts and frequency of lifts, and "Final" indicates the overall REBA score for the task (the sum of C and Activity). Conversely, for RULA, "A" represents the arms and wrists score, "B: represents the neck, trunk and leg score, and "C" is the overall RULA score associated with the task. Results that indicated low risk (1-3 for REBA, 1-2 for RULA) were displayed in green, medium risk (4-7 for REBA, 3-4 for RULA) in yellow and high risk (>7 for REBA, >4 for RULA) in red.

The results for the lifting posture were consistent for both sides of the body. The lowest score REBA was a 5 which occurred based on data taken from the right side of the body. This score indicates that there is a moderate amount of risk associated with this posture, it should be investigated further and changed soon.

The highest REBA score was a 9, obtained on the left side of the body. It represents high risk and the task should be changed immediately. RULA produced scores of 6 and 7 for all four participants. These are high risk scores that indicate change is needed soon.

There was more variability in the dumping scores based on which side of the body was observed. Low risk REBA scores (2, 2, 2 and 2) was obtained for the left side of all participants, but moderate risk scores were obtained for the right side (4, 5, 6 and 7). RULA produced scores associated with moderate risk for the left side of the body (3, 3, 4, and 4) and moderate to high risk for the right side (4, 6, 6 and 6).

A RULA score was also computed with the aid of the Jack simulation software. This score was based on a simulation of the entire task, as opposed to the individual postures. Jack reported a RULA score of 3, which indicates a moderate risk associated with the task. This score is lower than expected.

Table 1. REBA and RULA Scores

REBA					RULA				
Lift Left Side									
A	6	6	7	6	A	5	5	5	5
B	5	5	6	4	B	6	6	7	7
C	8	7	9	7	C	7	7	7	7
Activity	0	0	0	0					
Final	8	7	9	7					
Lift Right Side									
A	6	4	6	6	A	5	5	3	4
B	5	5	2	3	B	6	6	7	7
C	8	5	6	6	C	7	7	6	6
Activity	0	0	0	0					
Final	8	5	6	6					
Dump Left Side									
A	2	2	2	3	A	4	3	3	3
B	3	2	2	1	B	4	4	2	3
C	2	2	2	2	C	4	4	3	3
Activity	0	0	0	0					
Final	2	2	2	2					
Dump Right Side									
A	2	2	2	3	A	7	6	5	7
B	8	7	6	8	B	4	4	2	3
C	6	5	4	7	C	6	6	4	6
Activity	0	0	0	0					
Final	6	5	4	7					

3.2. 3DSSPP assessment

3DSSPP was used to analyze the lifting and dumping postures observed in the experiment. Joint angles collected for the RULA/REBA analysis were used to create the postures seen in Figures 2 and 3. Figure 2 represents the general lifting posture that participants used. 3DSSPP determined that only 86% of the population would be able to lift 9.5kg in this posture. The limiting body part in this pose was the hip.

Additionally, the program reported the compression on the L4/L5 to be 936lbs. Figure 3 modeled the dumping position. This posture was significantly better than the previous as 96% of the population would be capable of performing it. The compression of the L4/L5 vertebra was also greatly reduce to 286lbs.

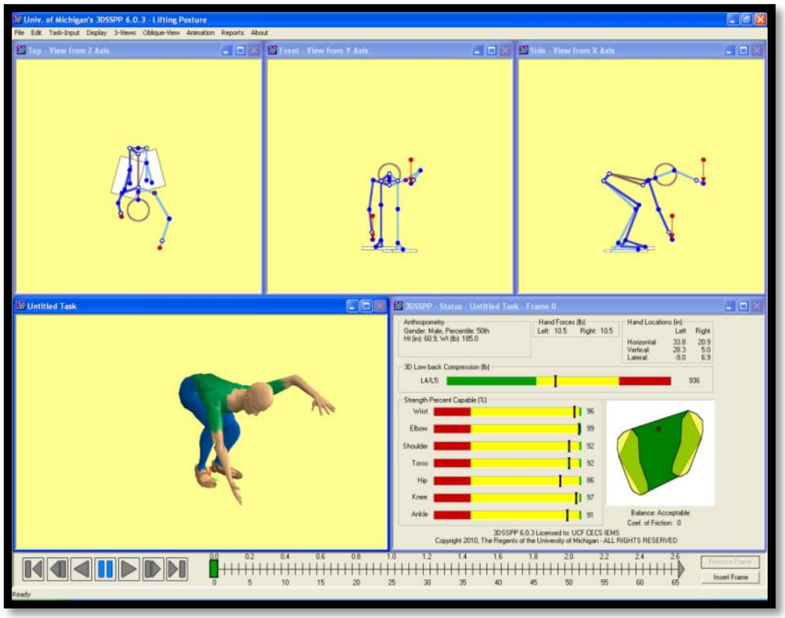

Figure 2. Lifting Posture in 3DSSPP

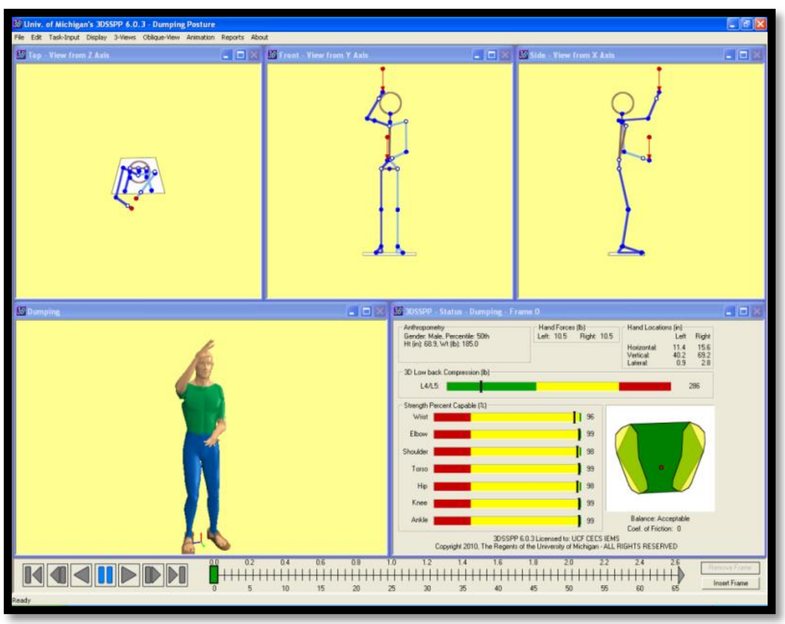

Figure 3. Dumping Posture in 3DSSPP

Additional models were created in 3DSSPP based on postures that differed from those measured for the RULA/REBA assessment. The postures were observed while participants performed the timed portion of the experiment and picture and/or videos were taken to document them. The first of these was a dumping pose where the subject leaned backwards and the 3DSSPP analysis (Figure 4) revealed that 95% of the population would be able to dump the trash can in this posture. The limiting factor was the model's wrist. Furthermore there were 203lbs of compressive force on the L4/L5.

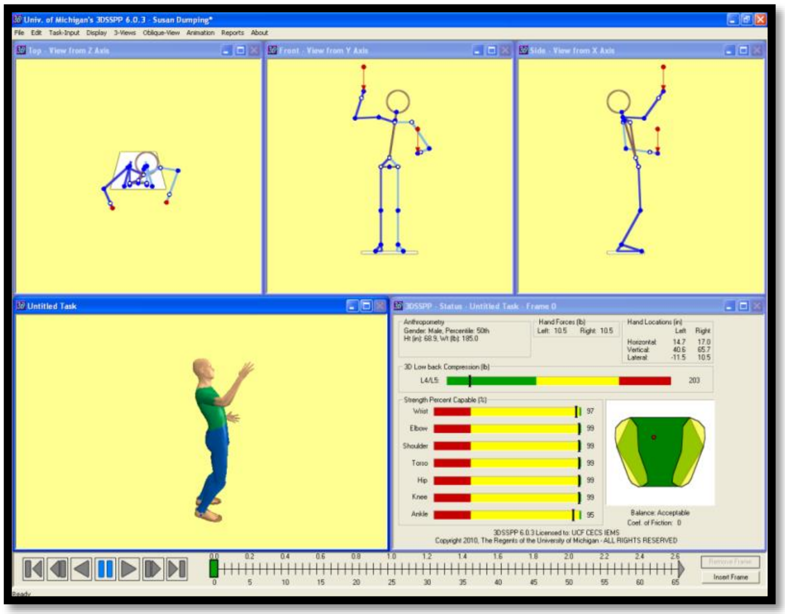

Figure 4. Observed Back-Arched Dumping Posture in 3DSSPP

The second unique posture observed was a lift where the subject used only one hand to lift the trash can to about chest height. The 3DSSPP model predicted that only 65% of the population would be able to perform the lift in this fashion due to the requirements on the wrist (Figure 5). The reported L4/L5 compressive force was 537lbs.

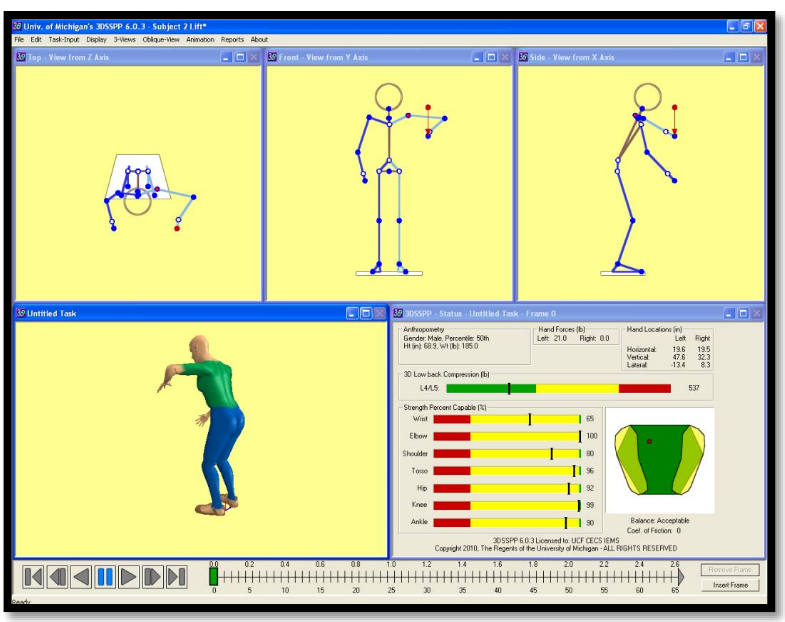

Figure 5. Observed One-Handed Lift in 3DSSPP

4.2. Heart rate and RPE

The correlation between heart rate and rate of perceived exertion (RPE) was also examined. A scatter plot (Figure 6) was used to graph the participants' heart rates (x-axis) against their RPE (y-axis). The results displayed an overall positive relationship between the two variables. This relationship can be interpreted to mean that as heart rate increased, RPE had a tendency to increase as well.

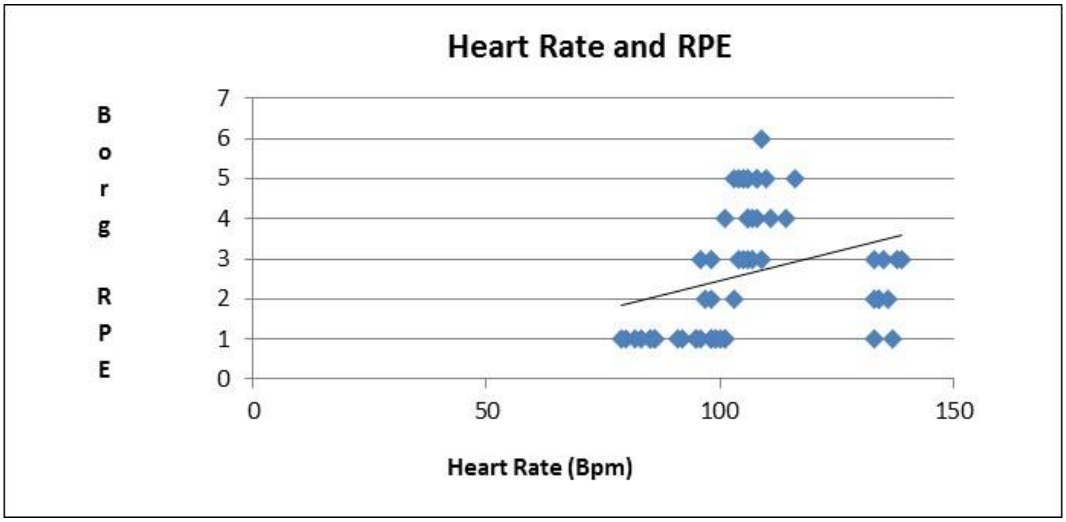

Figure 6. Chart of Heart Rate and RPE

4. Discussion

The results obtained using RULA and REBA indicated that the lifting and dumping postures are in need of change as soon as possible. There was some variability in the scores depending on which side of the body the measurements were taken. However, the lower scores, such as those obtained on the left side of the dumping posture, are negated by the higher ones because they represent the "worst case scenario." For the lifting posture, both the RULA and REBA scores indicated that the most improvement could be gained by adjusting the neck, trunk, and legs. The trunk was the most notable contributor of the three. The best way then to reduce the RULA/REBA score would be to reduce the amount of bending at the trunk. The arms and wrists scores were also high but it would be difficult to change the arm angles due to the location of the handles on the trash can. For the dumping posture, the arms and wrists scores were the main contributors. Again it would be difficult to improve these scores due to the locations of the handles on the can. The best solution may be to use a different trash can with handles that are closer together. Outside of the lab setting though, this solution would not be practical since people are able to purchase a large variety of garbage cans. It may also be important to note that the scores seen in the results section would have been higher had the weight not been reduce to half that of the average weight can.

The RULA results obtained through the use of Jack may not be reliable. The simulation created did not perfectly reflect the manner in which a normal human would lift and flip the trashcan. The simulated human bent his left arm in an impossible way to grasp the top of the can (represented by the solid object). The dumping posture was also erroneous because the model's left hand moved closer to the middle of the trashcan, instead of grasping the top, and the right hand came completely off of the can. These inconsistencies may have affected the results of the RULA computations in Jack and therefore these results cannot be relied on for an accurate comparison with the RULA values obtained through hand calculations.

The 3DSSPP analysis of the two postures (lifting and dumping) where the joint angles were measured revealed that only 86% of the population would be able to perform the task given that these two postures were used. This value should ideally be in the high nineties thus 3DSSPP indicates that the task needs to be changed, which supports the results from the RULA/REBA analysis. The compressive force of the L4/L5 also supports the conclusion that task needs improvement. It is also important to realize that only 9.5kg, half of the average trashcan load, was used in the analysis. When the load was increased to 19kg, only 57% of the population would be able to perform the lifting posture (Figure 7) while 70% would be able to do the dumping posture (Figure 8). Overall then, 57% of people would be able to perform the task using the two postures measured. The compressive force of the task increased to 1232lbs. Reducing the amount of bending in the trunk, as suggested in the RULA/REBA section, would also improve the 3DSSPP results. Therefore it is suggested that, waste collection employees should minimize bending at the trunk whenever possible. However, completely eliminating bending may not be a viable solution as will be demonstrated next.

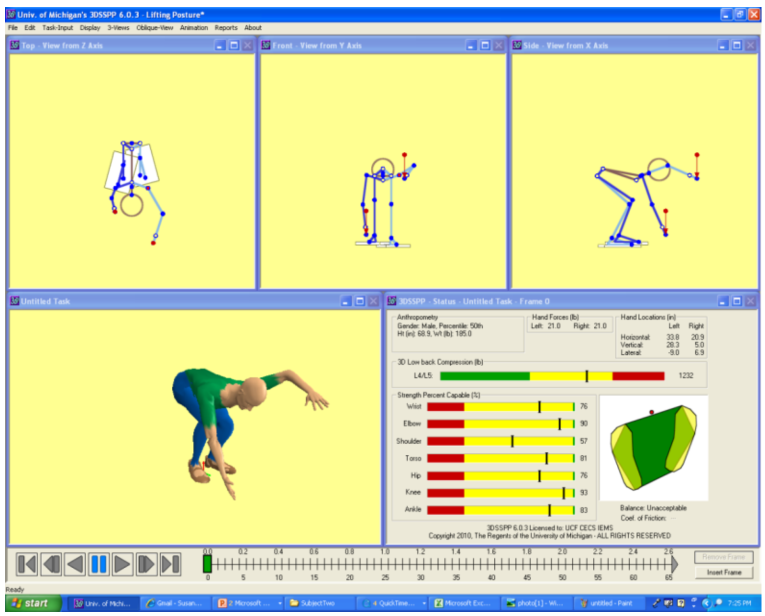

Figure 7. Lifting Posture with 19kg load

The two other postures were also reanalyzed with a 19kg load. The first, the dumping posture with an arched back, would be performable by only 78% of the population but would only have 221lbs of compressive force on the L4/L5. The compressive force result is a bit surprising since the back-arching would assumedly use the back to support more of the load. Despite this, it is still not an optimal posture and is not recommended for waste collection employees. The second posture, lifting with only the left hand, would be one solution to minimizing the amount of bending done at the trunk. However, the lift was not performable by any of the population. The program computed that the load placed on the wrist and shoulder would be too much for a human to hold the position. If is important to note though that a lift done in this fashion would be performed with a quick burst of strength, and the posture would not be held statically at all. Analyzing quick movements is one of the limitations of 3DSSPP so these results may not accurately reflect the manner in which the subject was performing the lift.

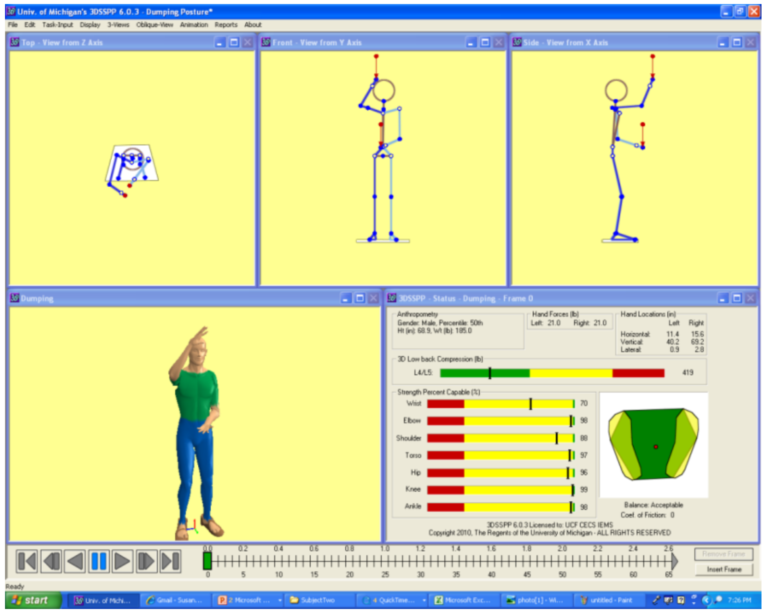

Figure 8. Dumping Posture with 19kg load

The results of the heart rate and RPE evaluation revealed a positive correlation between the variables. This relationship can be interpreted to mean that as heart rate increased, RPE had a tendency to increase as well. This result was expected and logical in that, as a person exerts himself his heart rate should increase as should his perception of that exertion. If the full 19kg load had been used, it would be expected that the heart rate and RPE values would have been higher, but the same positive relationship would have been seen. For this reason, the results obtained in the lab setting are an accurate reflection of those one would expect to see out in the field.

5. Conclusion

In this study, the postural risks of waste collection tasks mainly considering lifting and dumping tasks were evaluated, and the physiological impacts on waste collection task performance was assessed.

The results for the lifting posture were consistent for both sides of the body. The lowest score REBA was a 5 which occurred based on data taken from the right side of the body. This score indicates that there is a moderate amount of risk associated with this posture, it should be investigated further and changed soon. The highest REBA score was a 9, obtained on the left side of the body. It represents high risk and the task should be changed immediately. RULA produced scores of 6 and 7 for all four participants. These are high risk scores that indicate change is needed soon. There was more variability in the dumping scores based on which side of the body was observed. Low risk REBA scores (2, 2, 2 and 2) was obtained for the left side of all participants, but moderate risk scores were obtained for the right side (4, 5, 6 and 7). RULA produced scores associated with moderate risk for the left side of the body (3, 3, 4, and 4) and moderate to high risk for the right side (4, 6, 6 and 6). In summary, the results from the RULA and REBA scores indicated serious risk and a need for immediate change.

The 3DSSPP results also supported the need for improvement. 3DSSPP determined that only 86% of the population would be able to lift 9.5kg in lifting posture. Dumping posture was significantly better than the lifting as 96% of the population would be capable of performing it. When the load was increased to 19kg, only 57% of the population would be able to perform the lifting posture while 70% would be able to do the dumping posture. Overall then, 57% of people would be able to perform the task using the two postures measured. The compressive force of the task increased to 1232lbs. Major differences in the 3DSSPP results were observed when the 9.5kg load was increased to 19kg.

The limitation of this study was the decision to cut the trash can weight in half. Though it was done for safety concerns, this choice may have prevented the heart rate data from accurately reflecting the body's response to the simulated waste collection task. In conclusion, the research found that the waste collection task is in need of improvement. This study poses another limitation: only a limited number of participants were evaluated. These findings are preliminary given the limited number of participants. Despite the limited number of participants, this study showed that the lifting and dumping postures are in need of change as soon as possible. Thus, these results may provide a foundation for further studies that may include more participants.

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